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Assessing the Biological Performance of Living Docks—A Citizen Science Initiative to Improve Coastal Water Quality through Benthic Recruitment within the Indian River Lagoon, Florida

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Abstract: Like many estuaries worldwide, the Indian River Lagoon (IRL), has seen a decline in resources and overall water quality due to human activities. One method to help restore water quality and benthic habitats is to construct and deploy oyster restoration mats on dock pilings, known as the Living Docks program. This community-driven program was founded to promote the growth of filter-feeding benthic organisms and improve local water quality. The purpose of this study was to assess the growth and performance at four of the Living Dock locations and to provide feedback to the citizens who were involved in the initial process and deployments. Four docks were biologically assessed for temporal changes during three-time points throughout the year, as denoted by changes in temperature in October, February, and June. The back of each mat was also analyzed for organism cementation to the piling. The presence of filter-feeding organisms was found to vary both spatially and temporally, especially for the eastern oyster (*Crassostrea virginica*), encrusting bryozoan (*Schizobrachiella verrilli*), sponges (*Demospongiae*), and barnacles (*Amphibalanus amphitrite*, *Amphibalanus eburneus*). A greater diversity in the sessile benthic flora and fauna was seen during the June sampling period. Cementation on the pilings was due to a combination of barnacles and sponge growth. Cementation was observed to increase from October and decrease for all but one dock for the June sampling period. The results demonstrate this restoration project to be successful in promoting the growth of benthic organisms, while also providing understanding into seasonal trends amongst species. Hopefully, the positive output will encourage more community members and citizen scientists to participate in the ongoing effort to help restore water quality in the IRL.

Keywords: benthic communities; benthic ecology; biodiversity; citizen science; estuaries; filter feeders; fouling organisms; Indian River Lagoon; suspension feeders; restoration mats

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1. Introduction

Once known for its biological diversity, today, ecological benefits supplied by the Indian River Lagoon (IRL) are depleting. Drainage into the basin consists of slow, meandering streams, creeks, rivers, and wetlands [1]. With over 1.7 million people inhabiting the IRL region today, land-use changes have dramatically increased due to the growing population [2]. Widespread urbanization has caused a surplus of nutrients to leach into the IRL, resulting in eutrophication [1]. The increase in nutrients has led to more frequent harmful algal blooms (HABs) due to higher phytoplankton abundance. These HABs have detrimental impacts on the surrounding wildlife via the release of toxins and depleting oxygen concentrations throughout the water column. Increasing nutrients can also leave the water more turbid due to phytoplankton productivity, blocking sunlight from other surrounding ecosystems such as seagrass and oyster beds [3]. Another consequence of urbanization has been the degradation of natural shorelines through the construction of artificial structures (i.e., docks, breakwaters, bulkheads, and jetties) [4]. The loss of natural shorelines such as mangroves, seagrass beds, and oyster reefs results in coastal water bodies with different structures and functions [5].

Man-made structures associated with the increase in human development along the coastline provide a vast amount of hard surface area available for colonization of sessile organisms, also known as 'fouling' communities [6]. To combat water quality decline in the IRL, the Living Docks program was established in 2013 by the Florida Institute of Technology (Florida Tech), utilizing dock pilings as a method to promote the growth of sessile filter-feeding organisms [4]. The Living Docks program was started as a citizen science-based initiative to improve water quality [7]. Oyster mats are made from a polyethylene aquaculture grade mesh with 60 to 80 dead and dried oyster shells, 80 being the most ideal for greater recruitment. Oyster shells are used because they provide a natural hard substrate that promotes settlement. The calcium carbonate in the shells is also known to attract organisms that readily use this chemical compound for their shells (i.e., barnacles and oysters) [8]. While the goal is to target oysters for restoration, other benthic filtering organisms are attracted to the hard substrate. The accumulation of the community that forms on the oyster mats not only helps to improve water clarity but also forms a small-scale ecosystem, attracting mobile organisms such as crabs, shrimp, and fish [4].

The citizen science-led project was targeted to have an inexpensive outlook with the mindset of "letting nature do the work" [7]. In addition, there are other benefits of this project. Suspending the mats off the seafloor ensures there is a lack of competition with other benthic communities, such as mangroves and seagrass beds [4]. Wrapping the mats also encourages organisms to grow in areas where there is no muck or sediment to cover or suffocate them, compared to if they were on the IRL bottom [4]. The Living Docks program also works to involve residents, allowing young and old to take part in a restoration initiative while serving as citizen scientists in the process [9].

Since 2013, 13 Living Docks have been successfully created throughout the IRL. However, many questions remain as to the impact these benthic communities have on overall water quality and the IRL. The purpose of this study was to biologically assess four of these Living Docks for the presence of filter-feeding benthic organisms and the overall cementation to the dock pilings. Cementation was noted to determine the mats' ability to support themselves to the piling in the case that zip ties were to fail and for the longevity of the mats. In addition, a sampling interval of 4 months was chosen to assure assessments would have varying temperatures. Water temperature has been shown to play a prominent role in growth and development, affecting such things as the timing of reproduction, recruitment rates, and growth rates [10–14]. At the end of the assessment and analysis, the results were shared with volunteers and citizen scientists who were key in creating the Living Docks.

Assessments at the four dock locations in October (26.7 °C), February (17.7 °C), and June (30.5 °C) were conducted to address the following hypothesis: the abundance and diversity of benthic filtering species will be greatest during the warmer months compared to the community present during the cooler months.

2. Materials and Methods

2.1. Living Dock Construction

Implementing a citizen science-based approach, the goal of the Living Dock program is to educate residents while aiming to improve water quality and provide habit structure for sessile organisms [7]. Dock locations are determined by community interest and participation, with each constructed via a multi-step process. An initial dock inspection is conducted to analyze water quality conditions and to obtain piling measurements, ultimately to determine if the location is suitable for the oyster mat installation. A presentation is given that walks the citizens (i.e., neighborhood groups, elementary classes, or scout troop) through the process and answers questions. After this, a community-based oyster mat workshop is scheduled [4]. Oyster mats are constructed using an aquaculture grade polyethylene mesh cut into 0.61 m × 0.61 m dimensions. Holes are drilled into 60 to 80 dead and dried oyster shells, which are then attached to the mat with 0.20 m standard UV-resistant cable ties (Figure 1). Finally, Florida Tech and citizen scientists install the oyster mats. The mats are secured to the pilings using three 0.38 m cable ties with the remains clipped and disposed of properly. The number of pilings wrapped with the oyster mats is dependent on water depth, as the mats need to be fully immersed below the seasonal and low tide lines. The mats never encounter the lagoon floor, ensuring they will not be buried by sediment or harm any submerged aquatic vegetation.

Figure 1. A stack of completed oyster mats after a workshop in Melbourne Beach.

2.2. Living Dock Assessment

The Living Docks program has currently deployed a total of 13 docks, with a majority found in the northern section of Brevard County. This assessment consisted of analyzing four locations that span this area. Dock selection was based on location in the IRL, accessibility, and length of immersion (Table 1). In addition to having a large spatial variation throughout the IRL, the docks also vary in length of immersion and quantity of mats.

Table 1. The location, date of immersion, and the total number of mats deployed for each of the Living Docks were analyzed as part of this study.

Deployment	Location	Latitude/Longitude	Mat Total	Mats Analyzed
April 2017	Cape Canaveral	28°22′59″ N 80°36′32″ W	20	6
July 2020	Melbourne Beach	28°05′05″ N 80°33′01″ W	17	6
February 2018	Melbourne Shores	27°58′13″ N 80°30′46″ W	50	6
July 2019	Sebastian	27°49′26″ N 80°29′25″ W	4	4

Ten percent of the total number of mats, or at least three mats, on both the North and Southside of each dock were removed and examined for growth. Thus, a minimum of six mats were analyzed at each location, excluding Sebastian who had a total of four mats (Table 1). Mats were randomly selected spatially from the nearshore to the end of the dock. Individual photos of the front and back of the mats were taken, with a special focus on individual oyster shells and the growth that had accumulated. Six oyster shells were closely assessed and photographed for each mat. Sampled shells were marked with a colored zip tie to ensure replication and assessment during the next sampling period. Assessments took place mid-morning to mid-afternoon for each seasonal period. Sessile and mobile organisms were observed strictly on the mats themselves. Abundance of individual sessile and presence of mobile organisms were analyzed then identified to the lowest possible functional group using the Indian River Lagoon Species Inventory [15]. Water quality measurements were collected at each dock location. Salinity and temperature were taken using Yellow Springs Instruments (YSI) Model water quality sensor sourced from Yellow Springs, Ohio, USA. [4].

To assess temporal variation of the communities, mat analysis took place during three different periods: October, February, and June. The warmer months being October and June and the colder month February. The same four docks, mats, and shells were used for all assessments to determine how environmental conditions and time affect the organisms on the mats.

2.3. Mat Cementation

Cementation of the oyster mats to the pilings ensures that the mat will have a longer length of immersion and can continue to support benthic growth. Thus, during inspections, the cementation of the mats was noted upon removal. The posterior side of the mats were photographed and examined, noting coverage of organisms that are known to aid in the cementation process (i.e., barnacle, encrusting bryozoan, and sponge) Photographs were uploaded into Image J, and percent cover of organisms that aid in cementation were then calculated [4,16].

2.4. Statistical Analysis

Since multiple measurements were taken at each dock, a PERMANOVA was performed to measure differences between community composition for the seasonal assessments across all four Living Dock locations. MDS plots were conducted to compare seasonal differences amongst locations. ANOSIMs were used to compare the seasonal assessments for individual docks. This allowed for the comparison of time, temperature, and location to determine significant variation in the growth of benthic organisms. A SIMPER analysis was conducted to determine which species had the greatest impact on seasonal differences. A two-way repeated-measures ANOVA (two-way RMANOVA) was conducted on the cementation data to test for differences among locations and seasons. Species richness was calculated in the form of percent cover with the Shannon Weiner index used to determine species diversity. Statistical differences and diversity were then determined using an ANOVA with a Tukey post hoc test. A one-way ANOVA was conducted individually analyzing temperature and salinity significance across the three test periods, followed by a Games–Howell post hoc test. All statistical analyses were conducted using RStudio and the vegan package (Rstudio, Boston, MA, USA) [17,18].

3. Results

The temperature during October was, on average, 26.7 °C. The February assessment averaged in at 17.7 °C, while the June assessment averaged 30.5 °C. Salinity also varied among the seasons, with an average salinity in October of 21.8 ppt, February of 24.0 ppt, and 31.4 ppt in June. ANOVAs conducted on temperature and salinity data proved temperature was significant for the three-monthly assessments but not for dock location across the sampled periods. Salinity proved to be statistically significant for both month and dock location. A more detailed summary of water quality data collected at each of the four locations can be found in Table 2.

Table 2. Temperature and salinity at the four Living Dock locations during three assessment periods.

	October 2020		February 2021		June 2021	
Dock Location	**Temperature (°C)**	**Salinity (ppt)**	**Temperature (°C)**	**Salinity (ppt)**	**Temperature (°C)**	**Salinity (ppt)**
Cape Canaveral	26.3	19.3	16.1	20.4	29.9	21.8
Melbourne Beach	26.9	21.2	17.8	18.6	29.3	29.5
Melbourne Shores	26.5	23.7	17.4	22.9	30.0	38.5
Sebastian	27	22.9	19.5	34.1	32.8	35.6

3.1. Benthic Community Assessment

A range of benthic organisms were found inhabiting the oyster mats, including solitary and colonial forms (Figure 2). Several different filter-feeding organisms were found, including the eastern oyster (*Crassostrea virginica*), bryozoans (*Schizobrachiella verrilli*, *Bugula neritina*), sponge (*Demospongiae*), tunicates (*Tunicata*) and barnacles (*Amphibalanus amphitrite*, *Amphibalanus eburneus*). Dominant organisms present during the assessments included barnacles (*Amphibalanus amphitrite, Amphibalanus eburneus*), encrusting bryozoan (*Schizobrachiella verrilli*), sponge (*Demospongiae*), biofilm, and oysters (*Crassostrea virginica*). Based on the ANOSIM statistical test, the organisms most impacted by the seasonal change, and thus driving differences between assessment periods, are listed in Table 3. In addition to the attached organisms, many mobile organisms were found coexisting on the oyster mats for both the warm and cool assessments (Table 4). These included multiple species of crab, isopods, goby's, shrimp, and flatworms.

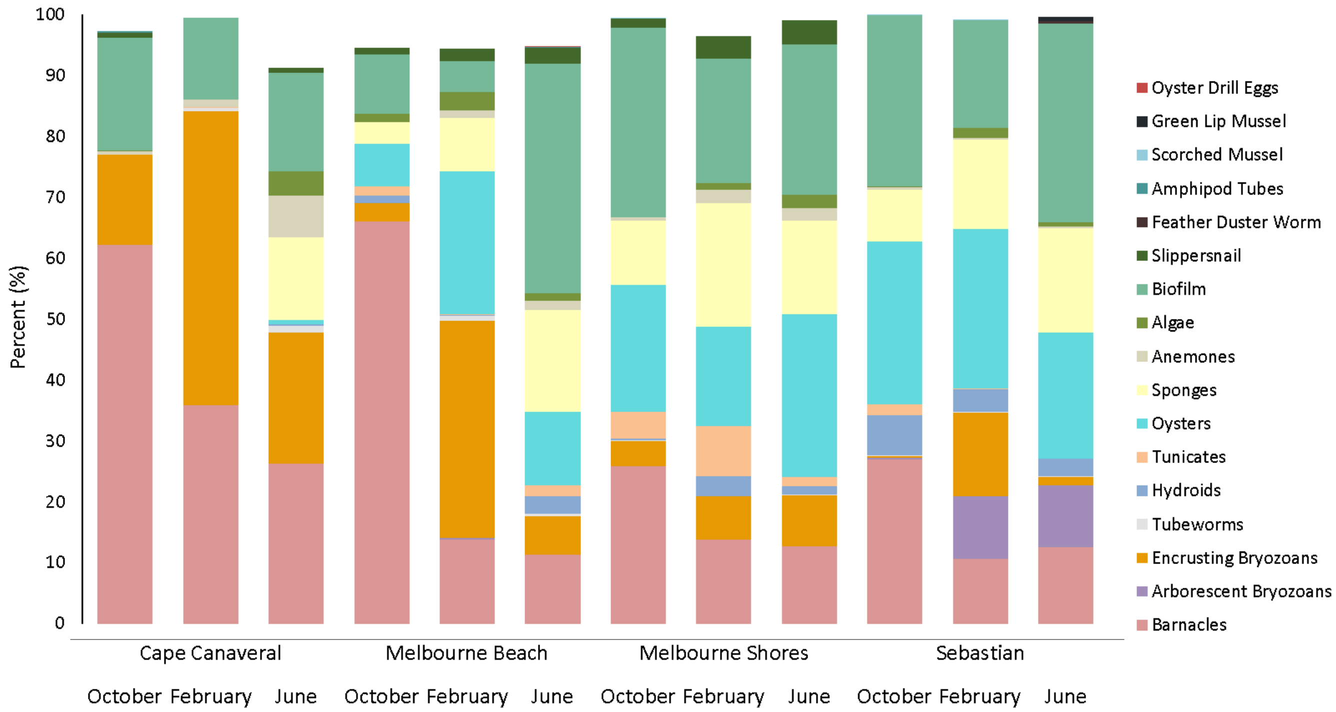

Figure 2. Organism abundance from the October (26.7 °C), February (17.7 °C), and June (30.5 °C) assessment periods.

Table 3. Organism functional groups showing the greatest change in percent cover between the assessment periods, listed alphabetically.

Dock Location	**October 2020–February 2021**	**October 2020–June 2021**	**February 2021–June 2021**
Cape Canaveral	Encrusting Bryozoan (*Schizobrachiella verrilli)* Ivory Barnacle (*Amphibalanus eburneus*) Striped Acorn Barnacle (*Amphibalanus amphitrite*)	Biofilm Encrusting Bryozoan (*Schizobrachiella verrilli* Ivory Barnacle (*Amphibalanus eburneus*) Sponges (*Demospongiae*) Striped Acorn Barnacle (*Amphibalanus amphitrite*	Biofilm Encrusting Bryozoan (*Schizobrachiella verrilli)* Ivory Barnacle (*Amphibalanus eburneus*) Sponges (*Demospongiae*) Striped Acorn Barnacle (*Amphibalanus amphitrite*)
Melbourne Beach	Encrusting Bryozoan (*Schizobrachiella verrilli)* Ivory Barnacle (*Amphibalanus eburneus*) Striped Acorn Barnacle (*Amphibalanus amphitrite*) Eastern Oyster (*Crassostrea virginica)*	Biofilm Ivory Barnacle (*Amphibalanus eburneus*) Sponges (*Demospongiae*) Striped Acorn Barnacle (*Amphibalanus amphitrite*)	Biofilm Encrusting Bryozoan (*Schizobrachiella verrilli)* Oyster (*Crassostrea virginica)* Sponges (*Demospongiae*)
Melbourne Shores	Biofilm Ivory Barnacle (*Amphibalanus eburneus*) Eastern Oyster (*Crassostrea virginica)* Sponges (*Demospongiae*) Striped Acorn Barnacle (*Amphibalanus amphitrite*)	Biofilm Ivory Barnacle (*Amphibalanus eburneus*) Eastern Oyster (*Crassostrea virginica)* Sponges (*Demospongiae*) Striped Acorn Barnacle (*Amphibalanus amphitrite*)	Biofilm Ivory Barnacle (*Amphibalanus eburneus*) Eastern Oyster (*Crassostrea virginica)* Sponges (*Demospongiae*) Striped Acorn Barnacle (*Amphibalanus amphitrite*)
Sebastian	Biofilm Ivory Barnacle (*Amphibalanus eburneus*) Eastern Oyster (*Crassostrea virginica)* Sponges (*Demospongiae*) Striped Acorn Barnacle (*Amphibalanus amphitrite*)	Biofilm Ivory Barnacle (*Amphibalanus eburneus*) Eastern Oyster (*Crassostrea virginica)* Sponges (*Demospongiae*) Striped Acorn Barnacle (*Amphibalanus amphitrite*)	Biofilm Encrusting Bryozoan (*Schizobrachiella verrilli)* Ivory Barnacle (*Amphibalanus eburneus*) Eastern Oyster (*Crassostrea virginica)* Sponges (*Demospongiae*) Striped Acorn Barnacle (*Amphibalanus amphitrite*)

Table 4. Mobile organisms noted upon inspection of the oyster mats during the three assessment periods listed alphabetically.

Dock Location	**October (26.7 ± 0.33 °C) Assessment**	**February (17.7 ± 1.40 °C) Assessment**	**June (30.5 ± 1.56 °C) Assessment**
Cape Canaveral	Green Porcelain Crab (*Petrolisthes armatus*) Marine Snail (*Gastropoda*) Mud Crabs (*Panopeus herbstii, Dyspanopeus sayi*) Thinstripe Hermit Crab (*Clibanarius vittatus*)	Frillfin Goby (*Bathygobius soporator*) Gammarid Amphipod (*Gammarus mucronatus*) Green Porcelain Crab (*Petrolisthes armatus*) Marine Isopod (*Sphaeroma terebrans*) Marine Worm (*Capitella capitata*) Mud Crabs (*Panopeus herbstii, Dyspanopeus sayi*) Thinstripe Hermit Crab (*Clibanarius vittatus*)	Frillfin Goby (*Bathygobius soporator*) Gammarid Amphipod (*Gammarus mucronatus*) Thinstripe Hermit Crab (*Clibanarius vittatus*) Marine Isopod (*Sphaeroma terebrans*) Marine Worm (*Capitella capitata*) Mud Crabs (*Panopeus herbstii, Dyspanopeus sayi*)
Melbourne Beach	Bigclaw Snapping Shrimp (*Alpheus heterochaelis*) Green Porcelain Crab (*Petrolisthes armatus*) Mud Crabs (*Panopeus herbstii, Dyspanopeus sayi*) Stone Crab (*Menippe mercenaria*) Thinstripe Hermit Crab (*Clibanarius vittatus*)	Frillfin Goby (*Bathygobius soporator*) Green Porcelain Crab (*Petrolisthes armatus*) Marine Worm (*Capitella capitata*) Mud Crabs (*Panopeus herbstii, Dyspanopeus sayi*) Thinstripe Hermit Crab (*Clibanarius vittatus*)	Frillfin Goby (*Bathygobius soporator*) Green Porcelain Crab (*Petrolisthes armatus*) Marine Isopod (*Sphaeroma terebrans*) Mud Crabs (*Panopeus herbstii, Dyspanopeus sayi*) Thinstripe Hermit Crab (*Clibanarius vittatus*)
Melbourne Shores	Frillfin Goby (*Bathygobius soporator*) Gammarid Amphipod (*Gammarus mucronatus*) Green Porcelain Crab (*Petrolisthes armatus*) Marine Isopod (*Sphaeroma terebrans*) Marine Snail (*Gastropoda*) Marine Worm (*Capitella capitata*) Mud Crabs (*Panopeus herbstii, Dyspanopeus sayi*) Stone Crab (*Menippe mercenaria*) Thinstripe Hermit Crab (*Clibanarius vittatus*)	Frillfin Goby (*Bathygobius soporator*) Green Porcelain Crab (*Petrolisthes armatus*) Marine Isopod (*Sphaeroma terebrans*) Marine Worm (*Capitella capitata*) Mud Crabs (*Panopeus herbstii, Dyspanopeus sayi*) Stone Crab (*Menippe mercenaria*) Thinstripe Hermit Crab (*Clibanarius vittatus*)	Frillfin Goby (*Bathygobius soporator*) Marine Isopod (*Sphaeroma terebrans*) Marine Snail (*Gastropoda*) Mud Crabs (*Panopeus herbstii, Dyspanopeus sayi*) Stone Crab (*Menippe mercenaria*) Thinstripe Hermit Crab (*Clibanarius vittatus*)

Table 4. *Cont.*

Dock Location	October (26.7 ± 0.33 °C) Assessment	February (17.7 ± 1.40 °C) Assessment	June (30.5 ± 1.56 °C) Assessment
Sebastian	Bigclaw Snapping Shrimp (*Alpheus heterochaelis*) Caribbean Spiny Lobster (*Panulirus argus*) Daggerblade Grass Shrimp (*Palaemonetes paludosus*) Frillfin Goby (*Bathygobius soporator*) Green Porcelain Crab (*Petrolisthes armatus*) Marine Snail (*Gastropoda*) Mud Crabs (*Panopeus herbstii, Dyspanopeus sayi*) Stone Crab (*Menippe mercenaria*) Thinstripe Hermit Crab (*Clibanarius vittatus*)	Bigclaw Snapping Shrimp (*Alpheus heterochaelis*) Decorator Crab (*Libinia dubia)* Frillfin Goby (*Bathygobius soporator*) Gammarid Amphipod (*Gammarus mucronatus*) Green Porcelain Crab (*Petrolisthes armatus*) Marine Worm (*Capitella capitata*) Mud Crabs (*Panopeus herbstii, Dyspanopeus sayi*) Stone Crab (*Menippe mercenaria*)	Atlantic Blue Crab (*Armases ricordi*) Bigclaw Snapping Shrimp (*Alpheus heterochaelis*) Caprellid Amphipod (*Caprella penantis*) Caribbean Spiny Lobster (*Panulirus argus*) Frillfin Goby (*Bathygobius soporator*) Gammarid Amphipod (*Gammarus mucronatus*) Green Porcelain Crab (*Petrolisthes armatus*) Mud Crabs (*Panopeus herbstii, Dyspanopeus sayi*) Oyster Toadfish (*Opsanus tau)* -Stone Crab (*Menippe mercenaria*) Thinstripe Hermit Crab (*Clibanarius vittatus*)

The benthic community composition tested through a PERMANOVA was found to be significant for both season and location ($p < 0.05$). Taking a closer look at localized seasonal variation through MDS plots, Melbourne Shores, and Sebastian failed to succeed where Cape Canaveral and Melbourne Beach demonstrated a stronger structure in terms of seasonal differences (Figure 3). A SIMPER analysis generated the functional groups most influenced by season and thus driving the differences. Between October and February, these were barnacles, biofilm, encrusting bryozoan, and oysters. From February to June, encrusting bryozoan, biofilm, oysters, barnacles, and sponge were most impacted. Species such as barnacles, biofilm, oysters, and sponges were most impacted and had the greatest change between October and June.

In general, the Shannon Weiner Diversity Index revealed a greater diversity during the warmest assessment in June. All docks were observed to have an increase in diversity from October to February, which was significant for Melbourne Shores, Melbourne Beach, and Sebastian. June assessments also had higher diversity, which were similar or higher to the February assessment. There were significant diversity values between these two assessment periods for Cape Canaveral (Figure 4). Significance was also observed between the cooler month of October to the warmest month of June for Cape Canaveral, Melbourne Shores, and Melbourne Beach.

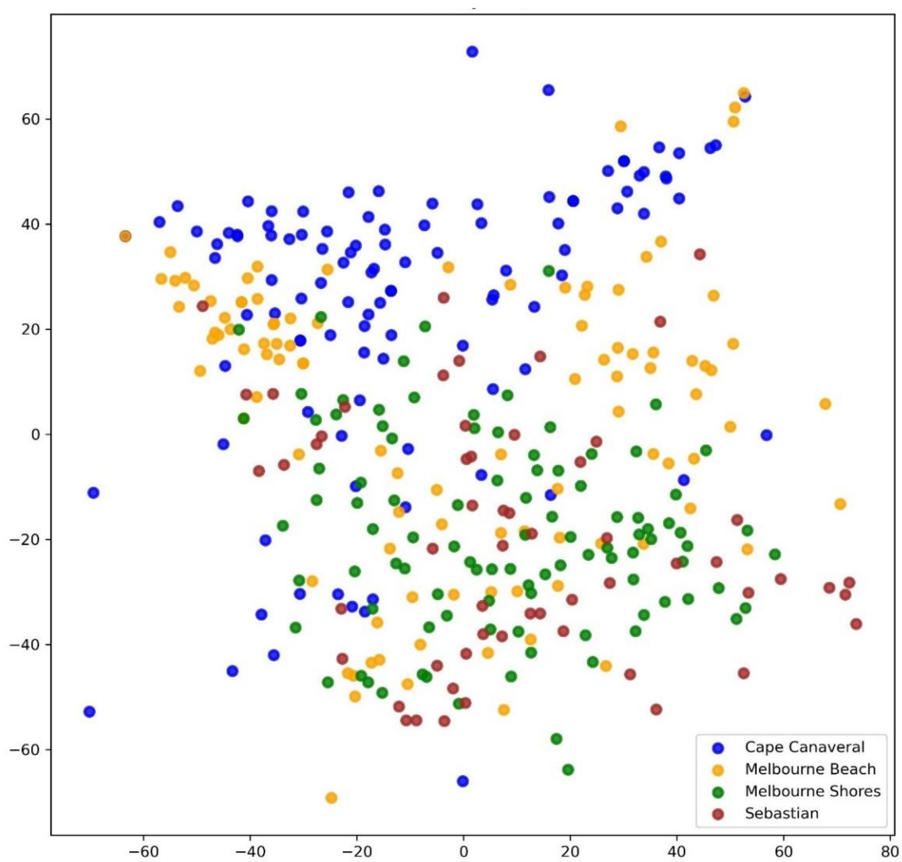

Figure 3. MDS plot of the four assessed dock locations with season as a factor.

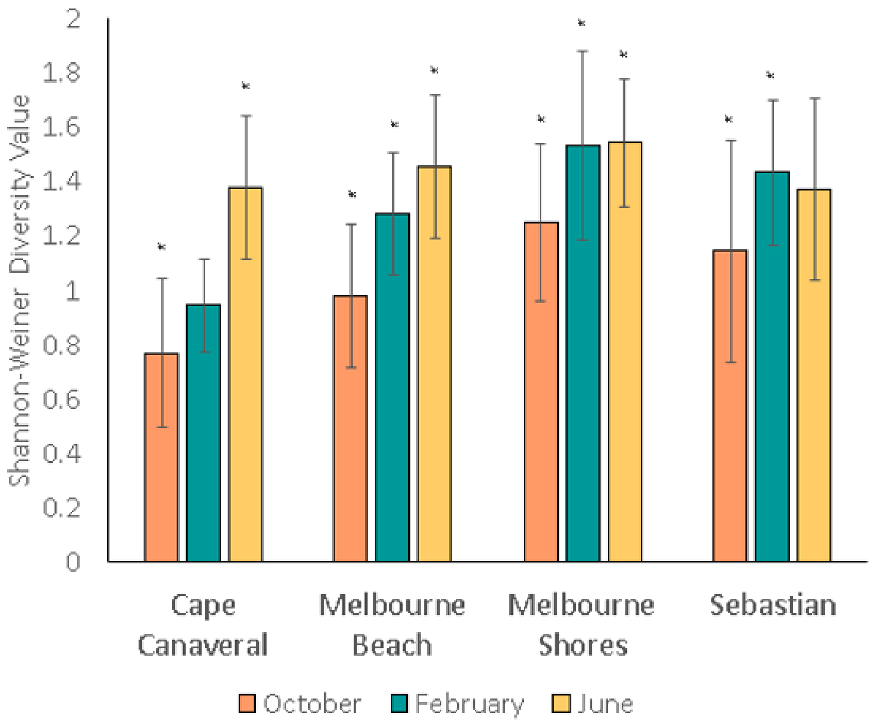

Figure 4. Shannon Weiner Diversity calculations for the October (26.7 °C), February (17.7 °C), and June (30.5 °C) assessment periods. The asterisks (*) denote statistical significance.

3.2. Mat Cementation

Cementation data that reported the percentage of the benthic organisms attached directly from the oyster mat to the dock piling is presented in Figure 5. During warm months, cementation was driven by the presence of barnacles, sponges, and encrusting bryozoan. Oysters were also present on the back of the mats, but they were not found to aid in cementation and were thus not included in cementation calculations. Cementation in the cooler months was dominated by sponge coverage. Results from the two-way RMANOVA showed a significant difference ($p < 0.05$) for cementation across the three settlement periods. All sites demonstrated a consistent trend increasing from October to February, and then had similar rates for June. Overall, the highest cementation was observed during the February and June assessments.

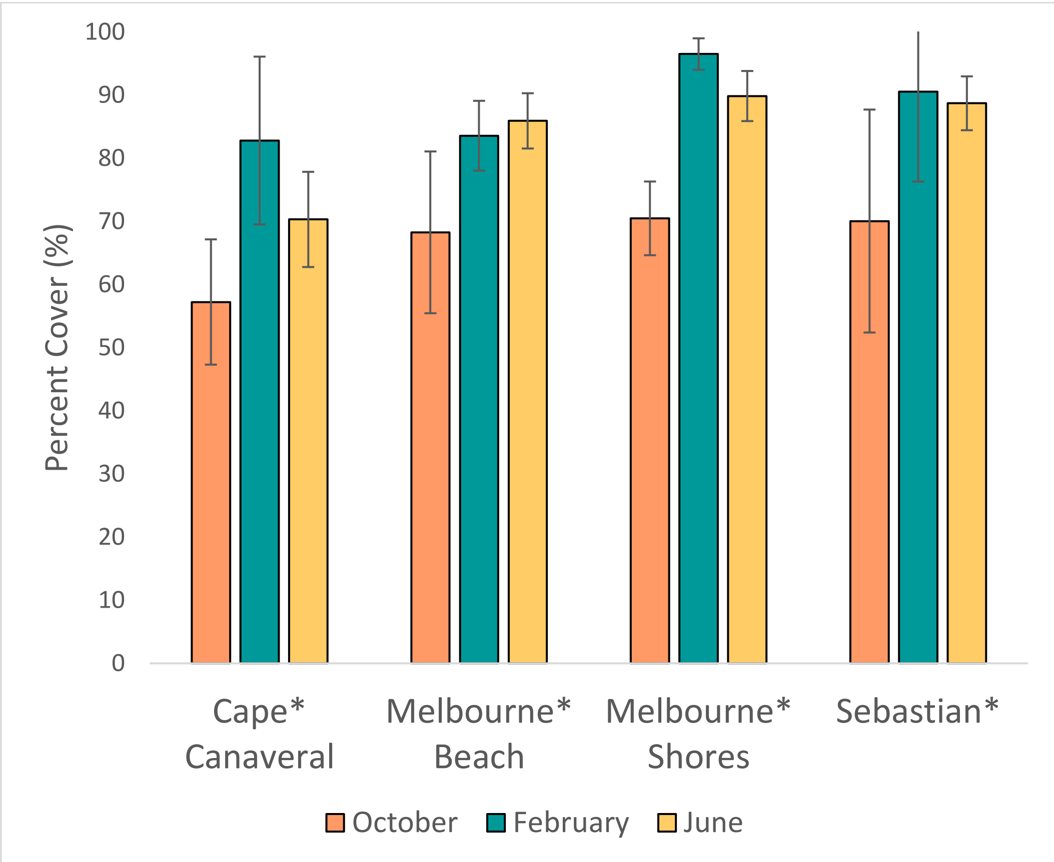

Figure 5. Average cementation percentages with standard deviation taken from analyzing the back of the oyster mats in the form of percent cover (%). All docks had a significant difference ($p < 0.05$) across seasonal assessments denoted by an asterisk (*).

4. Discussion

4.1. Benthic Community Assessment

Temperature is a prominent driver in benthic community composition, influencing recruitment rates and reproductive timing, so it is not surprising that it was found to influence the community observed at the four dock locations. It is known that temperature regulates larval development [19,20]. For example, Lathlean et al. (2013) analyzed barnacle larvae to find that post-settlement and survival were both inversely related to temperature [21]. Nasrolahi et al. (2011) found that barnacle larval duration was shorter by an average of 1.2 days at higher temperatures [22]. For the settlement of bryozoans, the temperature was found to be the most important tie to zooid size, becoming longer and wider at lower temperatures [13]. Whalan et al. (2008) analyzed sponge larvae and found temperature had a significant effect on larval mortality at temperatures between 22 and 36 °C [23].

Diversity of the benthic organisms was found to change both with location as well as with the sampling period. Even though the four Living Docks have different immersion times, greater diversity was seen during the February and June sampling months. Changes in diversity can be affected by several different parameters, such as substrate type, as was seen in a yearlong pilot study for Living Docks, in which diversification of oyster bags and mats were compared [7]. Located one mile south of the Eau Gallie causeway, shells attached to mats were predominately covered with barnacles, compared to the shells immersed in bags, which were covered by encrusting bryozoans, barnacles, sponges, and tunicates [7]. Between the two attachment methods, oyster bags were observed to have a higher amount of diversity in comparison to the mats. However, mats were ultimately chosen for restoration efforts over bags because of their low maintenance and ease of use for citizen science. Bags, which were tied between pilings, often fell off and settled into anoxic sediment, creating an inhospitable environment for the benthic organisms.

When pilings without the presence of oyster mats were analyzed, green algae, barnacles, and occasionally oysters were the only organisms found (Gilligan, personal observation). The oyster shells attached to the mats provide a natural substrate for benthic organisms to settle onto, increasing diversity on the dock pilings. In return, the oyster mats create a small-scale ecosystem where mobile organisms benefit from its resources. The increase in small mobile organisms then attract larger organisms such as juvenile and adult fish to the oyster mats.

In addition, changes in mat material can also influence benthic organisms' growth and the subsequent diversity of the community. Soucy (2020) analyzed different mat materials for Living Docks, including jute, coconut coir, and basalt [24]. She found that plastic oyster mats were more suitable for longevity. Another study looking at alternatives to plastic by Hunsucker et al. (2021) analyzed cathodically protected steel as a replacement for plastic mesh in the IRL [25]. They found that the steel was the most successful for enhancing oyster settlement while the plastic supported a more diverse community. Overall, future research is still needed to find a more environmentally friendly mat material for Living Docks and oyster restoration efforts.

Including locations from the previous Living Dock studies [7,24] as well as those analyzed during the present study, spatial differences can be observed as well as some general trends with settlement. While the four Living Dock locations, excluding Sebastian, are located on the eastern side of the IRL, two test locations from supporting studies [7,24] were conducted on the western side of the IRL. The test locations on the western side were observed to have more mussel coverage than docks located on the eastern side of the IRL. Oysters, on the other hand, were observed to have a high presence at the southern three locations, especially when compared to Cape Canaveral. The high presence of oysters at Sebastian was possibly due to its location. Situated close to the inlet, the influx of oceanic saltwater could have provided beneficial nutrients to the oysters. Barnacles were found across all four sites with growth diminishing in the south. The decrease in distribution could be due to the increase in diversity, which creates competition between species. Encrusting bryozoan presence was driven by the seasonal change in temperature, explaining the high presence during the February assessments. Sponge was observed to have a high influx at all four locations during June, with lower concentrations observed during the two other assessment periods. Like encrusting bryozoan, sponge was also driven by the seasonal change in temperature, preferring the warmer temperatures found in June.

Hydrodynamic conditions will also influence community diversity through the distribution of food and spawning [26]. A by-product of eutrophication, algal blooms could have influenced community composition of certain docks, depending on the scale of blooms. Blooms are commonly present during IRL warmer months as a result of higher levels of nutrients entering the system through increased rainfall. In late September (2020), an algal bloom was most prominent near Cocoa and Merritt Island but extended from Titusville to the Eau Gallie Causeway. This would have impacted community composition at the Cape Canaveral dock during the October assessment.

4.2. Mat Cementation

Living Docks oyster restoration mats are attached to pilings via zip ties. A successful immersion is dependent on weight of organism growth, hydrodynamic conditions on the mats/pilings, and strength of zip ties over time. Mat cementation was assessed to see how the growth begins to take over, attaching the mats to the piling, which would be important for long-term deployments or if zip ties may fail. All dock locations had an increase in cementation from the October to February assessment and a decrease from February to June (excluding Melbourne Beach). This is the result of variation in barnacle, encrusting bryozoan, and sponge abundance among the sampling periods. Barnacles prefer to settle throughout the year while bryozoans prefer cooler periods for settlement [27].

A stronger presence of sponge settlement could also be related to changes in biological activity of other benthic organisms. Wahab et al. (2011) found that sponge larvae settled and metamorphosed faster to surfaces with biofilms [28]. For the three assessments, a majority of the sponge was found on the posterior side of the mats. Settlement could be driven by the increased surface area of the piling, where a higher level of biofilm accumulates on the surface versus the mesh of the mats alone (Gilligan, personal observation). Potentially, sponge could have grown from the piling outward onto the mat.

Sponge is very important in benthic communities as they aid as a great stabilizer [29]. In this case, the sponge growth on the oyster mats was able to secure the mat to the piling with other benthic organisms, specifically barnacles. Barnacle settlement is driven by flow and availability of food, and higher drag forces are damaging for the cirri during their early life stages [26]. Increased coverage on the posterior side of the mats could be the result of the barnacle's need to have shelter from these higher drag forces.

Although benthic settlement may increase over time, it is not a proper indication of cementation. Not all organism growth aids in the mat cementing to the piling, e.g., arborescent bryozoans and sea anemones. Alternatively, the weight of the mats can outweigh cementation processes as well, which can be problematic if the mats are not installed properly, resulting in mats falling off pilings onto the Lagoon bottom. Cementation appears to be driven by the ideal conditions of water quality combined with settlement cues of benthic species. It is interesting to note that the cementation among all four dock locations is relatively the same, especially given that there is a difference in the total immersion time of the mats. For example, Sebastian mats had been on the dock for about 2 years, versus Cape Canaveral mats, which had been on the dock for about 4 years.

4.3. Citizen Science

The ability to collect large data sets across vast spatial locations and over long periods of time requires an arduous amount of work. Citizen science has been a way to obtain data while also engaging non-professionals in scientific research. The Living Docks project is driven by citizens and the utilization of their docks for placement of oyster restoration mats in the IRL. The creation and deployment of the oyster mats is fully inclusive with both children and adults participating in the process. Since the project is primarily driven by volunteers, the continuation of the initiative relies primarily on outreach and education. Through continuing education, volunteers may be more inclined to come forth and participate in the initiative after learning the benefits.

Projects such as Living Docks that are at a local scale and manageable by the general public of all ages, are one way that the public can get involved and make a difference. The data obtained from this study will provide evidence of how these oyster restoration mats help the environment through supplementing habitat, and future research will show the Living Docks project can help the environment by providing filtration of the water. Overall, the Living Docks project is a way to bring the public together and support the ongoing effort to help restore water quality in the IRL.

5. Conclusions

Given the results of this study, the hypothesis was partially supported. The four Living Dock locations were influenced biologically by the seasonal changes in temperature. Diversity among organisms was greatest following the warmest assessment period of June (excluding Sebastian). Overall, in a system as dynamic as the IRL, it is not only temperature that is important. Daily tidal changes, water quality conditions, and hydrodynamic flow play an imperative role in the distribution as well as diversity of these benthic ecosystems.

The data collected during the assessments demonstrate that filter-feeding organisms are present throughout the IRL and will settle on the oyster mats. The type and abundance of organisms, however, will vary based on location and time of year. This is important to note, especially when working with the public. The absence of the hallmark filter-feeding organism, the Eastern Oyster, is not entirely a concern for this study. Cape Canaveral was the only site without a presence of oysters noted across all seasons, possibly due to the lack of a pre-established population within the area. However, oysters appear to be in great abundance during certain periods of the year and may also be covered by other benthic organisms, making them visually harder to see. Other organisms present on the mats are also known to contribute to the reduction in algal biomass and suspended particulates, potentially filling different niches regarding particulate sizes that one species alone cannot provide. Ultimately, the Living Docks mats have proven to be a method that is conducive to citizen science and are successful at promoting the growth of benthic filter-feeding organisms for improved water clarity as well as habitat structure.

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