Underutilized Potential of Small-Scale Oyster Reef Restoration Units as Habitat for Invertebrates

by

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This thesis was prepared under the direction of the candidate's thesis advisor, Dr. Rachel J. Harris, and has been approved by the members of the supervisory committee. It was submitted to the faculty of The Honors College and was accepted in partial fulfillment of the requirements for the degree of Bachelor of Science in Biological and Physical Sciences.

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Abstract

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Oyster reefs play vital roles in an estuary's health by filtering the water and by serving as nurseries for many aquatic animals. The objective of this research was to investigate habitat use of smaller macroinvertebrates on restored oyster reefs. Small-scale (approx. 10 cm^3) cage (bagged shell) and string (hanging shell) oyster cultch units were deployed on two restored oyster reefs in the Loxahatchee River Estuary for one year. Fauna inhabiting the units were monitored monthly, identified to the lowest practical taxonomic level, and categorized into functional groups based on feeding mode, living position, and mobility. Results showed similar abundance, richness, and diversity of functional groups in cage and string units. These findings suggest that even small-scale oyster reef restorations, such as individual 'vertical oyster gardens' (i.e. string units), add valuable habitat for smaller organisms. This research provides additional options for small-scale restoration efforts.

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Introduction

Oyster Reefs

Eastern oysters, *Crassostrea virginica*, filter feed on particles suspended in the water column such as detritus, bacteria, and zooplankton (Galimany et al., 2017). This filtering capability improves water quality often decreasing phytoplankton biomass, increasing light penetration, and contributing to nutrient cycling (Wall et al., 2011). In addition to the benefits to water quality and shore stabilization, oysters are a vital source of food to various organisms (Tolley and Volety, 2005), including humans, and their pseudofeces along with detritus are consumed by amphipods (Kesler, 2015). Oyster reefs also provide habitat structure and a refuge from predation. Crabs, shrimp, and fish are more abundant on oysters than sandy bottom areas because they use oyster habitat as shelter from predation, spawning substrate, and a source of food (Tolley and Volety, 2005; Kesler, 2015). Depending on the inter-structural space size, predator size, and cross-sectional area of spaces to hide, this habitat may inhibit predator movement and ability to detect prey (Bartholomew et al., 2000). Therefore, oyster reefs serve as a physical structure in addition to its provision as a food source.

Overharvesting of shellfish areas, climate change, eutrophication, sedimentation, and habitat degradation all threaten oyster health and abundance in both the Gulf of Mexico and Atlantic Ocean (FWC, 2019). To improve declines in this keystone species, the state of Florida has developed primary goals to reduce habitat degradation and to restore the reefs by establishing oyster cultch (FWC, 2019). Oyster cultch describes the shell or aggregate of shell-like material used to facilitate juvenile oyster ‘spat’

recruitment and settlement, and a cultch can be deployed in oyster reef restorations and oyster aquaculture (Brumbaugh and Coen, 2009).

Restoration Techniques

Due to the ecological and commercial importance of *C. virginica*, various methods of growing the oysters have evolved for reef restoration and aquaculture. Many of these aquaculture techniques include hanging or floating devices to provide substrate for oyster spat recruitment. For example, in Alabama oyster gardening was examined using two floating culture methods, 'Taylor floats' and 'Eastfield Floats', finding that Eastfield floats had greater total growth, but the survival of the oysters was similar with both types of floats (Hamilton et al., 2005). Other aquaculture methods that have experimented with *Pinctada margaritifera*, blacklip pearl oysters, and *Pteria penguin*, winged oysters, have used a variety of methods including ear-hanging, mesh trays, and ropes with plastic mesh inserts. Studies of these aquaculture methods have found that the survival and growth of the oysters differed between the different culture types as the 3-D structure and mesh size altered the water flow, influencing food availability and biofouling (Southgate and Beer, 2000; Milione and Southgate, 2011).

In addition to aquaculture, natural resource managers and interested community-based habitat restoration groups often use oyster shell in bags and mats to restore declining oyster reefs. The Delaware Center for the Inland Bays and Delaware Sea Grant Marine Advisory Program 'oyster gardening' program is one example which began in 2003 (Ozbay et al., 2014). This program uses Taylor floats attached to docks to raise oyster spat on oysters and the community maintains the floats. At one point each float had

about 200 oysters filtering an estimate of 7.6 million liters of water every day, improving water quality and providing habitat in the inland bays (Ozbay et al., 2014). Also, these oyster reef restoration and gardening projects can improve the biodiversity of the area, increasing species richness of free-living organisms like crustaceans and fish as well as parasites (Moore et al., 2020). Another restoration pilot program, in the Indian River Lagoon, Florida, involved the community in gardening oysters in bags attached to their docks (Anderson et al., 2019). This pilot study demonstrated how oyster gardening is another option of restoration that does not require large amounts of land and oyster shells.

Few studies have considered the community composition of benthic invertebrates inhabiting the reef associated with different oyster cultch methods of reef restoration and rather, have focused on oyster shell growth and survivability. The value of oyster reefs in habitat provision is widely recognized. However, there is little information on the use of small-scale oyster gardens as habitat by smaller macroinvertebrates. This is an important gap since smaller macroinvertebrates are the base of the food chain on an oyster reef. In this study, small-scale oyster cultch units with cage (i.e. mimicking bagged shell oyster gardening/restoration techniques) and string (i.e. mimicking vertical oyster gardening/restoration techniques) treatments were established in an estuary and the communities of juvenile invertebrates were evaluated. The goal of this study was to establish whether different cultch-holding structures will result in different community compositions, measured by functional group abundance, richness, and diversity.

Functional Groups

The use of functional groups aids in determining the ecological roles that species play in habitat modification, bioturbation, nutrient cycling, predation and competition (Hernandez-Avila et al., 2020). For example, deposit feeders and suspension feeders can influence the environment and community via pelletization of sediment or feeding on recently recruited larvae (Barnes and Hughes, 1999). Depending on the goals and habitats of the study, some functional group considerations include structural fragility of body, adult body size, motility, living position, reproduction and development modes, primary and secondary feeding strategies, microhabitats, and living structures created (Hernandez-Avila et al., 2020; Greenfield et al., 2016; Bonsdorff and Pearson, 2009). In this study functional groups were considered to evaluate the role of the oyster reef, and oyster reef gardening/restoration techniques (i.e., cage vs string) in habitat provision by season (wet vs dry), at two study sites (Site A vs Site B), over the course of a year in the Northwest Fork of the Loxahatchee River.

Methods

Oyster Restoration Sites

In summer 2010, an oyster restoration project was conducted in the Northwest Fork of the Loxahatchee River, Florida (Fig. 1A). This restoration project was a joint agency collaboration between the Loxahatchee River District (LRD), National Oceanographic and Atmospheric Administration (NOAA), and Martin County. The American Recovery and Reinvestment Act of 2009 grant funded the 5.84-acre restoration project in which rock, shell, and dredged material was placed as reef substrate. The colonization of fauna on this reef was recorded over the first two years of the project and the community compositions of natural oyster reefs and restored oyster reefs (Fig. 1B from Jud and Layman, 2020). Jud and Layman (2020) noted that after almost 2 years the biomass and community compositions of restored reefs closely resembled that of natural reefs in the area, providing habitat to 'small, motile, oyster-associated organisms. Here, we revisit these restored sites to quantify the abundance of such 'small, motile, oyster-associated organisms' 10 years after the initial restoration.

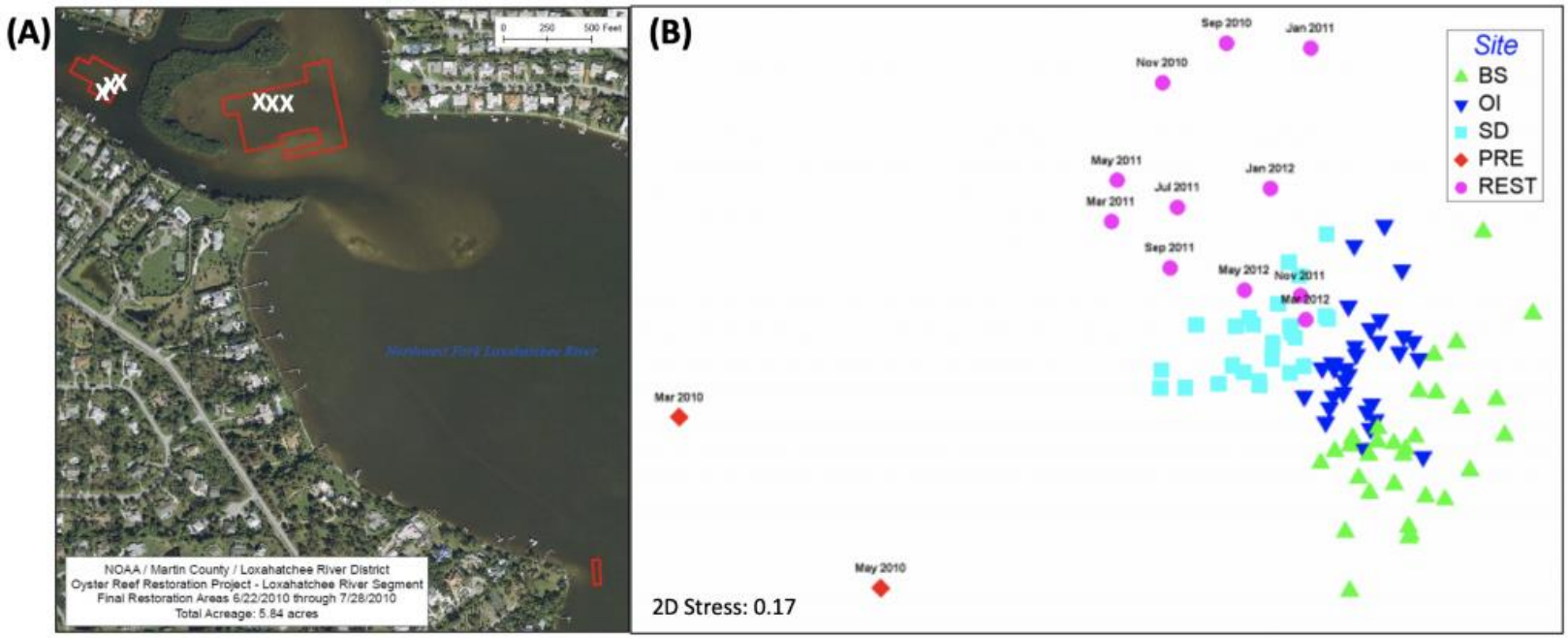

Figure 1. (**A**) Reef map showing three 2010 oyster reef restoration sites in the Northwest Fork (NWF) of the Loxahatchee River (red polygons), and current monitoring sites/locations (white X). (**B**) Multiple-dimensional scaling (MDS) plot showing BS= Boy Scout Camp natural oyster reef, OI= Oyster Island natural oyster reef, SD= Seventh Dock (small patch reef deployed under residential dock), Pre= largest restoration site before adding reef substrate and REST= largest restoration site following reef substrate addition; revised figure published in Jud and Layman 2020.

Field Study Design

The study was conducted at two sites (A and B) in the Northwestern Fork of the Loxahatchee River (Fig. 1A). Site C (smallest, southernmost restoration site in Fig. 1A) was not included in this study, since by 2018, when this study began, the location had been covered in sand. Three replicate treatments were deployed at each site and a total of 12 samples (one from each treatment; Table 1) were collected monthly for one year, from August 2018 to August 2019 (Table 2).

Table 1. Sites and treatments collected every month (n=12)

Sites	Treatment	Substrate	Replicate
A	Cage	Oyster	1
			2
			3
A	String	Oyster	1
			2
			3
B	Cage	Oyster	1
			2
			3
B	String	Oyster	1
			2
			3

Table 2. Final sample collection schedule.

	Deployed		**Retrieved**		
Period	**Date**	**Month**	**Date**	**Month**	**Days**
Aug-Sep	8/23/2018	Aug	9/20/2018	Sep	28
Sep-Oct	9/20/2018	Sep	10/18/2018	Oct	28
Oct-Nov	10/18/2018	Oct	11/20/2018	Nov	33
Nov-Dec	11/20/2018	Nov	12/13/2018	Dec	23
Dec-Jan	12/13/2018	Dec	1/11/2019	Jan	29
Jan-Feb	1/11/2019	Jan	2/5/2019	Feb	25
Feb-Mar	2/5/2019	Feb	3/7/2019	Mar	30
Mar-Apr	3/7/2019	Mar	4/4/2019	Apr	28
Apr-May	4/4/2019	Apr	5/6/2019	May	32
May-Jun	5/6/2019	May	6/4/2019	June	29
Jun-Jun	6/4/2019	June	6/27/2019	June	23
Jun-Jul	6/28/2019	June	7/25/2019	July	27
July-Aug	7/25/2019	July	8/22/2019	Aug	28

Cages were made of a 2.5x2.5cm gridded stainless-steel mesh, held together by wire, creating a 10 cm^3 hinged square box (Fig. 2A). In the field, each replicate oyster 'T' was set up with one cage and one string with oysters, hanging ≤ 5cm above the sediment surface (Fig. 2B). Each cage or string contained six oysters and was held in place suspended by string to the oyster 'T' (Fig. 2B). These monitoring stations were placed in groups of three (approx. 1 m apart) on an east to west orientation across the center portion of Site A and Site B (Fig. 2C).

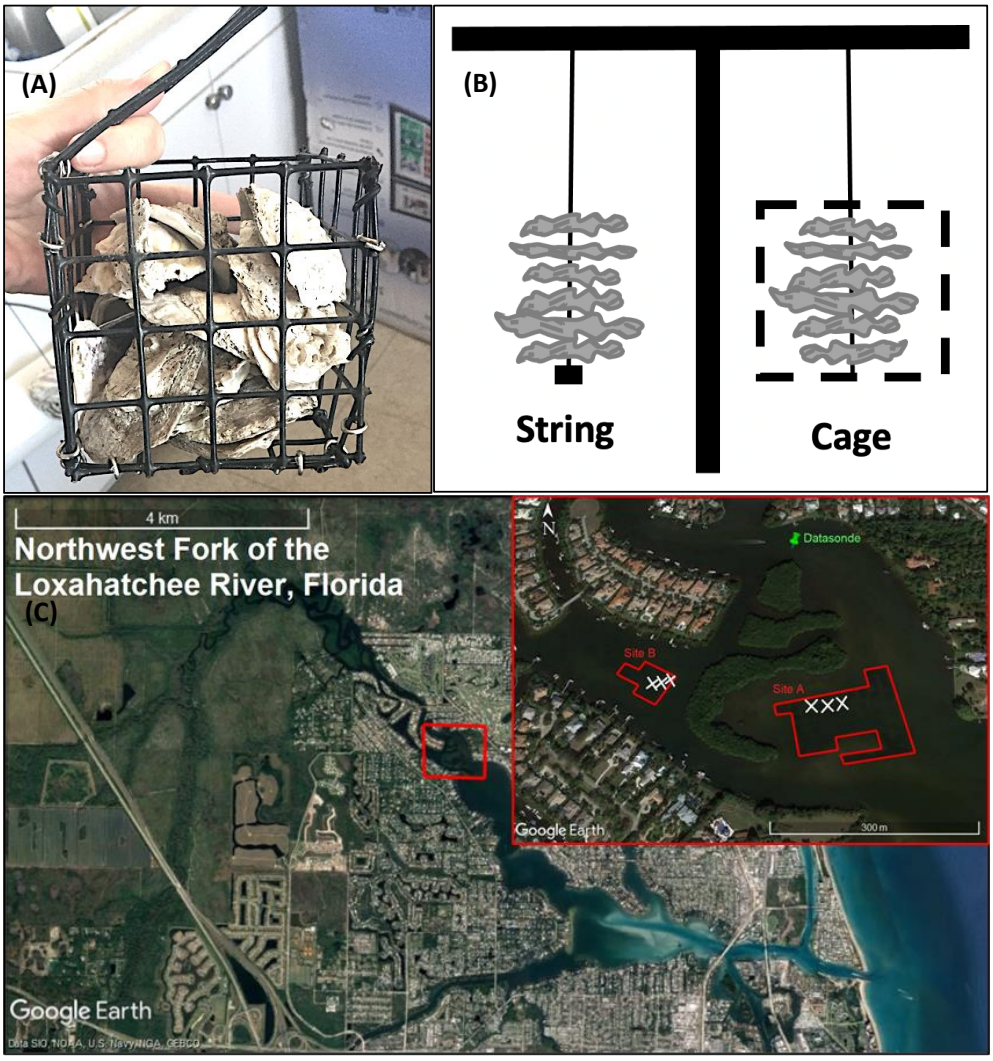

Figure 2. (**A**) 2.5x2.5cm gridded mesh cages, (**B**) Orientation of oysters in string and cage treatments, and **(C)** Approximate locations of replicate set-ups and datasonde.

Faunal Sampling and Processing

Sample collection followed Iliff et al. (2018) where fauna was retained by gently enclosing the oyster string/cage in a low-density polyethylene plastic Tupperware container underwater. Tupperware containing both water and sample were returned to the laboratory and sieved and sorted within 24 hours of sample collection. All juvenile and adult fauna retained in a 595 μm-mesh sieve were further sorted and preserved in 70% Isopropyl alcohol for identification. We also included spat counts of *Crassostrea virginica* on the oyster shell substrate; these are reported as a sum of tops and bottoms per 3 oysters.

Preserved meiofauna (< 1mm) and macrofauna (≥1mm) were identified to the lowest practical taxonomic group (i.e., 'Taxon'). Fauna were then assigned to functional groups based on motility, feeding strategy, and living position of the lowest identified taxon. These categories were chosen to determine if organism feeding and living position change with different oyster bed structures of the two restoration treatments (string *versus* cage). The information used to characterize/classify these functional groups was derived from observations reported in the field and a thorough review of the literature of identified taxon (Tables 3 and 4; Individual species classifications into functional groups provided in Appendix A).

Table 3. Feeding strategy categorization.

Code	Term	Description	References
SF	Suspension (Filter) feeder	Feeding on particles suspended in the water column. Presence of filter feeding apparatus including cilia, tentaculate, and setae covered limbs.	(Barnes, 1999, 22; Aller, 1977; Gibson et al., 2001)
DF	Deposit feeder	Feeding on material deposited on the sediment surface or subsurface of sediment containing bacteria, plankton, and detritus; they can consume/ingest entire sediment and excrete sediment while retaining organic material and/or have bristles/appendages to take up material.*	(Aller, 1977; Fauchald and Jumars, 1979)
SC	Scavenger	Feeding on dead organisms and/or parts of dead organisms (degree of decay non-specified). Eats live and dead material but not live algae. *	(Aller, 1977, p. 4 and 5)
PR	Predator	Actively pursues prey.	(Aller, 1977)
PC	Parasitic carnivore	Animal parasite that uses host as food source.	(Bonsdorff and Pearson, 2009)
HG	Herbivorous grazer	Feeds on live algae and/or plant material.	

Table 4. Living position and motility categorization.

Code	Term	Description	References
FL	Free-living	Does not create burrows or tubes and is not a parasite. Is mobile.	(Fofonoff et al., 2018a)
SE	Sessile	Primarily sessile, can create tubes or calcium-based shell.	(Fofonoff et al., 2018c)
FB	Free-burrower	Burrowing behavior in addition to free-living.	(Greenfield et al., 2016)
TD	Tube-dweller: sediment	Creation of tube with organism's silk/internal liquid cement and sediments, shell material, and/or algae.**	(Barnard et al., 1991)
CR	Co-resident or mutualistic / parasitic	Organisms that live inside tissue, shell, or burrow with another organism as living space.	(Silliman et al. 2003; Puglisi, 2008)
CA	Calcium-based shell	Organism uses calcium carbonate to produce a hard structure like shell or tube.	(Hewitt et al., 2008)

*****We cannot tell if organisms eat plant material that is decomposing or is living. Therefore, we chose to put any organisms that may or may not eat live material under deposit feeder.

** A mucus only 'tube' (or sheath) is not considered a tube-building behavior because it does not use silt, detritus, or algal particles from the environment. Mucus often lines burrows without creating a solid tube structure.

Size. In addition to taxon, we separated some species by size class. This is because some juvenile and larval species are difficult to differentiate, and/or have a distinct difference

motility, feeding strategy, and living position. For example, individuals could be confidently identified and separated into adult (>3mm) and juvenile (≤ 3mm) Xanthidae based on the identifying Xanthidae characteristics. However, we were unable to confidently identify zoea (specimens with elongated abdomen, appendages, and dorsal spine; generally, ≤ 1mm) and megalopae (specimens with eye stalks, rostrum, and pleopods developed with elongated abdomen and telson; generally, 1- 3 mm), and these individuals were categorized as Brachyura (Martin et al., 1988a and b).

Additional Data. In September 2019, upon the conclusion of this study, LRD conducted a survey to quantify oyster size, density, and percent live and dead oysters on Site A (n=40 random points) and Site B (n=30 random points) (Metz, 2021).

LRD continuously records environmental parameters through its water quality monitoring stations throughout the Loxahatchee River. One of these stations "OY" or "OYU" is located adjacent to the restored oyster reef areas (northeast of Site A) and records temperature and salinity every 15 minutes (data available https://loxahatcheeriver.org/river/datasonde/).

Data Analysis

Non-metric Multi-Dimensional Scaling (nMDS) plots based on the Bray-Curtis resemblance matrix and similarity percentages (SIMPER) based on species abundance data were used to compare community compositions (nMDS) and identify the dominant taxon (SIMPER) between (dissimilarities) and within (similarities) Sites A and B (Clarke and Gorley 2015). Abundance, richness, and Shannon-Wiener diversity index were

determined for each sample by functional groups. Shapiro-Wilk tests were run to determine the normality of distribution of the functional group data, and the log-transformed functional group data. 3-way analysis of variance (ANOVAs) were run with r studio package ‘ggpubr’ (Kassambara, 2020) based on the independent variables (site, treatment, and replicate (nested in site)) for the following response measures: (1) functional group log transformed abundance, (2) functional group richness, and (3) functional group diversity index. These ANOVAs were used to identify significant differences between sites (A *versus* B), replicates (1, 2, or 3), and treatment (string *versus* cage). Boxplots were used to visualize functional group abundance, richness, and diversity for treatment type and site by season using ‘ggplot2’ (Wickham, 2016).

Results

Environmental Parameters

There was a clear difference in both salinity and temperature between wet and dry seasons (Fig. 3). In the wet season (April–October) average temperatures ranged from 24.98 to 32.2 ˚C and salinity ranged from 4.78 to 27.79 ppt (Fig. 3), whereas in the dry season (November–March) average temperatures ranged from 18.54 to 27.74 ˚C and salinity ranged from 13.37 to 29.75 ppt (Fig. 3). Average temperatures ranged from 18.99 to 32.2˚C throughout the study (Fig. 3A). Minimum temperature ranged from 17.52 to 31.47˚C, and maximum temperature ranged from 19.62 to 33.74˚C (Fig. 3A). Average salinity ranged from 4.78 to 29.99 ppt (Fig. 3B). Minimum salinity ranged from 0.32 to 25.24 ppt and maximum salinity ranged from 22.23 to 34.5 ppt (Fig. 3B).

Figure 3. (A) Temperature data of daily minimum (cyan), daily average (black), and daily maximum (red) at Station OYU.

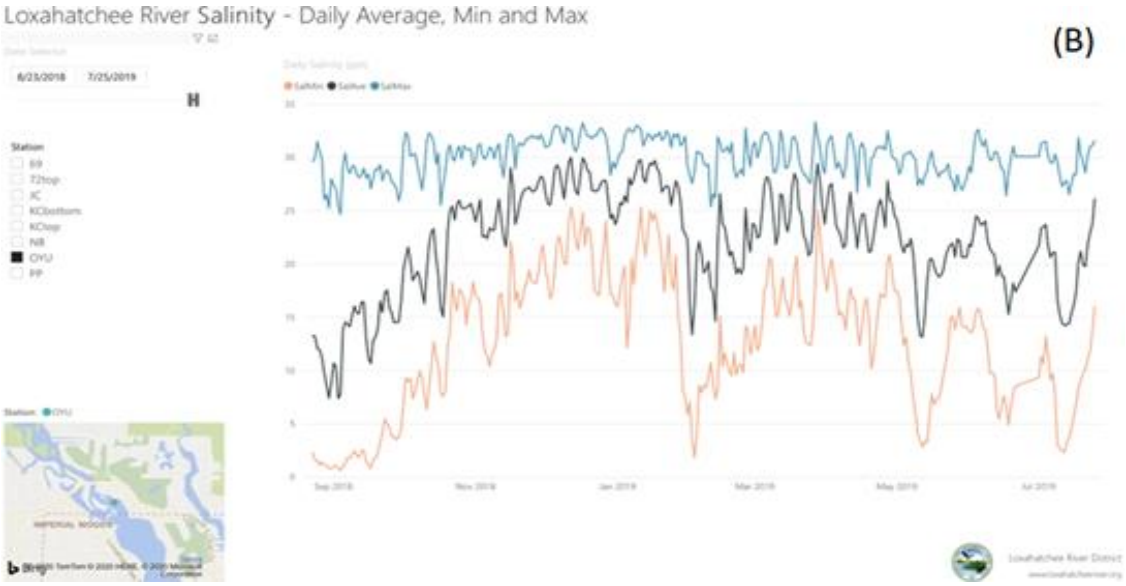

Figure 3. (B) Salinity data of daily minimum (orange), daily average (black), and daily maximum (blue) at Station OYU

Dominant Species: Between Sites A and B

During the study, 66 taxa were identified from the samples and 42 functional groups were categorized from these taxon (see Appendix A for entire taxa list), with 75% dissimilarity between sites (Table 5; for all species see Appendix C). The individual species contributing greater than 5% (SIMPER individual species ≥ 5 dissimilarity between sites) of differences in community composition between Sites A and B were *Idunella (Listriella) barnardi* (53.4%)*, Sinelobus* (*Tanais*) *stanfordi* (11.41%), *Astyris lunata* (8.31%), and *Americorophium ellisi* (5.65%) (Table 5; data visualized in Fig. 4).

Table 5. SIMPER output of individual species contributing (cont.) ≥5% of community compositions showing average (Avg.) abundance (abund.). Sites A and B. average between site dissimilarity = 75% (For all SIMPER dissimilarity results see Appendix C).

Species	**Cont.%**
Idunella barnardi (Listriella barnardi)	53.49
Sinelobus (Tanais) stanfordi	11.41
Astyris lunata	8.31
Americorophium ellisi	5.65

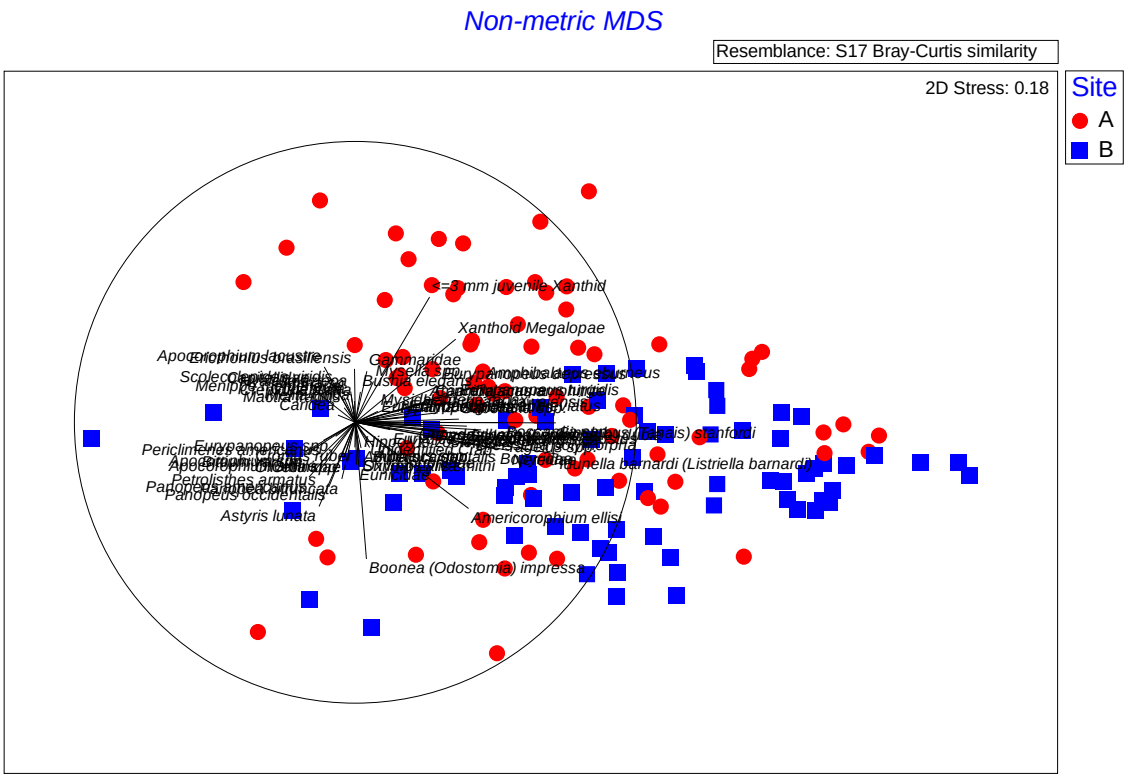

Figure 4. nMDS comparing overall community composition at Site A and Site B. Vectors showing individual species contributing to the dissimilarities between sites (SIMPER, 18%; Table 11).

Dominant Species: Within Site A and Site B

SIMPER tests were used to determine the percentage of individual species contributing to the similarities within Site A and Site B. There was an average 30% similarity of species abundance within Site A. 23% of this dissimilarity is driven by the abundance of *Idunella (Listriella) barnardi*, 13% by juvenile xanthids, 13% by *Americorophium ellisi*, and 12% by *Chondrochelia (Leptochelia) dubia* (Table 6). There was an average 31% similarity of community compositions at Site B. This was driven by the abundance of *Idunella (Listriella) barnardi* (54%), juvenile *Sinelobus* (*Tanais*) *stanfordi* (11%) and *Americorophium ellisi* (8%) (Table 7).

Figures 5 and 6 show a visual of the species abundance at Site A (Table 6) and Site B (Table 7) depicting species per unit by sample date throughout the study. For ease of visualization, individual species with greater than 1% (determined by SIMPER average within group similarity output) contribution to community composition are graphically provided in Figures 5 and 6. Since Site B is more diverse, this site was used to determine the threshold for the percentage contribution for the data visualization. The highest species abundances were reported in September to October at both sites (Fig. 5 and 6). At these sites, *Idunella (Listriella) barnardi* was dominant over time (Figs. 5 and 6; Tables 6 and 7), and it is obvious that Site B had an overall greater abundance of individuals (Figs. 5 and 6). Although individual species abundances changed over time at both sites, *Idunella (Listriella) barnardi,* less than 3mm xanthid, *Americorophium ellisi*, and *Chondrochelia (Leptochelia) dubia* occurred regularly at Site A (Table 6; Fig. 5) and *Idunella (Listriella) barnardi, Sinelobus (Tanais) stanfordi*, and *Americorophium ellisi* at Site B (Table 7; Fig. 6).

Table 6. SIMPER output of the top 4 individual species contributing (cont.) >10% of within site community composition similarity showing abundance. Site A within site similarity = 30% (for all SIMPER dissimilarity results see Appendix C).

Species	**Cont.%**
Idunella barnardi (Listriella barnardi)	23.76
<=3 mm juvenile Xanthid	13.31
Americorophium ellisi	12.68
Chondrochelia (Leptochelia) dubia	12.19

Table 7. SIMPER output of the top 3 individual species contributing (cont.) >8% of within site community composition similarity showing abundance. Site B within site similarity = 31% (for all SIMPER dissimilarity results see Appendix C).

Species	**Cont.%**
Idunella barnardi (Listriella barnardi)	53.49
Sinelobus (Tanais) stanfordi	11.41
Americorophium ellisi	8.31

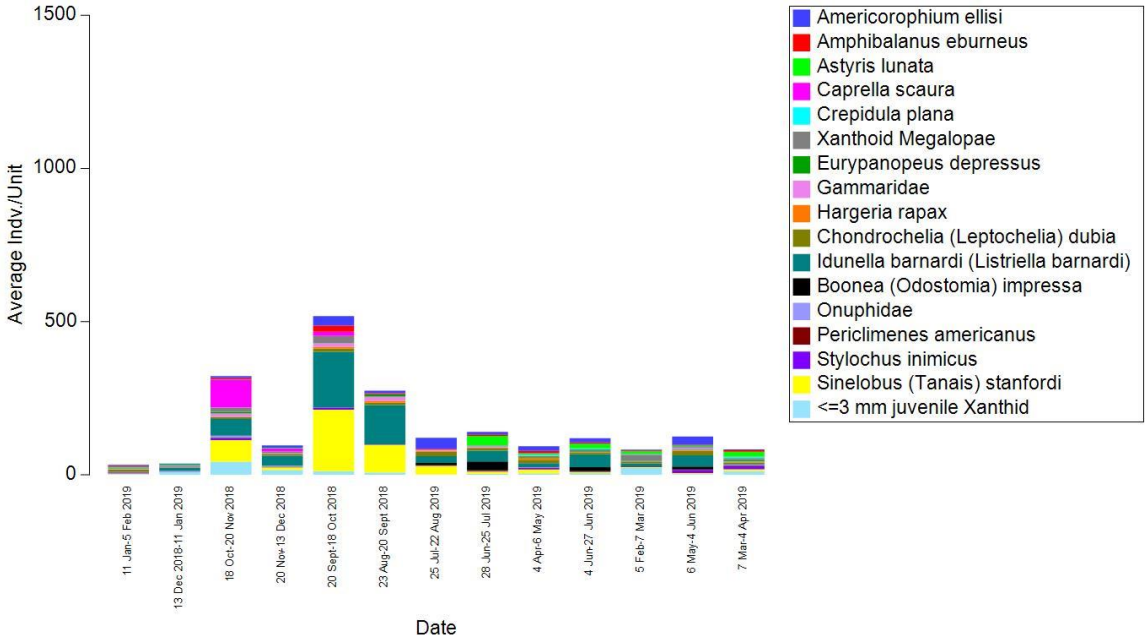

Figure 5. Site A. Average abundance of species shown as species contributing greater than 1% of community composition across sites.

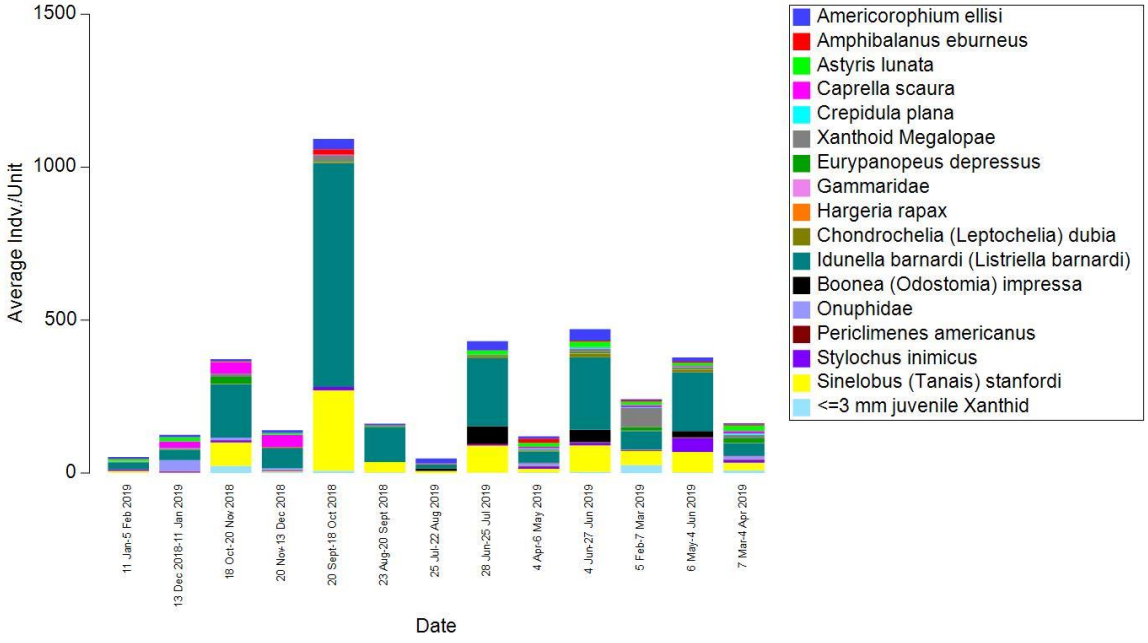

Figure 6. Site B. Average abundance of species contributing greater than 1% of community composition at either site.

Functional Group Abundance, Richness, and Diversity

Replicates were nested in the sites. The abundance, richness, and diversity of functional groups were not significantly different between replicates. Overall, the functional group abundance was higher in the wet season than dry season (Fig. 7). During the wet and dry seasons, the abundance of functional groups (Fig. 7) was significantly different between cage and string treatments in both Sites A and B (wet: $p=0.00000686$; dry: $p=0.01976$). String treatments had greater functional group abundance (Fig. 7). Also, functional group abundance was significantly higher at Site B than Site A during the dry season ($p=0.00378$) (Fig. 7).

There was no significant difference in functional group richness in regard to treatment, site, or replicate site interaction during the dry season (Fig. 8, Appendix B). However, in the wet season (Fig. 8), there was a significant difference in functional group richness between cage and string treatments ($p= 0.0336$). In general, there was greater functional group richness during the wet season (Fig. 8) than the dry season (Fig. 8).

There was no significant difference in functional group diversity between treatment, site, or replicate during the dry season (Fig. 9, Appendix B). However, there was a significant difference in the interaction between treatment and site ($p = 0.0455$) (Fig. 9). In the wet season, there was a significant difference in functional group diversity between Sites A and B with Site A having greater diversity (Fig. 9; $p = 0.00022$).

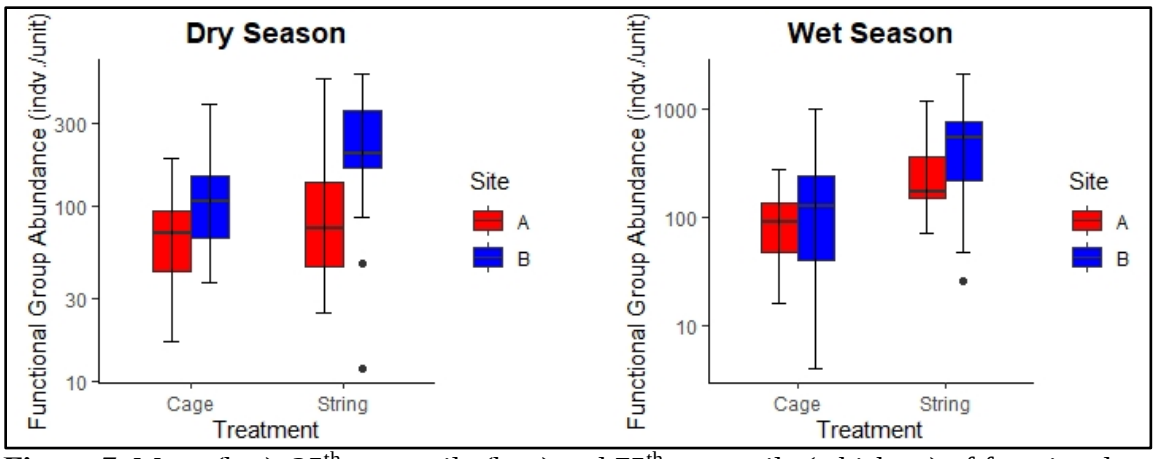

Figure 7. Mean (bar), 25th percentile (box) and 75th percentile (whiskers) of functional group abundance, by dry season (left) and wet season (right), at Site A (red) and Site B (blue).

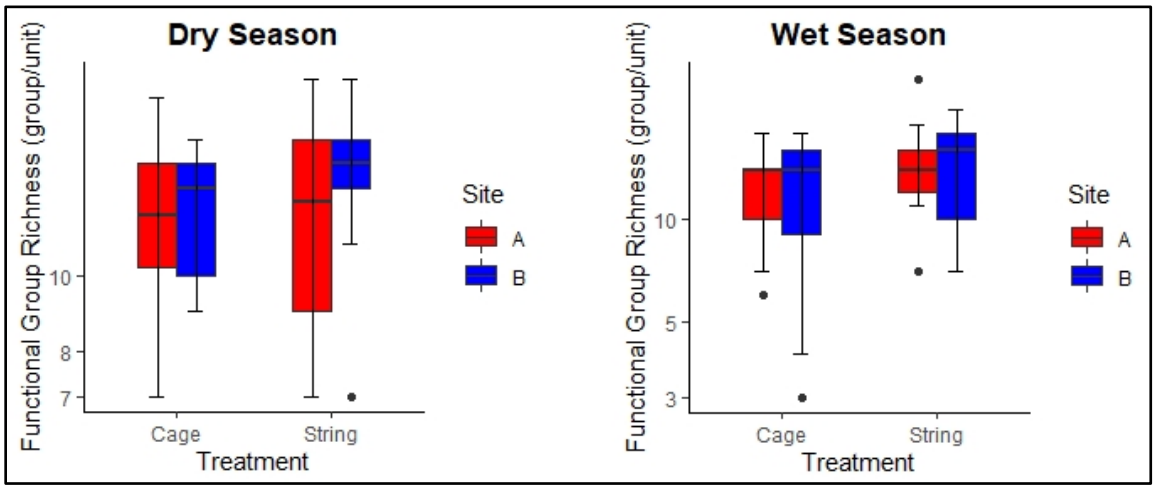

Figure 8. Mean (bar), 25th percentile (box) and 75th percentile (whiskers) of functional group richness, by dry season (left) and wet season (right), at Site A (red) and Site B (blue).

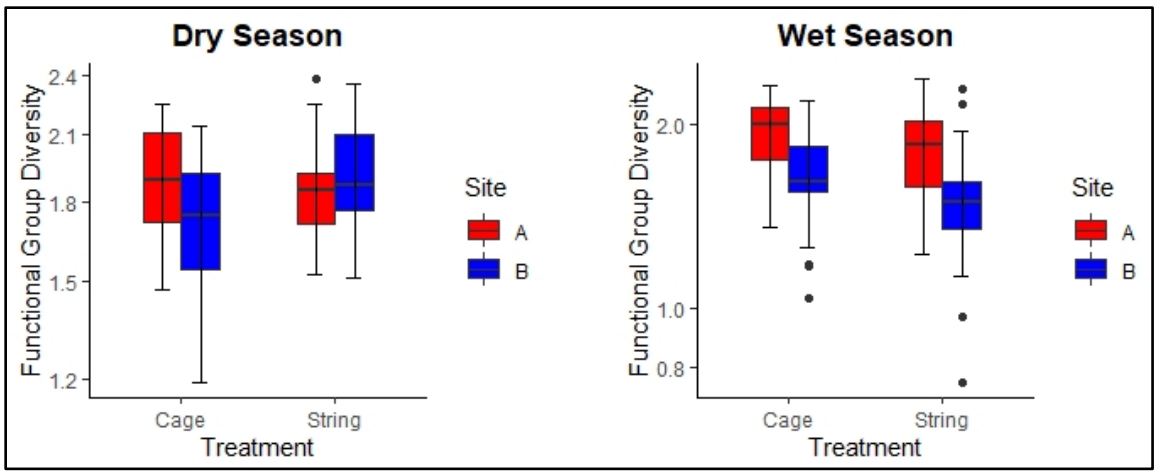

Figure 9. Mean (bar), 25th percentile (box) and 75th percentile (whiskers) of functional group diversity, by dry season (left) and wet season (right), at Site A (red) and Site B (blue).

Discussion

Organisms with a variety of trophic modes, living positions, and mobility utilize oyster reef habitats (e.g., Tolley et al., 2005; Jud and Layman, 2020). Here, the dominant species at both sites were *Idunella (Listriella) barnardi, Sinelobus* (*Tanais*) *stanfordi*, *Astyris lunata*, *Americorophium ellisi*, *Boonea (Odostomia) impressa,* less than 3 mm juvenile xanthids, and *Caprella scaura*. Since there were distinct differences in temperature and salinity by season, we analyzed the data separately. In doing so, we noted significantly greater functional group abundance during the wet season. Overall, the abundance of functional groups was significantly greater in the hanging string units which represent the oyster garden restoration technique, with no significant loss of functional group richness or diversity by treatment or season using either the string units (oyster garden restoration technique) or the cage units (oyster bag or cage restoration). The results show how these small units have potential to serve as habitat for organisms of various types of motility, living positions, and feeding strategies.

There were significant differences in functional group diversity and abundance between Sites A and B which may be related to the hydrodynamics of the sites. Total oyster larval recruitment was not greatly different between Site A (2806 individuals on both treatments) and Site B (3040 individuals on both treatments) (Metz, 2021). Site B is deeper and frequently experienced higher flow rates than Site A (field observations). The deposit feeding, predator, scavenger, free-living, burrowing Xanthidae mud crabs (13%, Table 6) and deposit feeding, tube dwelling *Chondrochelia (Leptochelia) dubia* (12%, Table 6) were commonly present at Site A whereas the deposit feeding, scavenger, free-living, burrowing, tube dwelling *Sinelobus (Tanais) stanfordi* was more abundant at Site

B (11%, Table 7). These differences are likely related to the depth of the reef at Site B, where the higher flow speed and lower sediment deposition affect species richness and abundance (Lenihan, 1999).

Unlike the other tube-dwelling, deposit feeding tanaids, *Hargeria rapax* and *Chondrochelia (Leptochelia) dubia, Sinelobus stanfordi* were only found in abundance at Site B. *S. stanfordi* is versatile, thriving in tropical and temperate and marine and estuarine regions (Van Haaren et al., 2009). This species can live in muddy or sandy bottoms, algae, and corals (Fofonoff et al., 2018d). There is not much information on the niches of these individual tanaid species. Thus, future research should focus on studying the requirements for tube-building and their preferred environmental parameters like sediment grain size, bacteria, depth, and water flow. In this study, the abundance of potential predators of *Sinelobus stanfordi* and *Chondrochelia (Leptochelia) dubia*, xanthid mud crabs varied between sites but nereid polychaetes did not vary greatly between the sites. We also observed the presence of the piscivore–invertivore notch-tongue goby (*Bathygobius curacao*) and the omnivorous crested-goby (*Lophogobius cyprinoides*) but any effects from the presence of vertebrates could not be evaluated because this would require a different sampling technique and was considered within the scope of this project (De Boer et al., 1973; Yeager and Layman, 2011).

Xanthids smaller than 3 mm were dominant at Site A (13% contribution, Table 6). Mud crabs of the Xanthidae family inhabit and feed in intertidal and subtidal zones, using oyster shells as refuge (Grant and McDonald, 1979; Margiotta et al., 2016). A study on the relationship between rugosity and mud crab use of the oyster reef, noted a positive correlation between the rugosity of dead shell oyster reefs and the abundance of the

common free living, omnivore *E. depressus* (Margiotta et al., 2016). Thus, the physical structure, proximity to shore, and hydrodynamics may affect the appearance of xanthids. Another study by Reustle and Smee (2020) reported that crab mesopredators, including xanthids, were more abundant, and larger, on oyster reefs with higher turbidity and was also associated with decreased fish predation.

Although there are differences in the dominant species of Sites A are B, the same trends between cage and string treatments are observed at both sites. Both sites contained deposit feeding, tube-dwelling tanaids as well as corophiid *Americorophium ellisi* (13% Site A, 8% Site B, Tables 6 and 7). Both sites also contained the deposit feeding, co-resident, tube-dwelling amphipod *Idunella barnardi*, but this species dominated community composition at Site B (54%, Table 7). There are few studies that examine the ecological niche of these species, but in general, deposit feeding tube dwelling organisms are ecosystem engineers that promote biodiversity and increase nutrient cycling through their feeding strategies.

The physical structure of different oyster reef gardening techniques will alter water flow and the cages may exclude species. For example, in a study on recruitment of sessile suspension feeding ivory barnacles (*Amphibalanus eburneus*), oyster cultch type and orientation of shells affected flow speeds and larval recruitment (Johnson and Soltis, 2017). The structure may also influence epiphyte growth due to increased surface area and effects of flow speed. Another study focused on algae growth and herbivory on tiles in a coral reef, comparing nutrient-enriched, predator excluded, and control treatments in Hawaii (Smith et al., 2001). Fertilizer was used to enrich treatments and the cages were made from 1-inch diameter wire mesh to exclude macroherbivores (Smith et al., 2001). In

this study algal biomass was higher on tiles with nutrient enrichment and herbivore exclusive cages (Smith et al., 2001). The water motion was not different inside and outside the cages, but the highest sedimentation was measured in caged tile treatment as compared to nutrient-enriched tiles (Smith et al., 2001). In studies within seagrass beds and oyster reefs, the use of cages resulted in the exclusion of predatory fish like Sheepshead (*Archosargus probatocephalus*) and provided a refuge for carnivorous decapods, which then could prey on r-selected organisms like polychaetes and bivalves (Young et al., 1976; Johnson et al., 2014). However, the cages would also be so small that carnivorous crabs would limit the abundance and species richness of those living inside (Young and Young, 1978). Here, we did not observe an increase in visible algae in cage treatments, nor did we measure a significant increase in sessile invertebrates in cages, suggesting that hydrodynamics and/or predation were not significantly altered by cages.

The greater abundance and functional group richness during the wet season indicate a seasonal change in in organisms inhibiting the oyster reef. The higher salinity and lower temperatures in the dry season may cause stress to some organisms, influencing their abundance, whereas the lower salinity during the wet season may allow more species to utilize the reef. Although not the most abundant, key indicator species were detected over the course of this study. *Boonea impressa* can cause stress on its host, *Crassostrea virginica,* reducing valve movement, filtration, growth, and survival (Ward and Langdon, 1986). Overall, the abundance of *Boonea impressa* was higher in the wet season than the dry season (wet season $\bar{x} = 25$, $\sigma = 26.18$ and dry season $\bar{x} = 1.83$, $\sigma = 1.33$). During the wet season, the mean abundance was greater at Site B than A and greater in cage treatments than string ($p=0.03713$; $p=0.00489$). *Stylochus inimicus*

abundance was not greatly different between seasons (wet season $\bar{x}$ = 14.78, σ = 22.28 and dry season $\bar{x}$ = 8.44, σ = 7.68) In both seasons, the mean abundance of *Stylochus inimicus* was higher in the string treatments (p= 3.03E-06; p=0.000112). The differences in abundance of *Boonea impressa* and *Stylochus inimicus* may be related to abiotic factors like salinity and temperature but also biotic factors like larval recruitment of oysters, their main host.

A similar pattern was noted for oyster spat, where Sites A and B both had greater oyster larval recruitment during the wet season (2093 individuals at Site A and 2187 individuals at Site B; not standardized by unit area) than the dry season (713 individuals at Site A and 853 individuals at Site B; not standardized by unit area) (Metz, 2021). Additionally, 16 species were unique to the wet season and 8 species to the dry season. *Dreissena polymorpha*, a freshwater suspension feeding mussel, and Eunicidae, a family of marine polychaetes, were two taxa that were the most abundant in the wet season and did not appear in the dry season. *Dreissena polymorpha* were most abundant from 23 August to 18 October, 2018 when the salinities were slightly lower. Zebra mussels prefer freshwater for fertilization and development yet have a large range of temperature tolerance (Fofonoff et al., 2018c). Based on this we do not expect that the differences in temperature during the seasons would have a profound effect on the abundance of this mussel. Unlike zebra mussels, the Eunicidae population was consistent throughout the wet season. As juveniles, these marine polychaetae rockworms, have lower salinity tolerance with decreased growth and survival rates at 15, 20, and 40 psu (Garcês and Pereira, 2011; Thi Thu et al., 2019). However, the adults and eggs are more resistant to salinity change (Thi Thu et al., 2019; Krishnamoorthi, 1951). In addition, the functional

group diversity varied between replicates and site in the dry season which is likely due to differences in habitat heterogeneity. It may indicate that one replicate is used by a functional group more than another, and that these differences are larger in the dry season when species are less abundant.

The results show that oyster reefs serve as a key habitat for animals with various functions. There was not significantly less functional group richness or diversity in hanging strings compared to caged units and in fact hanging string units had a significantly greater abundance of functional groups. These findings suggest that vertical oyster gardens (i.e. string cultch types) can be used as additional habitat, providing physical structure and a food source. The value of the small-scale reef restorations has been previously recognized (Brumbaugh and Cohen 2009) and may be an economical method of restoring *C. virginica* oyster reefs in South Florida. The presence of juvenile macrofauna that benefit from the oyster reefs measured here supports community-based programs such as Restore Our Shores 'oyster gardening' program (Brevard Zoo, n.d.) which uses methodologies similar to our 'caged' treatments and Tampa Bay Watch's 'vertical oyster gardening' program, which uses methodologies similar to our string treatments (Tampa Bay Watch, n.d.).

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Appendix A

Table 8. Functional Group Codes for Each Taxon.

Taxa ID	Reference ID	References: Feeding Strategies	References: Living Position	Feeding Strategy Code	Living Position Code	Calcium-Based Shell/Tube (Yes/No)
Alpheus spp.	*Alpheus heterochaelis*	Silliman et al., 2003; Hunt and Scheibling, 1997; Masterson, 2008a	Tolley and Volety, 2005; Rahman, et al. 2003; Raz-Guzman et al., 2005	DF/P/SF	CR/FB	
Americorophium ellisi	*Americorophium ellisi*	Walton et al., 2013	Barnard et al., 1991	DF	TD	
Ampelisca spp.	*Ampelisca abdita*	Kennish et al., 2009; Fofonoff et al., 2018a	Kennish et al., 2009; Fofonoff et al., 2018a	DF/SF	TD	
Amphibalanus amphitrite	*Amphibalanus eburneus*	Freeman et al., 2018	Hunt and Scheibling, 1997	SF	SE	Y
Amphibalanus eburneus	*Amphibalanus eburneus*	Freeman et al., 2018	Hunt and Scheibling, 1997; Johnson and Soltis, 2017	SF	SE	Y
Amygdalum papyrium	*Amygdalum papyrium* and *Mytiloida*	Zimmerman et al., 1989; Puglisi, 2008a	Coan and Valentich-Scott, 2006	SF	FB/SE	Y
Apocorophium lacustre	*Apocorophium lacustre*	Gaston et al., 1998; Gaston and Nasci, 1988	LeCroy, 2004; Feely and Wass, 1971	DF/SF	TD	
Apocorophium simile	*Apocorophium simile* and *A. lacustre*	Watling, 1976; Gaston et al., 1998; Gaston and Nasci, 1988	LeCroy, 2004	DF/SF	TD	
Apocorophium spp.	*Apocorophium simile and A. lacustre*	Watling, 1976; Gaston et al., 1998; Gaston and Nasci, 1988	LeCroy, 2004; Feely and Wass, 1971	DF/SF	TD	
Astyris lunata	*Astyris lunata*	Osman et al., 1992; Macdonald et al., 2012; De Maintenon, 1999	Stachowicz and Whitlatch, 2005	SC/P/DF	FL	Y

Taxa ID	Reference ID	References: Feeding Strategies	References: Living Position	Feeding Strategy Code	Living Position Code	Calcium-Based Shell/Tube (Yes/No)
Atrina spp.	*Atrina zelandica. Atrina sp., A. rigida,* and *A. fragilis*	Kesler, 2015	Tyler-Walters and Wilding, 2017; Winckworth, 1929; Grave, 1911	SF	FB	Y
Bittiolum varium	*Bittiolum varium*	Masterson, 2008b; Young et al., 1978	Young et al., 1978	DF / HG / SC	FL	Y
Boccardia spp.	*Polydora ligni* and *P. socialis*	Gaston and Nasci, 1988; Dauer et al., 1981	Puglisi and Thiebaud, 2008; Dauer, 1981	DF/SF	FB/TD	
Boonea impressa	*Boonea impressa*	Powell et al., 1987; Caroll and Finelli, 2015	Powell et al., 1987; Caroll and Finelli, 2015	PC	CR	Y
Bopyridae	Bopyridae, *Aporobopyrus curtatus, Bopyrina abbreviate, Diplophryxus* sp., Probopyria alphei, *Probopyrinella latreuticola*, and *Probopyrus pandalicola*	Kensley et al., 1995; Markham, 2003	Kensley et al., 1995; Markham, 2003	PC	CR	
Brachidontes exustus	*Brachidontes exustus*	Ward and Shumway, 2004; Odum and heald, 1972	Arkle and Miller, 2018	SF	FL	Y
Bulla occidentalis	*Bulla occidentalis*	Malaquias et al., 2009	Leal, n.d.	P/HG/S	FB	Y
Bushia elegans	*Bushia elegans*	Turgeon et al., 2009; Kelley, 2008; Coan and Valentich-Scott, 2006	Turgeon et al., 2009	P/SF/DF	FB	Y
Capitellidae	Capitellidae and *Capitella capitata. Capitella* spp.	Gaston et al., 1988; Myers 1977; Masterson, 2008c	Grill and Dorgan, 2015	DF	FB	
Caprella scaura	*Caprella scaura*	Ros et al., 2014; Masterson, 2008d	Bueno and Leite, 2019	HG/P/SF	FL	
Caridea	*Palaemonetes paludosus, P. vulgaris, P. intermedius,* and *Alpheus heterochaelis*	Beck and Cowell, 1976; Raz-Guzman et al., 2005; Hunt and	Tolley and Volety, 2005; Rahman, et al. 2003; Raz-	DF/SC	FB	

Taxa ID	Reference ID	References: Feeding Strategies	References: Living Position	Feeding Strategy Code	Living Position Code	Calcium-Based Shell/Tube (Yes/No)
		Scheibling, 1997; Masterson, 2008a	Guzman et al., 2005			
Chondrochelia dubia	*Chondrochelia dubia*	Myers, 1977; Odum, 1972	Myers, 1977; Mendoza, 1982	DF	TD	
Copepoda	Copepoda	Chen et al., 2018	Chen et al., 2018	DF	FL	
Crassostrea virginica	*Crassostrea virginica*	Galimay et al., 2017; Wall et al., 2011	Galimay et al., 2017; Wall et al., 2011	SF	SE	Y
Crepidula plana	*Crepidula plana*	Fofonoff et al., 2018b	Fofonoff et al., 2018b	SF	FL/SE	Y
Cronius ruber	*Cronius ruber*	Schäfer et al., 2019	González et al., 2017	P/SC	FB	
Dreissena polymorpha	*Dreissena polymorpha*	Fofonoff et al., 2018c	Fofonoff et al., 2018c	SF	FL/SE	Y
Erichthonius brasiliensis	*Erichthonius brasiliensis*	Hagerman, 1966	Hughes, 1975	DF	TD	
Eunicidae	*Marphysa spp., Lysidice ninetta, L. ninetta, L. collaris,* and *Nematonereis unicornis*	Gambi et al., 2003; Castriota et al., 2003	Gambi et al., 2003; Fauchald and Jumars, 1979; Lu and Fauchald, 2000	P/SF	FB/TD	
Eurydice spp.	*Eurydice spp., E. caudata, E. littoralis, E. affinis.* and Isopoda	Bruce, 1986; Kalman, 2006	Myers, 1977	P/PC/SC	FB	
Eurypanopeus abbreviatus	*Eurypanopeus depressus, E. dissimilis.* and *E. abbreviates*	Milke and Kennedy, 2001; Puglisi, 2008b; Garcés, 1987; Hunt, 1997	Williams, 1984; Powers, 1977	DF/P/PC/SC	FL	
Eurypanopeus depressus	*Eurypanopeus depressus*	Milke and Kennedy, 2001; Puglisi, 2008b	Tolley and Volety, 2005	DF/P/SC	FL	
Eurypanopeus dissimilis	*Eurypanopeus dissimilis*	Garcés, 1987; Hunt, 1997	Garcés, 1987	DF/P/SC	FB/FL	
Eurypanopeus turgidis	*Eurypanopeus dissimilis*	Garcés, 1987; Hunt, 1997; Milke and	Garcés, 1987; Tolley and Volety, 2005	DF/P/SC	FB/FL	

Taxa ID	Reference ID	References: Feeding Strategies	References: Living Position	Feeding Strategy Code	Living Position Code	Calcium-Based Shell/Tube (Yes/No)
		Kennedy, 2001; Puglisi, 2008b				
Eurypanopeus spp.	*Eurypanopeus turgidis, E. depressus, E. dissimilis.* and *E. abbreviatus*	Milke and Kennedy, 2001; Puglisi, 2008b; Garcés, 1987; Hunt, 1997	Williams, 1984; Powers, 1977; Garcés, 1987; Tolley and Volety, 2005	DF/P/SC	FB/FL	
Gammaridae	*Cymadua compta, Gammarus mucronatus, Melita nitida,* and *Grandidierella bonnieroides*	Zimmerman et al., 1979; Cruz-Rivera and Hay, 2000	Cruz-Rivera and Hay, 2000; Gutow et al., 2020; Bousfield, 1969	DF/HG/SC	FB/FL/TD	
Hargeria rapax	*Hargeria rapax* and *Leptochelia spp.*	Gaston et al. 1988; Odum and Heald,1972	Rader, 1984	DF/SF	TD	
Hippolyte zostericola	*Hippolyte zostericola*	Zupo and Nelson, 1999	Raz-Guzman et al., 2005	DF	FL	
Hyalella azteca	*Hyalella azteca*	Hargrave, 2011; Odum and Heald, 1972	Hargrave, 2011; Winnell and Jude, 1987	DF	FB	
Idunella barnardi	*Idunella chilkensis, I. janisae., I. barnardi* and Lilieoborgiidae	Seo et al., 2014; Seo et al., 2012; Wongkamhang, 2004	Fox and Bynum, 1975; Watling and Maurer, 1972	DF	CR/TD	
Mactra fragilis	*Mactra fragilis*	Livingston, 2002; Kranz, 1974	Almeida et al., 2018; Turgeon et al., 2009	SF/DF	FB	Y
Melita nitida	*Melita nitida*	Zimmerman et al., 1979; Odum and Heald, 1972	Zimmerman et al., 1979; Odum and Heald, 1972	DF	FL	
Menippe mercenaria	*Menippe mercenaria* and Menippidae	Tolley and Volety, 2005; Hunt and Scheibling, 1997	Tolley and Volety, 2005; Hunt and Scheibling, 1997	P/SC	FL	
Mysella spp.	*M. planulata* and *M. bidentata*	Pohlo, 1982; Franz, 1973	Nickell et al., 1995; Franz, 1973	SF	CR/FB/SE	Y

Taxa ID	Reference ID	References: Feeding Strategies	References: Living Position	Feeding Strategy Code	Living Position Code	Calcium-Based Shell/Tube (Yes/No)
Mysidae	Mysidopsis almyra and Mysidae	Gaston et al., 1988; Odum and Heald, 1972	Gaston et al., 1988	SF	FL	
Nereidae	*Neanthes arenaceodonta, N. virens,* and *N. succinea*	Pardo and Dauer, 2003; Masterson, 2008e	Myers, 1977; Masterson, 2008e	DF/P/SC	FB	
Neritina virginica	*Neritina virginica*	Blanco-Libreros, 2005; Murayama, 2016; Sweat, 2009	Blanco-Libreros, 2005; Murayama, 2016; Sweat, 2009	HG/DF/SC/P	FL	Y
Olivella (Oliva) spp.	*Oliva sayana, O. adelae,* and *O. minuta*	Checon et al., 2020; Miller, 1997	Miller, 1997	P/SC/DF	FB	Y
Onuphidae	*Diopatra cuprea, D. neapolitana,* and *D. ornate*	Clemo and Dorgan, 2017; Fauchald and Jumars,1979	Ban and Nelson, 1987; Fauchald and Jumars, 1979	DF/HG/SC	SE/TD	
Orbinidae	*Scoloplos rubra, Haploscoloplos foliosus, Orbinidae. Scoloplos robustus* and *Haploscoloplos foliosus*	Fauchald and Jumars, 1979; Bloom, 1983	Webb and Montagna, 1993; Myers, 1977	DF	FB	
Oxyurostylis smithi	*O. smithi* and *Cyclaspis varians*	Odum and Heald, 1972; Myers, 1977	Myers, 1977	DF	FB	
Panopea bitruncata	*Panopea generosa* and *P. bitruncata*	Konrad, 2013	Alexander et al., 2005	SF	FB	Y
Panopeus americanus	*Panopeus occidentalis*	Greenway, 1995; Quinn, 2020	Tolley and Voelty, 2005; Powers, 1977	DF/P/SC	FL	
Panopeus occidentalis	*Panopeus occidentalis*	Greenway, 1995; Quinn, 2020	Tolley and Voelty, 2005; Powers, 1977	DF/P/SC	FL	
Parhyale hawaiensis	*Parhyale hawaiensis* and *Parhyale* spp.	Poovachiranon et al., 1986; Macko, 1982	Vader and Tandberg, 2013; Poovachiranon et al., 1986	DF	CR/FL	

Taxa ID	Reference ID	References: Feeding Strategies	References: Living Position	Feeding Strategy Code	Living Position Code	Calcium-Based Shell/Tube (Yes/No)
Periclimenes americanus	*Periclimenes americanus, Palaemonetes intermedius, P. paludosus,* and *P. Pugio*	Odum and Heald, 1972	Holmquist, 1997	DF/HG/SC	FL	
Petrolisthes armatus	*Petrolisthes armatus*	McGlaun and Withers, 2012; Zimba et al., 2016; Caine, 1975	Tolley and Volety, 2005	DF/SC/SF	FB	
Sabellaria spp.	*Sabella penicillus, Notaulax tenuitorques,* and *Anamobaea orstedi*	Jorgensen et al., 1984	Vinn et al., 2018; Fauchald and Jumars, 1979	SF	TB	Y
Scolecolepides viridis	*Scolecolepides viridis*	Dauer et al., 1981	Dauer et al., 1981; Kennish et al., 2009	DF/SF	FB	
Shrimp larva	*Penaeus setiferus, P. duorarum,* and *P. aztecus*	Hill, 2002a; Hill, 2002b; Hill, 2005	Hill, 2002a; Hill, 2002b; Hill, 2005	DF/HG/SC	FL	
Sinelobus (Tanais) stanfordi	*Sinelobus (Tanais) stanfordi*	Fofonoff et al., 2018d	van Haaren and Soors, 2009; Fofonoff et al., 2018d	DF/SC	FB/FL/TD	
Stylochus inimicus	*Stylochus inimicus*	Landers, 1970	Myers, 1977	PC	CR/FL	
Tagelus spp.	*Tagelus* spp., *T. divisus, T. plebeius, T. dombeii. Tagelus* spp. and *T. divisus.*	Arruda et al., 2003; Staff et al., 1985; Navarro et al., 2008; Fraser, 1967	Sheridan, 1983; Staff et al., 1985	SF/DF	FB	Y
Unidentified crab	*Eurypanopeus* and *Panopeus* species	*Eurypanopeus* and *Panopeus* References	*Eurypanopeus* and *Panopeus* References	DF/P/SC	FL/FB	
Xanthidae	*Eurypanopeus* and *Panopeus* species	*Eurypanopeus* and *Panopeus* References	*Eurypanopeus* and *Panopeus* References	DF/P/SC	FL/FB	
Xanthoid Megalopae	*Eurypanopeus* and *Panopeus* species	*Eurypanopeus* and *Panopeus* References	*Eurypanopeus* and *Panopeus* References	DF/P/SC	FL	

Appendix B

Table 9. Shapiro-Wilk Test Results.

Data	Abundance	Richness	Shannon-Wiener Diversity Index
Species Data	w = 0.66123; p < 2.2*10^-16	w = 0.98254; p = 0.04844	w = 0.97976; p = 0.023
Log-Transformed Species Data	w = 0.99407; p = 0.7857	w = 0.92474; p = 0.0000003227	w = 0.96342; p = 0.0004195
Functional Group Data	w = 0.66123; p < 2.2*10^-16	w = 0.98335; p = 0.06027	w = 0.98553; p = 0.1087
Log-Transformed Functional Group Data	w = 0.99407; p = 0.7857	w = 0.92267; p = 0.0000002342	w = 0.94608; p = 0.00001221

Table 10. Results of 3-Way ANOVAs of Functional Group Data.

Log10 Abundance - Wet Season	Df	Sum Sq	Mean Sq	F value	P-value
Type	1	5.27	5.27	23.35	6.86E-06
Site	1	0.613	0.613	2.717	0.103
Site(Replicate)	2	0.119	0.059	0.263	0.77
Type:Site	1	0.08	0.08	0.354	0.554
Type:Site(Replicate)	2	0.11	0.055	0.243	0.785
Residuals	76	17.152	0.226		
Log10 Abundance - Dry Season	Df	Sum Sq	Mean Sq	F value	P-value
Type	1	0.755	0.7548	5.726	0.01976
Site	1	1.194	1.1938	9.055	0.00378
Site(Replicate)	2	0.132	0.066	0.5	0.60879
Type:Site	1	0.075	0.0745	0.565	0.45501
Type:Site(Replicate)	2	0.038	0.019	0.144	0.86588
Residuals	62	8.174	0.1318		
Richness - Wet Season	Df	Sum Sq	Mean Sq	F value	P-value
Type	1	84	84	4.681	0.0336
Site	1	0.4	0.43	0.024	0.8776
Site(Replicate)	2	4.6	2.31	0.129	0.8792

Type:Site	1	0.2	0.24	0.013	0.908
Type:Site(Replicate)	2	5.2	2.58	0.144	0.8661
Residuals	76	1363.8	17.94		
Richness - Dry Season	Df	Sum Sq	Mean Sq	F value	P-value
Type	1	13.7	13.729	1.521	0.222
Site	1	9.7	9.708	1.076	0.304
Site(Replicate)	2	3.3	1.645	0.182	0.834
Type:Site	1	14.2	14.202	1.574	0.214
Type:Site(Replicate)	2	5	2.5	0.277	0.759
Residuals	62	559.5	9.024		
Diversity - Wet Season	Df	Sum Sq	Mean Sq	F value	P-value
Type	1	0.258	0.2576	2.24	0.13861
Site	1	1.732	1.7324	15.066	0.00022
Site(Replicate)	2	0.029	0.0145	0.126	0.88198
Type:Site	1	0.013	0.013	0.113	0.73791
Type:Site(Replicate)	2	0.02	0.0102	0.089	0.91528
Residuals	76	8.739	0.115		
Diversity - Dry Season	Df	Sum Sq	Mean Sq	F value	P-value
Type	1	0.159	0.15899	2.906	0.0933
Site	1	0.087	0.08669	1.584	0.2129
Site:Replicate	2	0.253	0.12653	2.313	0.1075
Type:Site	1	0.228	0.22804	4.168	0.0455
Type:Site:Replicate	2	0.069	0.03448	0.63	0.5359
Residuals	62	3.392	0.05472		

Appendix C

Table 11. SIMPER Results. Sites A and B. Average dissimilarity = 75%.

	Group A	Group B				
Species	**Av.Abund**	**Av.Abund**	**Av.Diss**	**Diss/SD**	**Contrib%**	**Cum.%**
Idunella barnardi (Listriella barnardi)	43.77	151.43	22.92	1.36	30.74	30.74
Sinelobus (Tanais) stanfordi	33.44	56.13	9.96	1.04	13.37	44.11
Astyris lunata	6.83	8.54	4.12	0.7	5.53	49.63
Americorophium ellisi	12.81	13.95	4.1	0.74	5.49	55.13
Boonea (Odostomia) impressa	4.54	10.29	3.87	0.53	5.2	60.32
<=3 mm juvenile Xanthid	11.03	6.72	3.81	0.77	5.11	65.43
Caprella scaura	9.35	9.01	3.59	0.52	4.82	70.25
Xanthoid Megalopae	6.68	10.01	3.18	0.65	4.26	74.51
Chondrochelia (Leptochelia) dubia	8.1	2.86	2.52	0.81	3.38	77.88
Stylochus inimicus	3.64	7.79	2.12	0.6	2.84	80.72
Boccardia spp.	5.35	12.74	1.99	0.59	2.67	83.4
Onuphidae	1.47	5.83	1.86	0.41	2.49	85.89
Amphibalanus eburneus	4.6	4.38	1.65	0.67	2.22	88.11
Eurypanopeus depressus	2.32	5.33	1.45	0.74	1.94	90.05
Gammaridae	3.88	0.14	1.23	0.49	1.65	91.69
Bopyridae	2	5.11	1.15	0.69	1.54	93.24
Hargeria rapax	2.42	0.82	0.73	0.65	0.97	94.21
Crepidula plana	1.32	1.45	0.7	0.68	0.94	95.15
Eurypanopeus turgidis	1.08	2.28	0.67	0.66	0.89	96.04
Periclimenes americanus	1.12	1.36	0.6	0.7	0.81	96.85
Nereidae	1.22	2.16	0.45	0.7	0.6	97.45
Tagelus spp.	0.65	1.37	0.26	0.66	0.35	97.8
Brachidontes exustus	0.22	1.14	0.19	0.61	0.26	98.06
Parhyale hawaiensis	0.38	0.38	0.16	0.42	0.22	98.28

	Group A	Group B				
Species	**Av.Abund**	**Av.Abund**	**Av.Diss**	**Diss/SD**	**Contrib%**	**Cum.%**
Ampelisca spp.	0.1	0.3	0.14	0.36	0.19	98.47
Bittium varium	0.23	0.07	0.11	0.35	0.15	98.62
Petrolisthes armatus	0.15	0.12	0.1	0.3	0.14	98.76
Sabellaria spp.	0.49	0.28	0.1	0.39	0.13	98.89
Melita nitida	0.12	0.12	0.09	0.23	0.13	99.02
Dreissena polymorpha	0.1	0.42	0.08	0.33	0.11	99.13
Hippolyte zostericola	0.1	0.13	0.08	0.37	0.1	99.23
Scolecolepides viridis	0.18	0	0.07	0.24	0.1	99.33
Eunicidae	0.05	0.11	0.05	0.29	0.07	99.4
Apocorophium spp.	0.03	0.04	0.05	0.16	0.06	99.46
Amphibalanus amphitrite	0.15	0.07	0.05	0.28	0.06	99.52
Bulla occidentalis	0.04	0.09	0.05	0.28	0.06	99.58
Eurypanopeus dissimilis	0.06	0.05	0.03	0.27	0.04	99.62
Unidentified Crab	0.1	0	0.03	0.12	0.04	99.66
Cronius ruber	0.01	0.04	0.02	0.21	0.03	99.69
Menippe mercenaria	0.04	0	0.02	0.14	0.02	99.71
Alpheus spp.	0	0.05	0.02	0.21	0.02	99.73
Hyalella azteca	0.04	0	0.01	0.11	0.02	99.75
Eurydice spp. (convexa)	0.05	0.01	0.01	0.17	0.02	99.77
Atrina spp.	0.04	0	0.01	0.16	0.02	99.79
Mysella spp.	0.05	0	0.01	0.18	0.02	99.81
Caridea	0.03	0	0.01	0.09	0.02	99.82
Copepoda	0.03	0	0.01	0.14	0.01	99.84
Capitellidae	0.01	0	0.01	0.08	0.01	99.85
Amygdalum papyrium	0.08	0.03	0.01	0.2	0.01	99.87
Ericthonius brasiliensis	0.03	0	0.01	0.1	0.01	99.88

	Group A	Group B				
Species	**Av.Abund**	**Av.Abund**	**Av.Diss**	**Diss/SD**	**Contrib%**	**Cum.%**
Apocorophium lacustre	0.01	0	0.01	0.08	0.01	99.89
Panopeus americanus	0.01	0	0.01	0.08	0.01	99.9
Apocorophium simile	0.01	0	0.01	0.08	0.01	99.91
Panopeus occidentalis	0.03	0	0.01	0.14	0.01	99.92
Crassostrea virginica	0.01	0.08	0.01	0.25	0.01	99.93
Bushia elegans	0.03	0	0.01	0.15	0.01	99.94
Mysidae	0	0.03	0.01	0.15	0.01	99.95
Eurypanopeus spp.	0.01	0	0.01	0.1	0.01	99.96
Mactra fragilis	0.01	0	0.01	0.1	0.01	99.97
Oxyurostylis smithi	0	0.01	0	0.11	0.01	99.97
Shrimp Larva	0	0.01	0	0.11	0.01	99.98
Eurypanopeus abbreviatus	0.03	0.01	0	0.16	0.01	99.98
Olivella spp.	0.01	0	0	0.1	0	99.99
Orbinidae	0.01	0	0	0.1	0	99.99
Panopea bitruncata	0.01	0	0	0.1	0	100
Neritina virginea	0.01	0	0	0.11	0	100

Table 12. SIMPER Results. Site A. Average similarity: 29.64

Species	**Av.Abund**	**Av.Sim**	**Sim/SD**	**Contrib%**	**Cum.%**
Idunella barnardi (Listriella barnardi)	43.77	7.04	0.94	23.76	23.76
<=3 mm juvenile Xanthid	11.03	3.95	0.78	13.31	37.07
Americorophium ellisi	12.81	3.76	0.98	12.68	49.75
Chondrochelia (Leptochelia) dubia	8.1	3.61	1.09	12.19	61.94
Sinelobus (Tanais) stanfordi	33.44	2.15	0.56	7.26	69.2
Xanthoid Megalopae	6.68	1.97	0.78	6.63	75.83
Astyris lunata	6.83	1.43	0.36	4.83	80.66
Amphibalanus eburneus	4.6	0.9	0.49	3.03	83.69

Species	Av.Abund	Av.Sim	Sim/SD	Contrib%	Cum.%
Gammaridae	3.88	0.74	0.44	2.48	86.17
Eurypanopeus depressus	2.32	0.69	0.62	2.33	88.5
Hargeria rapax	2.42	0.55	0.56	1.86	90.36
Boonea (Odostomia) impressa	4.54	0.5	0.23	1.68	92.04
Periclimenes americanus	1.12	0.48	0.52	1.62	93.66
Stylochus inimicus	3.64	0.41	0.26	1.39	95.05
Crepidula plana	1.32	0.36	0.45	1.22	96.28
Caprella scaura	9.35	0.26	0.2	0.89	97.17
Bopyridae	2	0.19	0.29	0.63	97.8
Boccardia spp.	5.35	0.16	0.19	0.55	98.35
Eurypanopeus turgidis	1.08	0.14	0.3	0.48	98.83
Onuphidae	1.47	0.14	0.24	0.46	99.29
Nereidae	1.22	0.07	0.29	0.25	99.54
Bittium varium	0.23	0.03	0.13	0.09	99.63
Tagelus spp.	0.65	0.02	0.14	0.07	99.7
Parhyale hawaiensis	0.38	0.02	0.17	0.07	99.77
Scolecolepides viridis	0.18	0.01	0.09	0.04	99.82
Ampelisca spp.	0.1	0.01	0.08	0.04	99.86
Petrolisthes armatus	0.15	0.01	0.09	0.03	99.89
Sabellaria spp.	0.49	0.01	0.13	0.03	99.91
Brachidontes exustus	0.22	0.01	0.1	0.02	99.93
Hippolyte zostericola	0.1	0.01	0.08	0.02	99.95
Amphibalanus amphitrite	0.15	0	0.07	0.01	99.97
Melita nitida	0.12	0	0.04	0.01	99.98
Menippe mercenaria	0.04	0	0.02	0	99.98
Dreissena polymorpha	0.1	0	0.04	0	99.98
Bulla occidentalis	0.04	0	0.03	0	99.99

Species	Av.Abund	Av.Sim	Sim/SD	Contrib%	Cum.%
Mysella spp.	0.05	0	0.04	0	99.99
Atrina spp.	0.04	0	0.03	0	99.99
Eurypanopeus dissimilis	0.06	0	0.04	0	99.99
Eunicidae	0.05	0	0.03	0	99.99
Copepoda	0.03	0	0.02	0	100
Eurydice spp. (convexa)	0.05	0	0.03	0	100
Panopeus occidentalis	0.03	0	0.02	0	100
Unidentified Crab	0.1	0	0.02	0	100
Hyalella azteca	0.04	0	0.02	0	100
Bushia elegans	0.03	0	0.02	0	100
Apocorophium spp.	0.03	0	0.02	0	100
Amygdalum papyrium	0.08	0	0.03	0	100

Table 13. SIMPER Results. Site B. Average similarity: 30.71%

Species	Av.Abund	Av.Sim	Sim/SD	Contrib%	Cum.%
Idunella barnardi (Listriella barnardi)	151.43	16.43	1.36	53.49	53.49
Sinelobus (Tanais) stanfordi	56.13	3.5	0.68	11.41	64.9
Americorophium ellisi	13.95	2.55	0.98	8.31	73.21
Astyris lunata	8.54	1.73	0.52	5.65	78.85
Xanthoid Megalopae	10.01	0.96	0.53	3.12	81.98
Eurypanopeus depressus	5.33	0.79	0.69	2.57	84.55
<=3 mm juvenile Xanthid	6.72	0.66	0.48	2.16	86.71
Boonea (Odostomia) impressa	10.29	0.64	0.23	2.1	88.81
Caprella scaura	9.01	0.64	0.3	2.07	90.88
Stylochus inimicus	7.79	0.39	0.33	1.27	92.15
Amphibalanus eburneus	4.38	0.35	0.48	1.15	93.29
Periclimenes americanus	1.36	0.34	0.42	1.12	94.41

Species	Av.Abund	Av.Sim	Sim/SD	Contrib%	Cum.%
Onuphidae	5.83	0.28	0.21	0.93	95.33
Bopyridae	5.11	0.25	0.38	0.81	96.14
Crepidula plana	1.45	0.23	0.41	0.75	96.89
Eurypanopeus turgidis	2.28	0.23	0.53	0.74	97.63
Chondrochelia (Leptochelia) dubia	2.86	0.22	0.5	0.71	98.34
Boccardia spp.	12.74	0.21	0.27	0.7	99.04
Hargeria rapax	0.82	0.08	0.35	0.25	99.28
Nereidae	2.16	0.07	0.33	0.23	99.52
Brachidontes exustus	1.14	0.04	0.26	0.14	99.66
Tagelus spp.	1.37	0.04	0.3	0.14	99.8
Ampelisca spp.	0.3	0.01	0.11	0.04	99.84
Parhyale hawaiensis	0.38	0.01	0.1	0.03	99.86
Hippolyte zostericola	0.13	0.01	0.1	0.02	99.88
Melita nitida	0.12	0.01	0.04	0.02	99.9
Dreissena polymorpha	0.42	0	0.09	0.02	99.92
Petrolisthes armatus	0.12	0	0.08	0.01	99.93
Eunicidae	0.11	0	0.08	0.01	99.94
Bulla occidentalis	0.09	0	0.06	0.01	99.96
Bittium varium	0.07	0	0.05	0.01	99.97
Sabellaria spp.	0.28	0	0.09	0.01	99.97
Gammaridae	0.14	0	0.07	0.01	99.98
Apocorophium spp.	0.04	0	0.02	0.01	99.99
Eurypanopeus dissimilis	0.05	0	0.04	0	99.99
Alpheus spp.	0.05	0	0.04	0	99.99
Cronius ruber	0.04	0	0.03	0	100
Amphibalanus amphitrite	0.07	0	0.06	0	100
Crassostrea virginica	0.08	0	0.04	0	100

Species	**Av.Abund**	**Av.Sim**	**Sim/SD**	**Contrib%**	**Cum.%**
Mysidae	0.03	0	0.02	0	100
Amygdalum papyrium	0.03	0	SD=0!	0	100
Apocorophium lacustre	0	0	SD=0!	0	100
Apocorophium simile	0	0	SD=0!	0	100
Atrina sp.	0	0	SD=0!	0	100
Bushia elegans	0	0	SD=0!	0	100
Capitellidae	0	0	SD=0!	0	100
Caridea	0	0	SD=0!	0	100
Copepoda	0	0	SD=0!	0	100
Ericthonius brasiliensis	0	0	SD=0!	0	100
Eurydice spp. *(convexa)*	0.01	0	SD=0!	0	100
Eurypanopeus abbreviatus	0.01	0	SD=0!	0	100
Eurypanopeus spp.	0	0	SD=0!	0	100
Hyalella azteca	0	0	SD=0!	0	100
Mactra fragilis	0	0	SD=0!	0	100
Menippe mercenaria	0	0	SD=0!	0	100
Mysella spp.	0	0	SD=0!	0	100
Neritina virginea	0	0	SD=0!	0	100
Olivella spp.	0	0	SD=0!	0	100
Orbinidae	0	0	SD=0!	0	100
Oxyurostylis smithi	0.01	0	SD=0!	0	100
Panopea bitruncata	0	0	SD=0!	0	100
Panopeus americanus	0	0	SD=0!	0	100
Panopeus occidentalis	0	0	SD=0!	0	100
Scolecolepides viridis	0	0	SD=0!	0	100
Shrimp Larva	0.01	0	SD=0!	0	100
Unidentified Crab	0	0	SD=0!	0	100

Appendix D

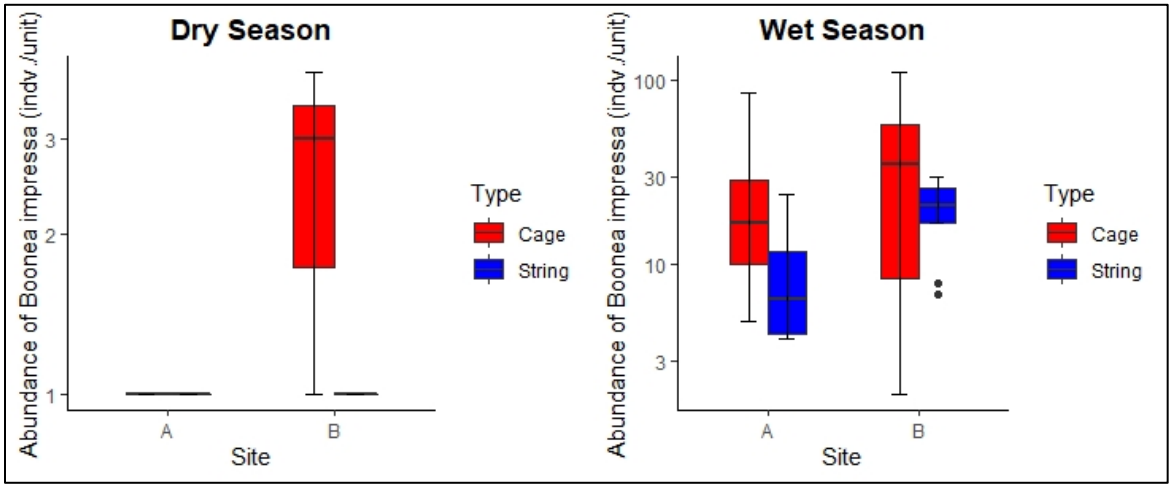

Figure 10. Abundance of *Boonea impressa* during dry and wet seasons.

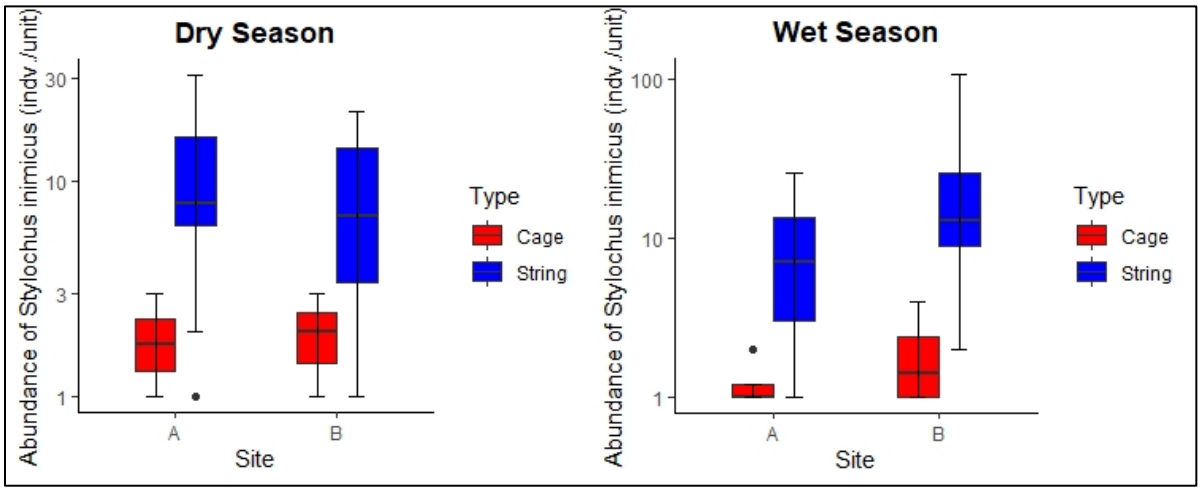

Figure 11. Abundance of *Stylochus inimicus* during dry and wet seasons.