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The Impact of Benthic Organisms to Improve Water Quality in the Indian River Lagoon, Florida

Alain Despeignes · Alyssa Sharma · Rebecca Beltran · Sandra Rech · Kelli Hunsucker · Ryan T. White · Robert J. Weaver · Nezamoddin N. Kachouie

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Abstract The Living Docks restoration program was implemented in the Indian River Lagoon (IRL), Florida, with the goal of affixing oyster restoration mats to dock pilings to promote the growth of filter feeding benthic organisms which can help improve local water quality. However, the relationship between IRL water quality parameters and the presence of filter feeders on the mats is not entirely clear. This study investigates the presence of benthic organisms on eight Living Docks which were deployed throughout the central part of the IRL. Environmental factors (e.g., water salinity, turbidity, pH, and temperature) were collected from the closest available water station to each dock. The main goal was to identify the presence and overall change in percent cover of specific benthic organism(s), those which are known filter feeders, in relationship to environmental parameters. Among functional groups which were identified, barnacles, biofilms, encrusting bryozoans (EBs), oysters, and sponges demonstrated significantly higher cover than the others. Barnacles were higher in abundance at specific dock locations and an increased water pH (up to 8.1), turbidity, and temperature. EB presence was positively impacted by salinity but did not respond to changes in turbidity or temperature within the measured ranges. Oysters were not observed to be impacted by any of the factors within measured ranges. Sponges had sustained abundance in half of the docks in this study. However, they did not respond to any of the environmental factors within measured ranges in different seasons. Results from this study can help target future Living Dock locations which will provide the best environment for the recruitment of filter feeding organisms.

Keywords Benthic organisms · Water quality · Filtration · Restoration · Statistical modeling · Beta regression

A. Despeignes · S. Rech · K. Hunsucker · R. T. White · R. J. Weaver · N. N. Kachouie (✉)
Florida Institute of Technology, Melbourne, FL, USA
e-mail: nezamoddin@fit.edu

A. Sharma
Appalachian State University, Boone, NC, USA

R. Beltran
Aquinas College, Grand Rapids, MI, USA

1 Introduction

The Indian River Lagoon (IRL) is a large sub-tropical estuary located on the east coast of Florida. Like many estuaries worldwide, it has seen a decline in water quality due to anthropogenic stressors, a consequence of which has led to the presence of harmful bacteria, large-scale algal blooms, fish kills, and seagrass die-off (Indian River Lagoon 2011; Barile, 2018; Indian River Lagoon, 2016).

Increased human development is the main stressor for the IRL. The homogenization of cities throughout the USA has created unanticipated outcomes such as overdevelopment and overpopulation in the US coastal regions. Coastal ecosystems have been drastically altered by human activities, resulting in substantial decay in provisioning of ecosystem services that are of value for both humans and wildlife (Barbier et al., 2011; Worm et al., 2006). One of the most challenging among the myriad of human impacts on coastal systems is habitat alteration (Lotze et al., 2006). Habitat alteration takes many forms, with the most obvious being conversion of natural shoreline to artificial structures. Docks, breakwaters, bulkheads, and jetties are common in urbanized coastal areas, and are often the dominant intertidal and subtidal habitat types (Bulleri & Chapman, 2010). Not as obvious is the increase in organic matter and fine sediments entering the waterway. The organic matter increases the nutrient loading in the system, potentially fueling algal blooms. The fine sediment increases turbidity, and in turn blocking sunlight penetration. Together this added mass can cover the estuary bottom in a layer of anoxic sediment that is inhospitable for benthic organisms.

Previous studies have shown that the deterioration of the coastal ecosystems can also be attributed to climate change (Harbour et al., 2020). Global warming increases water temperature which increases ammonia, pentachlorophenol, and algae blooms (U.S., 2009). Moreover, the predicted increase in size and frequency of tropical storms and hurricanes will increase discharge of the freshwater carrying nutrients, fine sediments, and other pollutants off into the IRL that will damage marine flora and fauna (Hanisak & Freese, 2020). Past hurricanes have caused widespread flooding that resulted in significant sewage spills and fertilizer runoff adding to the pollution problem (Trefry & Fox, 2021). Acidification caused by climate change is driven by the absorption of CO_2 into the oceans which decreases the pH of the water (Gattuso et al., 2015). A decrease in water pH will impact the health of ecosystem that can cause the death of marine life and change in reproductive and behavioral functions of the marine animals. Global warming along with the human developments near the coastline have negatively impacted the IRL's water quality (Parkinson et al., 2020).

A feasible approach to improve the water quality in the IRL is to increase the presence of benthic organisms, which are known for their high-water filtration capacity. This is a sustainable approach that does not require expensive machinery to filter the polluted water. To this end, the Living Docks program was developed at Florida Tech in 2013. Living Docks is a citizen science-based restoration program that implements oyster mats to provide substrate and promote the growth of benthic communities which in turn may help with water filtration (Hunsucker et al., 2021; Weaver & Hunsucker, 2018). Since the program was started, at the time of this study, 13 docks have been modified based on the Living Docks design. New docks are modified as communities come together to acquire the materials, assemble the mats, and attach the mats to the docks. The hallmark benthic organisms for water filtration are oysters; however, many benthic organisms are also known to filter large volumes of water (e.g., sea squirts, bryozoans) (Hunsucker et al., 2021). As environmental conditions continue to change in estuaries, it is important to understand how they may influence the growth of benthic organisms and the subsequent impact on restoration projects.

A field study in Southern Japan has tried to explain the habitat complexity of water conditions that may correlate with organism growth, but its operation under variable natural conditions is not well understood, particularly in freshwater (Taniguchi & Tokeshi, 2004). Studies have shown how climate change has affected the lives of many benthic organisms. Environmental changes associated with climate change are linked to larger ecological processes, including changes in larval dispersal and recruitment success, shifts in community structure and range extensions, and the establishment and spread of invasive species (Przeslawski et al., 2008). Research study at two coastal lagoons in Ghana has shown that decline in oligochaete composition or density in the Domini Lagoon along with increase in benthos richness and diversity can improve ecological conditions in the lagoon's environment favorable for a wider range of organisms. Similarly, a higher invertebrate diversity across all portions of Aman Suri would suggest prevalence of improved conditions across the lagoon. On the other hand, the reduction in invertebrate composition, richness, and diversity can deteriorate environmental characteristics of the lagoons (Aggrey-Fynn et al., 2011). Predictive modeling is a new and promising direction in pollution analysis, and greater effort should be devoted to the development of this technique. The use of newly developed multivariate procedures, and the predictive algorithms they generate, allows for the identification of potential environmental stress (Johnson & Wiederholm, 1993).

This study is part of a larger effort to monitor oyster mats of the Living Dock project (Hunsucker et al., 2021) with an emphasis on understanding the impact of environmental parameters on the settlement of filter feeding benthic organisms. Knowing this information will be important for determining the optimal locations for future restoration efforts and predicting the success of existing and future restoration efforts. The information presented in this study will also aid in long-term monitoring and understanding of how continuing anthropogenic stressors and climate change may impact filter feeding organisms in the future. Specifically, the objectives of this effort were to use statistical modeling to:

- compare the presence/abundance of dominant benthic organisms at different dock locations along the IRL, and
- identify the impact of environmental factors on benthic organism abundance.

2 Data Collection

Living Docks are created using oyster mats which are affixed to dock pilings at pre-determined dock locations along the IRL (Weaver & Hunsucker, 2018). Docs in the Northern IRL that have been in the Living Docks program for more than a year were selected for this study. These locations of opportunity provide a window into the number and types of organisms that live in the vicinity of those docks. At each of these locations, mats were selected for analysis, and four to six shells were marked with colored zip ties. This allowed for these shells to be tracked over time (Hunsucker et al., 2021). Nineteen organisms were identified with 681 samples in fall, spring, and summer.

Figure 1 demonstrates a schematic diagram of the deployment and data collection process. Water quality data was downloaded from sensors maintained by the St. John's River Water Management Agency, which continuously record environmental factors including pH, turbidity, salinity, and temperature (Indian River Lagoon, 2011).

Sensor locations were chosen to coincide with locations of the Living Docks, specifically those deployed at Banana River, Eau Gallie, and Vero Beach. The environmental data was collected with an average of 30 days among the three water stations.

3 Materials and Methods

Kruskal–Wallis (Vargha & Delaney, 1998) and pairwise Wilcoxon (Conover, 1999; Wilcoxon, 1945) tests were used to compare the average abundance between organisms. Percentage abundance was modeled using beta regression (Douma & Weedon, 2019; Ferrari & Cribari-Neto, 2004) to identify predictors that are correlated with the organism's presence. In beta regression, the distribution of response variable, i.e., percentage cover in this study, is modeled using beta probability distribution:

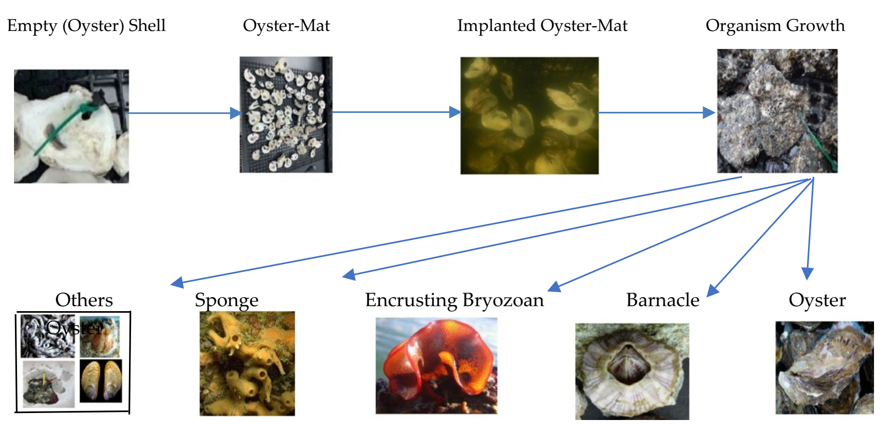

Fig. 1 Schematics of deployment and data collection process

$$f(y;p,q) = \frac{\Gamma(p+q)}{\Gamma(p)\Gamma(q)} y^{p-1}(1-y)^{q-1}, 0 < y < 1 \quad (1)$$

where y is the percentage (response), Γ is the gamma function, and p and q are parameters of the beta probability distribution. The expected value of response is:

$$\mu = E(y) = \frac{p}{p+q} \quad (2)$$

and its variance is:

$$var(y) = \frac{pq}{(p+q)^2(p+q+1)} \quad (3)$$

A logit or Probit link function g takes the expected value of the response μ that falls in the interval (0, 1), and transforms it to the continuous domain of real numbers. The logit (or log of odds ratio) link function is:

$$g(\mu) = \log(\frac{\mu}{1-\mu}) \quad (4)$$

The Probit link function is defined by:

$$g(\mu) = \phi^{-1}(\mu) \quad (5)$$

where ϕ is the cumulative distribution function of the standard normal distribution. As we can see in Eq. 6, a logit link function in the beta regression maps the linear combination of regressors (predictors) to a continuous domain as a function of expected response:

$$g(\mu_i) = \log\left(\frac{\mu_i}{1-\mu_i}\right) = \sum_{k=1}^{K} x_{ik}\beta_k \quad (6)$$

where K is the number of predictors (covariates), x_{ik} are observed/measured predictors, and $\beta_k's$ are the coefficients of predictors in the regression model. Maximum likelihood estimation is then used to estimate the unknown parameters $(\beta_k's)$.

Beta regression uses an appropriate error term to prevent bias and produce unbiased estimates when data is doubly bounded between 0 and 1 (percentage data). Beta regression provides reliable parameter estimates in natural science studies where effect size is considered important as hypothesis testing (Geissinger et al., 2022). In the context of generalized linear models, the beta regression model is used for estimating the parameters of the regression model as a preferred alternative to multiple regression with the transformed response variable (Eskelson et al., 2011; Mehmet al. &i Cengiz, 2020; Yellareddygari et al., 2016).

4 Results

4.1 Spatiotemporal Variation in Benthic Organism Abundance

The differences in organism abundance are compared using a boxplot (Fig. 2 (left)) based on the data that was collected between 2020 and 2021. The visual assessment of the boxplot suggests that five organisms including barnacle, biofilm, EB, oysters, and sponges at the Living Dock locations have substantially greater abundance among all organisms. To confirm, a Kruskal–Wallis test was performed to compare the abundance of organisms. The result from Kruskal–Wallis with a chi-square value of 6097 and p-value < 2.2e-16 recommended that there is a significant difference in average abundance among these organisms.

Next, Wilcoxon pairwise test was performed to identify organisms with significantly higher abundance. This test confirmed that barnacles, biofilm, EB, oysters, and sponges as organisms with significantly higher presence at the Living Dock locations.

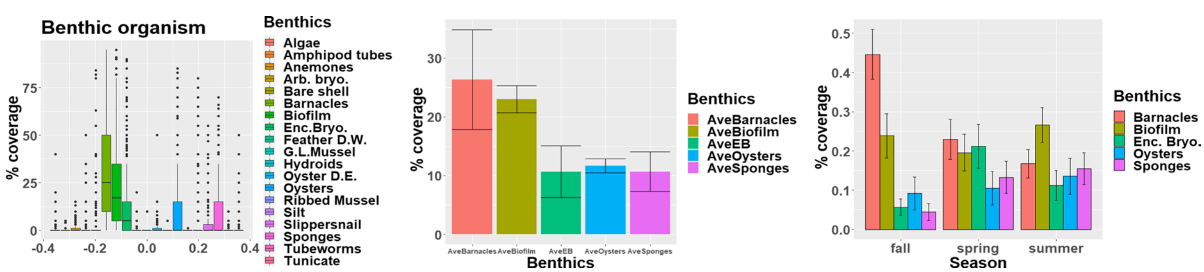

Fig. 2 Boxplot for overall organism abundance (left); overall percent cover (all dock locations and all seasons) of top five organisms (middle); overall percent cover (all seasons at each dock location) of top five organisms in different seasons (right)

Figure 2 (middle) shows the average percent cover calculated using all dock locations over all seasons for barnacle, biofilm, EB, oyster, and sponge (from left to right) with average percent coverage of 26.6, 23.1, 11.3, 11.9, and 11.2, respectively. Barnacles have a higher percent cover in fall and spring while biofilm is often dominant in summer. EB has a higher abundance in the spring, oysters in the summer, and sponges in the spring and summer (Fig. 2 (right)).

The organism abundance was compared at different dock locations during fall, spring, and summer in Fig. 3. Results indicate barnacles were more abundant at dock A1A during the fall season, at dock Wingate during the spring, and at Cape Canaveral in the summer. EB was dominant at dock IAP through all three seasons. Oysters were more prevalent at Sebastian during the fall and spring, and at dock LC during the summer. Among top 5 dominant organisms, biofilms are generally not considered a filter feeder but rather an extracellular matrix of microalgae, bacteria, and their excreted substances. Therefore, to further align with the goals of this study, biofilm was removed from the list as it does not contribute to water filtration.

The percent cover of the four remaining organisms were compared among different dock locations in different sessions. Examining the data in Fig. 3, it was found that dock A1A has the highest percent cover of barnacles during the fall at 66%. Dock IAP has the highest percent coverage of EB at 48% in spring and fall. Dock Sebastian has the highest percent cover of oysters at 26% in spring, and second highest in fall and summer. Dock LC has the highest percent coverage of sponges in spring. Dock MS shows the highest abundance of sponges during the fall and second highest in spring with an equal percent coverage of 26%. Barnacles have a greater percentage at dock A1A in fall, followed by dock Wingate in the spring at 41%, and IAP at 26% during the summer. EB was highest at dock IAP during all three seasons. Oysters show consistent abundance at dock SB in fall and spring; however, dock LC has the highest percentage of oysters in summer at 26% among all docks. Sponges are consistent at dock MS for both spring and fall at 26%, and at Sebastian with 17% in summer.

After studying the abundance of organisms in relation to the IRL docks and seasons, the presence of individual organisms is investigated. Depicted in Fig. 4, organisms including barnacle, EB, oyster, and sponge were ordered based on their abundance

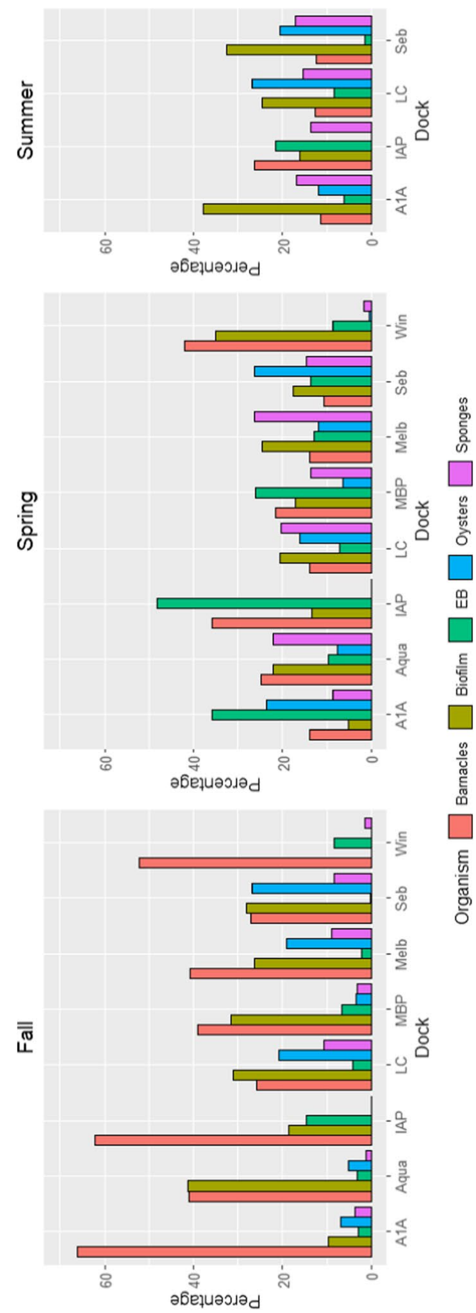

Fig. 3 Organism percentage abundance among docks during the fall (left); spring (middle); and summer (right)

at each dock location (averaged over all seasons). For barnacles, the greatest abundance was at dock Wingate at 47%, and the least coverage at docks LC and Sebastian at 17%. For EB, the data indicated its greatest cover at dock IAP with 28%, and lowest cover at dock Sebastian at 5%. Oysters, however, had the greatest abundance at dock Sebastian at 25%, with no growth at docks IAP and Wingate. Sponges had the greatest cover at dock MS with 17%, and the lowest presence at dock Wingate with 1%.

4.2 Modeling Organism Abundance Using Environmental Factors

Beta regression was used to model abundance as response to four environmental factors along with dock location as predictors. Figure 5 and Figs. 8, 9, and 10 in the Appendix show organism cover regarding environmental factors including salinity, turbidity, temperature, and water pH with their progress at each dock location. These factors can vary across the IRL spatially and temporally. For locations closer to an inlet, these variables will be regulated by the coastal ocean waters. For locations far from an inlet, the variables are governed by evapotranspiration and proximity to freshwater inflows.

As can be observed in Fig. 5 and Fig. 14 in the Appendix, barnacles almost have a linear increase with rising salinity among all docks. Dock Wingate had the highest abundance of barnacles (largest intercept), while dock A1A showed the fastest rate in barnacle growth (largest slope). At dock Cape Canaveral, there was a steady decline with increased salinity to under 20 and it was resumed between salinity levels 20 and

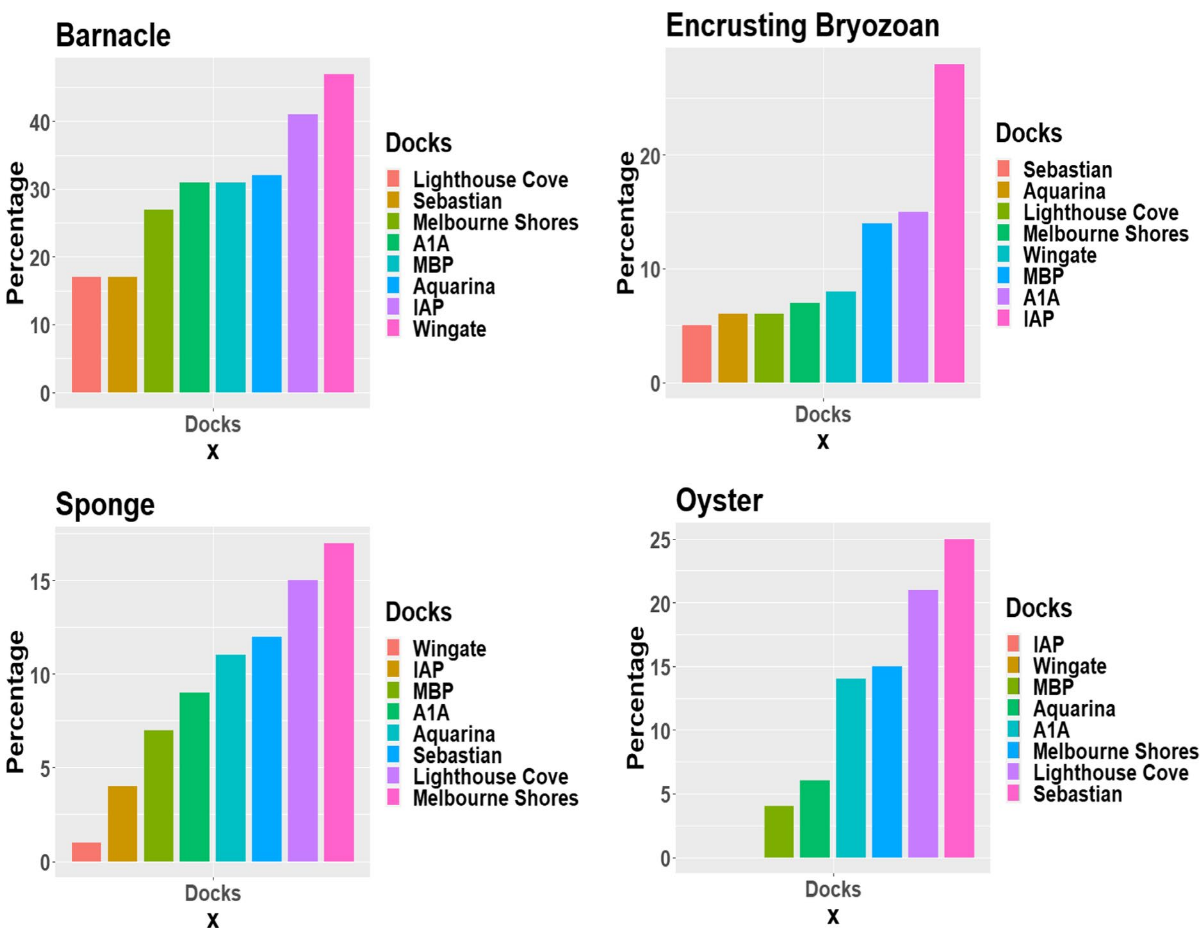

Fig. 4 Organism percentage growth in different docks: Barnacle (top left); EC (top right); sponge (bottom left); Oyster (bottom right)

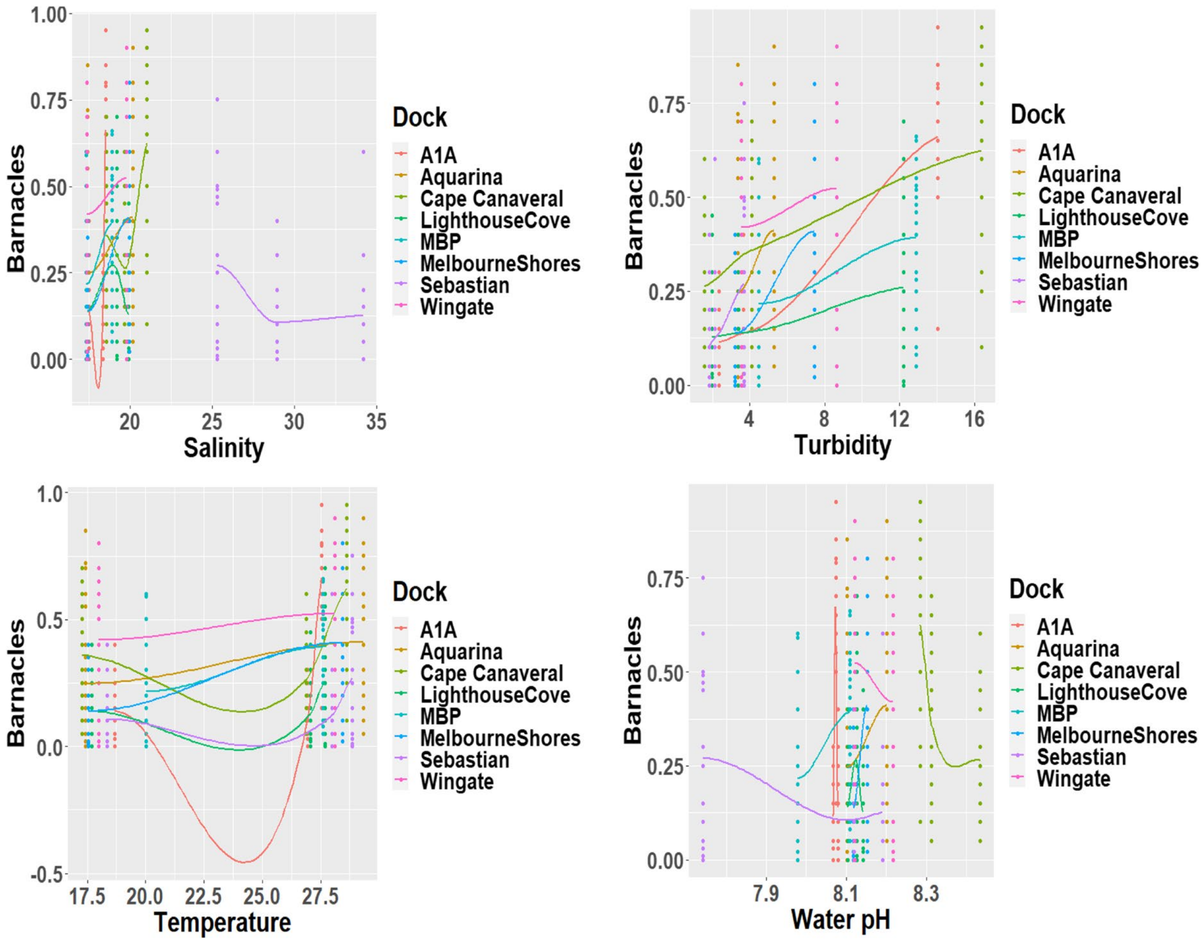

Fig. 5 Impact of salinity, turbidity, temperature, and pH on organism's growth at different dock locations for barnacle

21. Dock Sebastian has shown a collection of barnacles with salinity recorded above 25, but the abundance steadily declined with salinity values between 25 and 30, and it then settled at about 13% percent cover. For turbidity values between 2 and 16, all dock locations showed a positive correlation between barnacle abundance and turbidity. A positive correlation between barnacles and pH was observed at docks Aquarina, MBP, and MS for pH levels between 8.0 and 8.2. All other docks showed a decline in barnacles with increasing pH values. With growing temperatures, barnacle accumulation showed modest abundance.

EB abundance was negatively related to salinity, turbidity, temperature, and pH at nearly all dock locations, as depicted in Figs. 8 and 15 in the Appendix. A sharp increase was observed at a pH level of about 8 at dock A1A. The maximum abundance of EBs was observed at pH right above 8.3 at dock Cape Canaveral. Figures 9 and 16 in the Appendix illustrate the sponge growth regarding environmental factors at different dock locations.

An increase in salinity has a depreciating effect on sponge abundance among all docks except for dock Sebastian, where sponges exhibit moderate percent cover starting at 25 ppt. It was also observed sponges' presence changed with regard to turbidity at all docks. An increase in temperature seems to contribute to an overall decrease in sponges at all docks, especially with temperatures rising above 25 °C. Increasing pH seems to have a negative impact on sponge abundance at all docks, except at dock Sebastian, which showed an increase from pH levels of 7.7 to 8.2 and dock Cape Canaveral with pH values from 8.3 to under 8.5. We have also observed a steady low sponge abundance with regard to all four environmental factors.

As depicted in Figs. 10 and 17 in the Appendix, oysters demonstrated mixed responses to the environmental factors at different dock locations. For example, docks Cape Canaveral and MS showed an increasing abundance in response to increased salinity levels of up to 20 ppt, but all other docks showed declining growth responses including dock Sebastian from salinity values between 25 and 35 ppt. Oysters also showed mixed response among the docks with reference to turbidity. All docks (but MS and Sebastian) showed increasing oyster abundance, with dock Sebastian showing higher intercept for percent cover. Oyster abundance mostly shows declining response to increasing temperature among the docks, except for dock LC with a late decrease at temperature of above 25 °C, and dock MS being the only one with steady abundance as temperature grows. In response to pH levels, there is a narrow increase in oyster abundance at pH level of around 8.1 at docks A1A, LC, and MS. All other docks showed either steady, or declining outcome from water pH greater than 8.0.

The average percent cover for barnacle, EB, sponge, and oyster in response to each environmental factor (regardless of dock location) is shown in Fig. 6 and Figs. 11, 12, and 13 in the Appendix. The summary is as follows:

- Barnacle: Rising salinity has an average increase on barnacles at the 25 ppt mark, but gradually declines beyond that level. Increasing turbidity showed changes among barnacles, with declines at pH levels above 8.3. Rising temperature indicates an increased accumulation for barnacles.
- EB: It tends to prefer water pH level between 8.0 and 8.3. It was observed that increased values above 20 for salinity, above 4 for turbidity, and above 20 °C for temperature constitute a negative impact on their average overall abundance.
- Sponge: The analysis was inconclusive regarding increased salinity but depicts fading cover as tur-

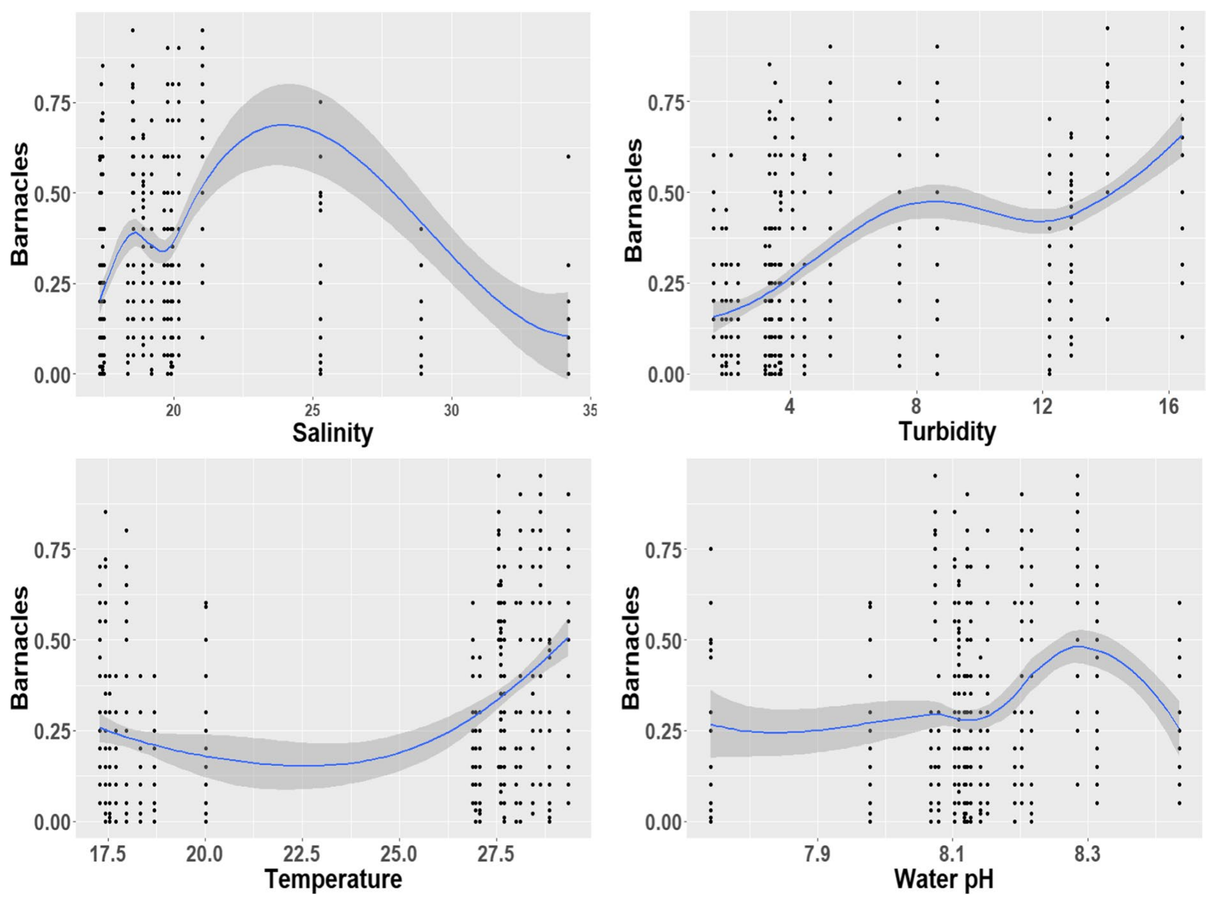

Fig. 6 Impact of salinity, turbidity, temperature, and water pH on organism's growth regardless of dock locations for barnacle

bidity and temperature rises. Water pH levels above 8.1 tend to also demonstrate a negative impact.
- Oysters: The response to the increased salinity was inconclusive. However, steadily decline was observed in response to increase in turbidity and water pH levels between 8.1 and 8.2 were favorable. Temperature, however, seems to have no significant effect on their percent cover.

Figure 7 illustrates the correlation matrix of the four environmental factors with their degree of significance highlighted by the red stars, and the size of the numbers demonstrates the strength of the correlation. Correlation of environmental factors can be summarized in the following:

- The Banana River water station (Fig. 7 (top left)): Water pH has negative correlation (−0.77) with salinity and with temperature (−0.83). Water salinity has positive correlation with temperature (1.00) and turbidity (0.51).
- Vero Beach water station (Fig. 7 (top right)): Water pH has positive correlation with salinity (0.89), and water temperature has positive correlation with turbidity (0.75). There is a significant negative correlation between turbidity and water pH (−0.75) and salinity (−0.97). Water pH is negatively correlated with water temperature (−0.55).
- The Eau Gallie station water station (Fig. 7 (bottom left)): Positive correlation among all environmental factors. From a strong correlation between water salinity and temperature (0.95) to a weak correlation between water pH and temperature (0.27).
- All three water stations combined (Fig. 7 (bottom right)): Only two moderate correlations were observed. Water temperature has positive correlation with turbidity (0.52) and salinity (0.33).

The summary of the beta regression to model abundance of each organism in response to predictors including environmental factors, season, dock, and their interactions are displayed in Table 1. Each model is evaluated using goodness of fit criteria including pseudo-R^2 and Akaike information criterion. Interaction terms are shown using Factor 1/factor 2 format. For example, Temp/turbidity is the interaction term between temperature and turbidity. The summary follows:

- Barnacles: Dock location had a significant impact on the presence of barnacles. The top three dock locations with regard to barnacle abundance were Aquarina, MBP, and A1A. Moreover, the season also had a significant impact. The highest percent cover of barnacles was observed in the spring, followed by the summer and fall. Turbidity, pH, and temperature were all positively related to barnacle abundance. Salinity had a negative impact on barnacles.
- Encrusting bryozoan (EB): Dock location had a significant impact on EB presence. The top three dock locations with regard to the EB abundance were A1A, LC, and MBP. Moreover, season also had a significant impact on EB. The highest EB abundance was observed in the fall, followed by the summer and spring. Salinity has shown a positive impact on EB, but turbidity and temperature were not significant.
- Oysters: Dock location had a significant impact on oyster presence. The top three dock locations with regard to the presence of oysters were A1A, Aquarina, and MBP. Season did not show to have significant relevance toward oyster abundance, nor did environmental factors.
- Sponges: The top three docks with regard to sponge abundance were Sebastian, MS, and LC. Season and environmental factors and their combinations did not show relevance toward sponge presence.

5 Discussion

This study examines the existing benthic communities on eight Living Docks and compares those communities to the measured water quality parameters near each site. The analysis identified five main functional groups that dominated the benthic community growing on oyster shells: barnacles, biofilm, EBs, oysters, and sponges. The dominance of these groups is in line with previous studies on benthic recruitment to hard substrates and oyster mats in the IRL (Wassick et al., 2022; Weaver & Hunsucker, 2018). Of the five main functional groups, the four known filter feeders (barnacles, EB, oysters, and sponges) were found to vary in their correlation with season, dock location, and water quality parameters. This is not surprising as larval supply and recruitment triggers are different for each of these organisms, often dependent on environmental conditions (Chicharo & Chicharo, 2000). Previous work based on a subset of data in this study has also determined dock location as well as the age of the Living Dock influence the type and abundance of growth on the mats (Hunsucker et al., 2021).

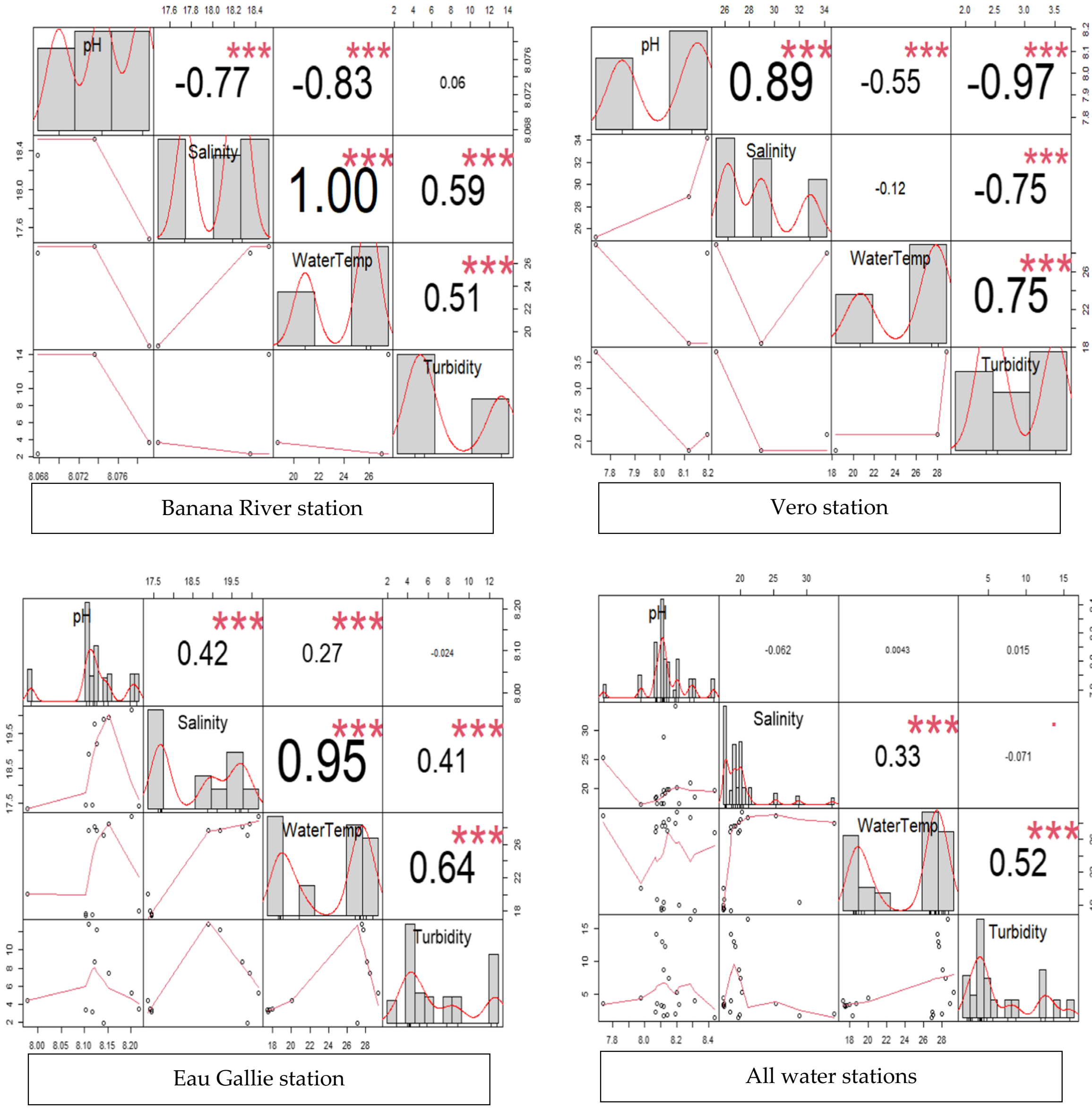

Fig. 7 Correlation matrix of the environmental factors collected in different water stations

Oysters are known for their large filtration capacity (Ehrich & Harris, 2015). Based on the results of this study, oysters did not show much variation within the measured ranges with the environmental factors. None of the factors within the measured ranges was identified to have significant impact on the oyster's abundance by the beta regression model (depiction in Fig. 13 in the Appendix). With regard to salinity, this makes sense as the dominant oyster in the IRL, *Crassostrea virginica* (Dickinson et al., 2012; Pruett et al., 2021), is a euryhaline species, known for its ability to thrive in a range of salinities (Galtsoff, 1964). However, the ability to grow and survive could be negatively impacted by drastic changes in environmental conditions, such as was seen by mimicking flooding conditions (Pruett et al., 2021). The ability of these organisms to survive

Table 1 Beta regression models with identified significant predictors explaining organism presence and abundance

Organism, Dock, Season, Factor	$\hat{\beta}$	Std-error	*P*-value
Barnacle: Pseudo R2 = 0.28, AIC = −632, ***Dock:*** *Aquarina*	0.942	0.218	1.68e-05
Cape Canaveral	−4.348	1.299	0.000818
MBP	1.249	0.354	0.000415
Melbourne Shore	−1.163	0.428	0.00667
Wingate	−2.9	0.883	0.00102
Season: *Spring*	27.431	5.864	2.90e-06
Summer	6.963	1.532	5.49e-06
Factors: pH	109.207	22.936	1.92e-06
Salinity	−42.603	13.134	0.00118
Turbidity	81.939	19.944	3.98e-05
Temperature	50.888	12.298	3.51e-05
pH/salinity	4.954	1.534	0.00124
pH/temp	−6.196	1.504	0.00124
pH/turbidity	−13.789	3.376	4.44e-05
Salinity/turbidity	0.996	0.258	0.000116
Temp/turbidity	0.420	0.098	1.96e-05
EB: Pseudo R^2 = 0.35, AIC = −2300			
Dock: Aquarina	−1.559	0.240	9.04e-10
Lighthouse Cove	−1.166	0.179	6.55e-11
MBP	−1.314	0.440	0.00284
Sebastian	−9.329	2.094	8.43e-06
Season: Spring	−20.865	7.933	0.00854
Summer	−5.279	2.150	0.0140
Factors: *Salinity*	61.923	16.565	0.000185
Temperature	−48.065	16.278	0.003151
Turbidity	−62.900	27.236	0.02090
pH/salinity	−7.204	1.933	0.000195
pH/temp	5.941	1.985	0.002770
pH/turbidity	11.086	4.566	0.015198
Salinity/turbidity	−0.798	0.356	0.02511
Salinity/temp	−0.022	0.008	0.00614
Temp/turbidity	−0.444	0.131	0.000687
Oyster: Pseudo R^2 = 0.38, AIC = −3055			
Dock: *Aquarina*	−0.820	0.274	0.00277
MBP	−1.053	0.445	0.01812
Sebastian	−5.206	2.026	0.01021
Factor: *Salinity/temp*	−0.0191	0.00796	0.01628
Sponge: Pseudo R^2 = 0.39, AIC = −2982			
Dock: *Aquarina*	0.641	0.277	0.02074
Lighthouse Cove	0.843	0.221	0.000137
Melbourne Shore	1.387	0.453	0.0022
Sebastian	4.103	2.087	0.0492

in a range of turbidities, especially higher conditions, is also a benefit, as they have the potential to aid in the removal of suspended solids from the water column, including algae blooms. Oysters were once thriving throughout the IRL system, but due to overharvesting, their presence has drastically decreased (Garvis et al., 2015; Wilson et al., 2005). There are many efforts to bring back these important filter feeders, but these projects are often limited to specific sections of the IRL due to current larval supply. As seen with the current analysis, oyster presence is more site or dock specific which may be related to the source population of oysters and the overall dispersal of larvae. A recent study investigating the recruitment patterns of the eastern oyster found the highest spat densities within 400 m of a parent reef (Atwood & Grizzle, 2020).

Barnacles thrive in the IRL and are found during all seasons. Barnacles are known to dominant submerged surfaces, with background levels detected throughout the year and peaks occurring during spring and summer (Wassick et al., 2022). There is interspecies competition among benthic communities, and although barnacles are present in the water column, they may be outcompeted for space by other organisms (e.g., tubeworms, tunicates, oysters) (Hunsucker et al., 2021). EB and sponges are both low growth forms that can cover both surfaces and other benthic organisms. While not as efficient at filtering water as oysters, both groups can provide a substantial impact when covering large areas (Rech, 2022). Based on the data collected, EB were found to prefer higher salinity levels while higher temperature and turbidity had a negative impact on their presence. Sponges exhibited the lowest abundance of the organisms analyzed and showed no preferences to environmental factors or seasons.

The establishment of benthic communities are known to provide significant water filtration (Gilligan et al., 2022; Layman et al., 2014). Understanding how benthic organisms grow in response to environmental parameters may be useful, especially for restoration efforts. The environmental variables, especially water quality conditions, are not consistent within the IRL. The fact that benthic organisms prefer different environmental conditions is an advantage, and still allows for benthic recruitment throughout the IRL regardless of the type of organism. This helps emphasize Living Docks to be implemented on just about any dock location (Weaver & Hunsucker, 2018) throughout the IRL. For example, there is an effort to establish Living Docks in lower salinity tributaries to the IRL. The data established during this study can help predict which species may dominate in these low-saline areas and where the placement can be the most useful.

Selecting the ideal sites for oyster mats can promote the recruitment of organisms in optimal conditions for their growth, especially with changing environmental factors related to climate change and increased pollution. More researchers are reporting impacts of climate change stressors on benthic organisms. For example, Dickinson et al. (Dickinson et al., 2012) reported interactive effects of lower salinities and elevated CO_2 on *C. virginica*. Understanding the conditions at potential Living Dock locations or how species may respond is a critical step in restoration efforts (Howie & Bishop, 2021). While previously Living Docks were driven by the involvement of citizen scientists, the reverse may also be favorable for enhanced ecosystem services. Thus, using knowledge from the current study as well as others from within the IRL (Gilligan et al., 2022; Rech, 2022; Wilson et al., 2005) can be used to determine where it may be the most beneficial for Living Dock placement.

6 Conclusion

Decline in water quality of many estuaries worldwide due to anthropogenic stressors is a pressing issue and has attracted much attention among researchers to address it (Ali et al., 2009; Basheer, 2018a, 2018b; Gilligan et al., 2022; Howie & Bishop, 2021; Layman et al., 2014; Rech, 2022). This study is focused on the impact of oysters, barnacles, sponges, and EB to improve water quality in IRL. Other organisms were not considered in this study and may also contribute to water filtration and have been found throughout the IRL such as sea squirts, colonial tunicates, tubeworms, and arborescent bryozoans (Hunsucker et al., 2021; Wassick et al., 2022). If feasible, future work will also consider sensors attached directly to the dock locations to allow precise local measurements at dock locations. Poor water quality caused by eutrophication and suspended sediments has been an ongoing challenge in the IRL and many estuaries worldwide. Promoting the growth of filter feeding benthic organisms demonstrates a resourceful means to confront this pollution. The results from this study can be used to target specific locations in the IRL to allow for the settlement and recruitment of the major benthic filter feeding organisms, especially those analyzed as part of this study: oysters, barnacles, sponges, and encrusting bryozoans. As the Living Docks program and other restoration efforts throughout the IRL continue to grow, the data presented within this study provides a useful bench mark for determining the relationship between water quality and benthic growth and using this as a metric for site selection.

Appendix

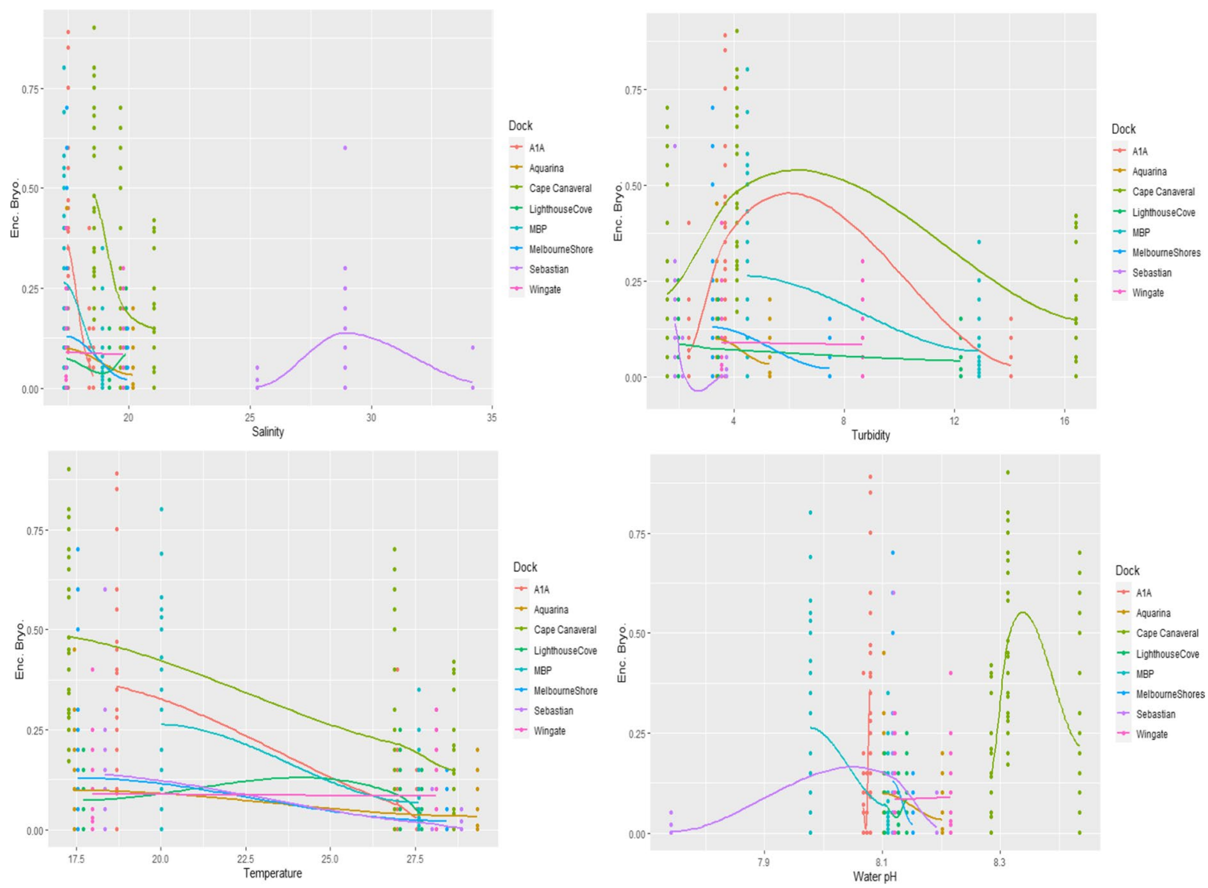

Fig. 8 Impact of salinity, turbidity, temperature, and pH on EB's growth at different dock locations

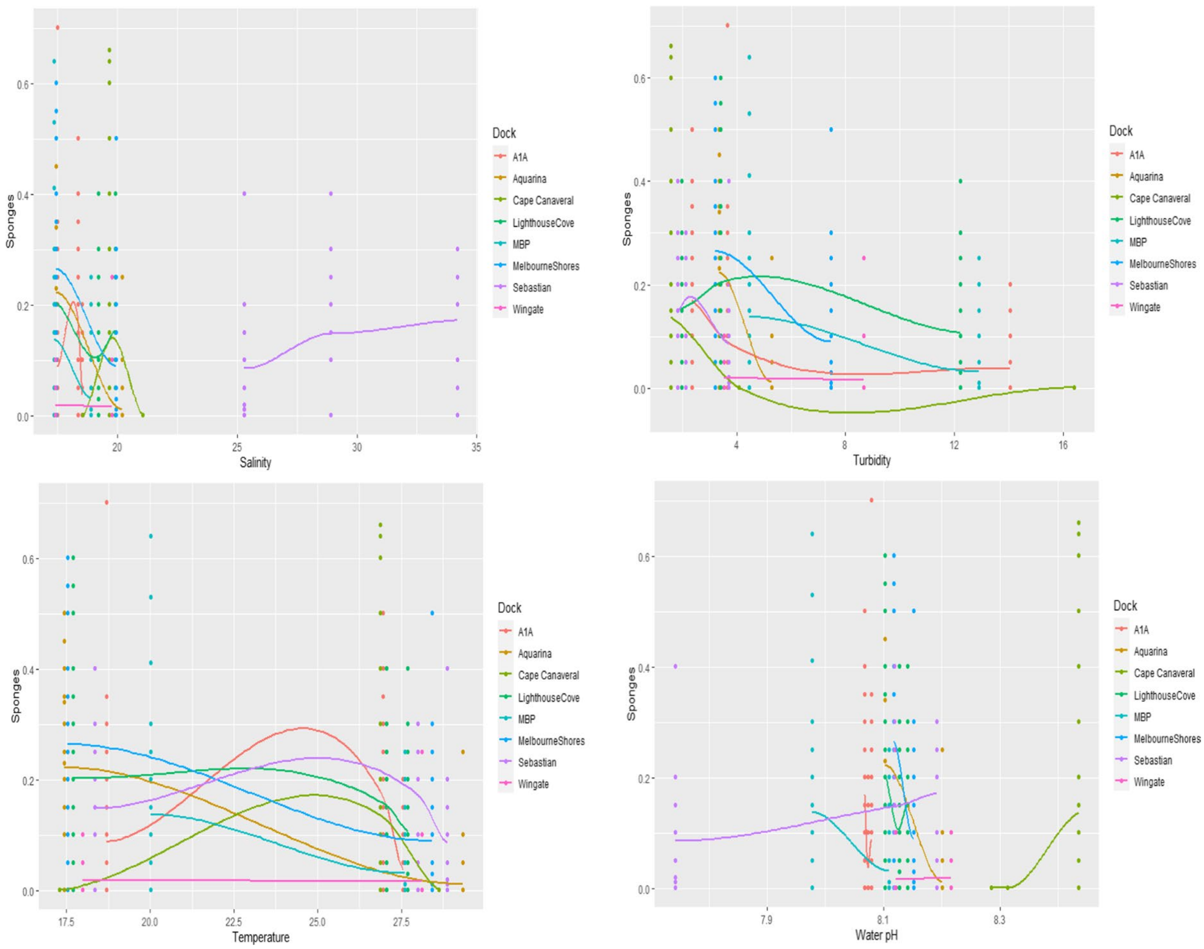

Fig. 9 Impact of salinity, turbidity, temperature, and pH on sponge's growth at different dock locations

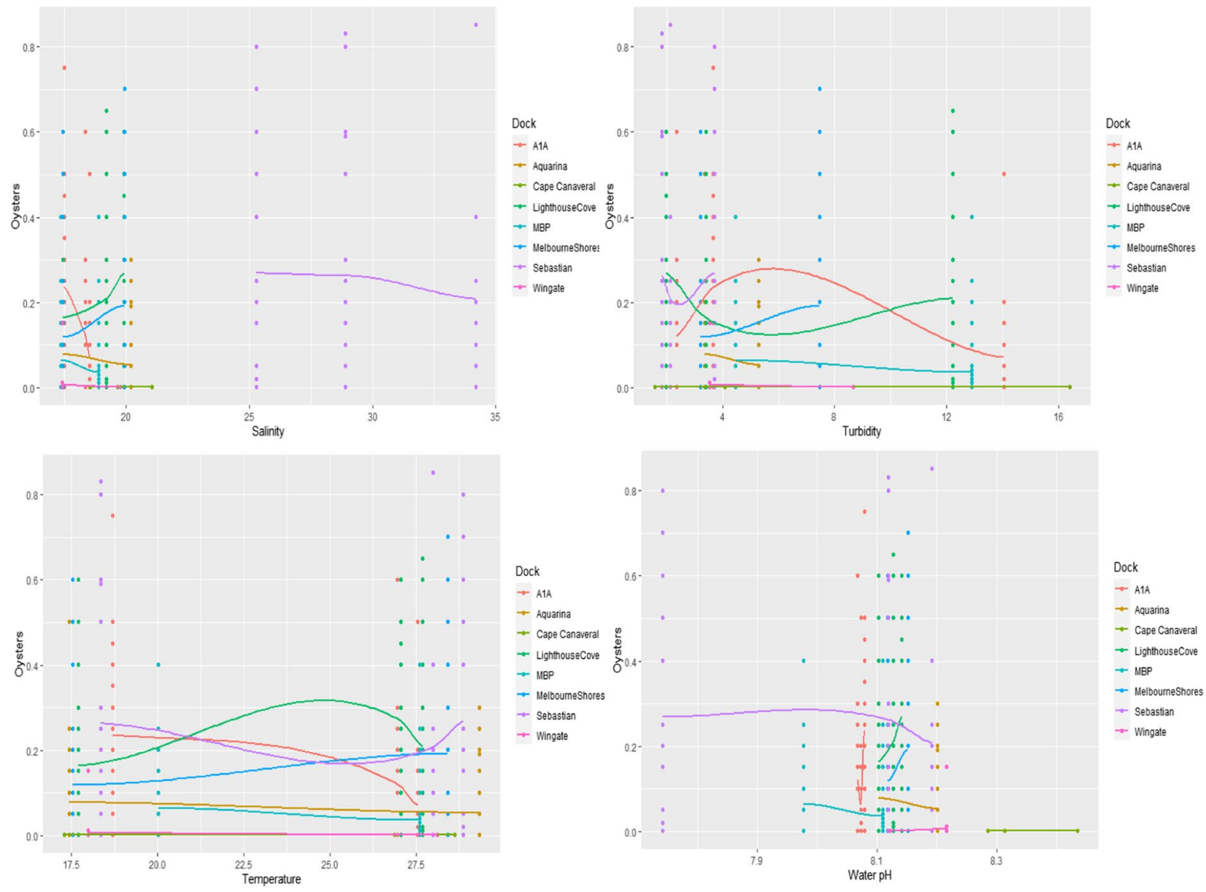

Fig. 10 Impact of salinity, turbidity, temperature, and pH on oyster's growth at different dock locations for

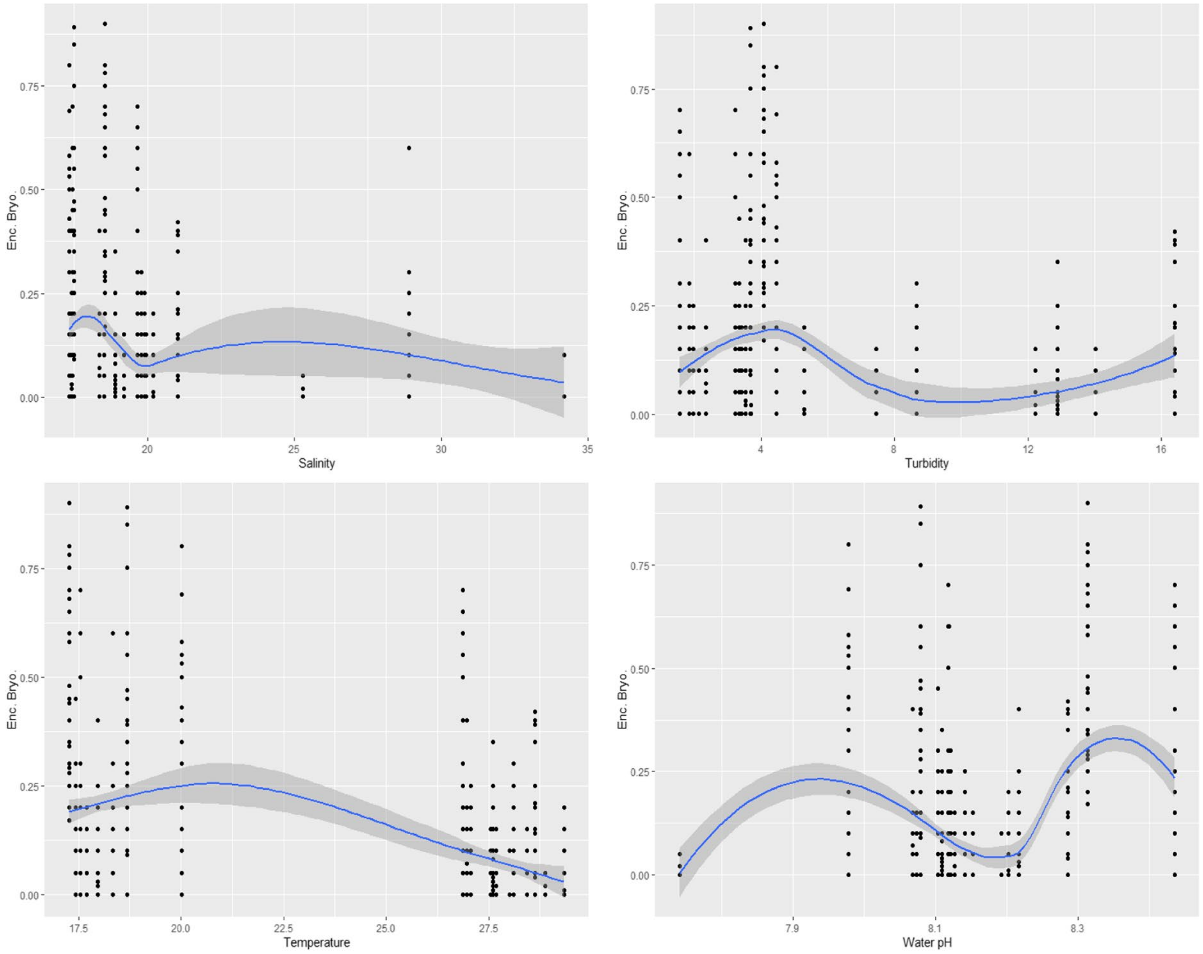

Fig. 11 Impact of salinity, turbidity, temperature, and water pH on EB's growth regardless of dock locations

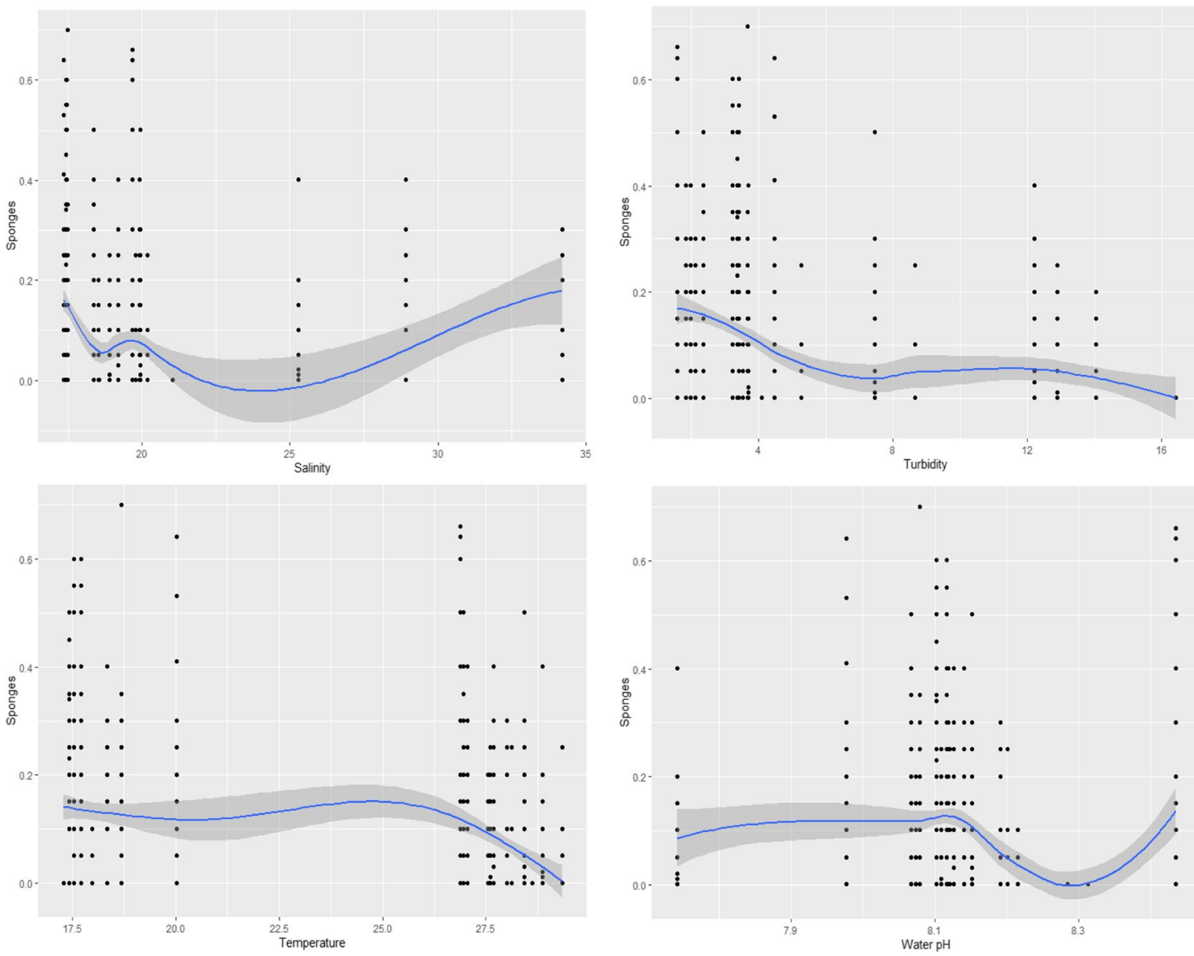

Fig. 12 Impact of salinity, turbidity, temperature, and water pH on sponge's growth regardless of dock locations

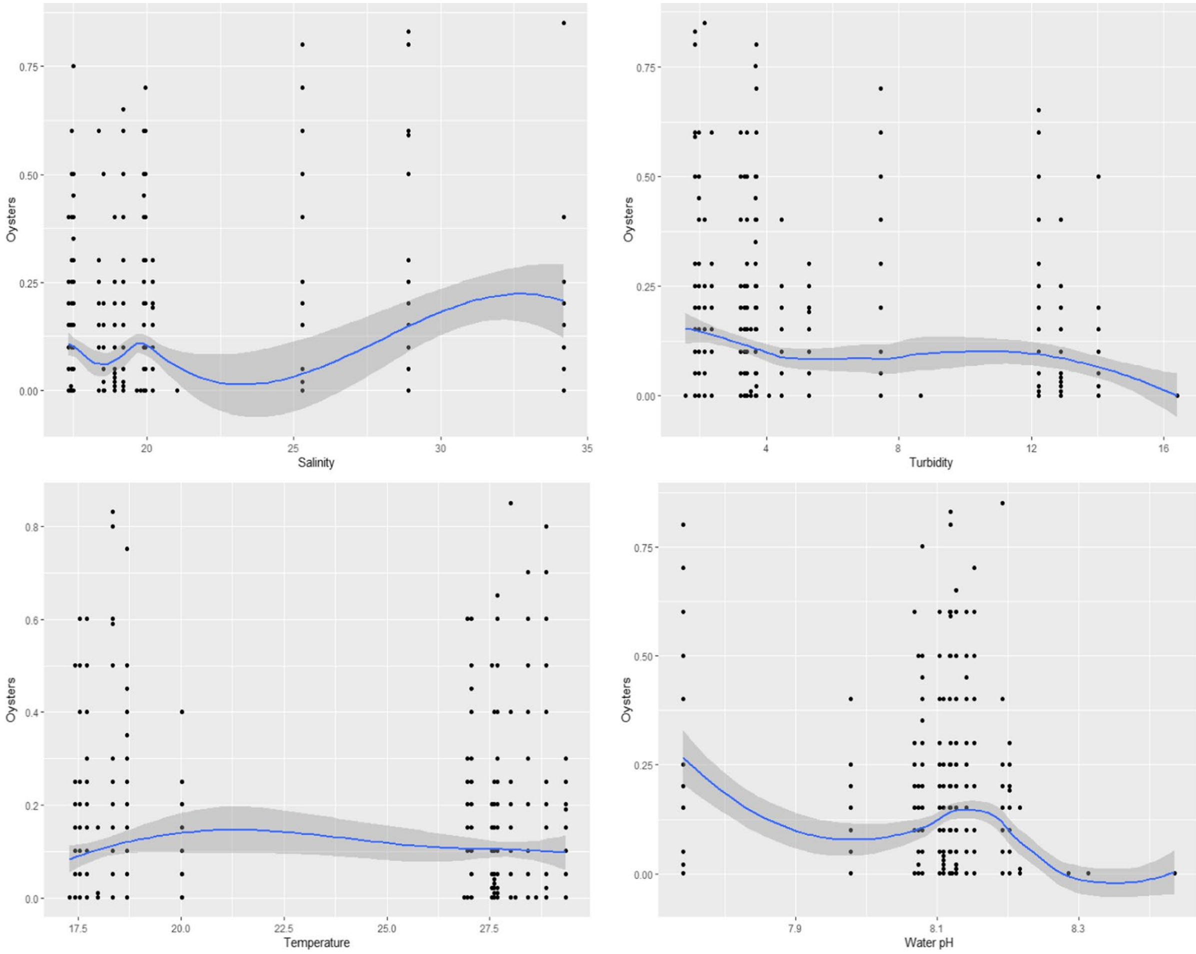

Fig. 13 Impact of salinity, turbidity, temperature, and water pH on oyster's growth regardless of dock

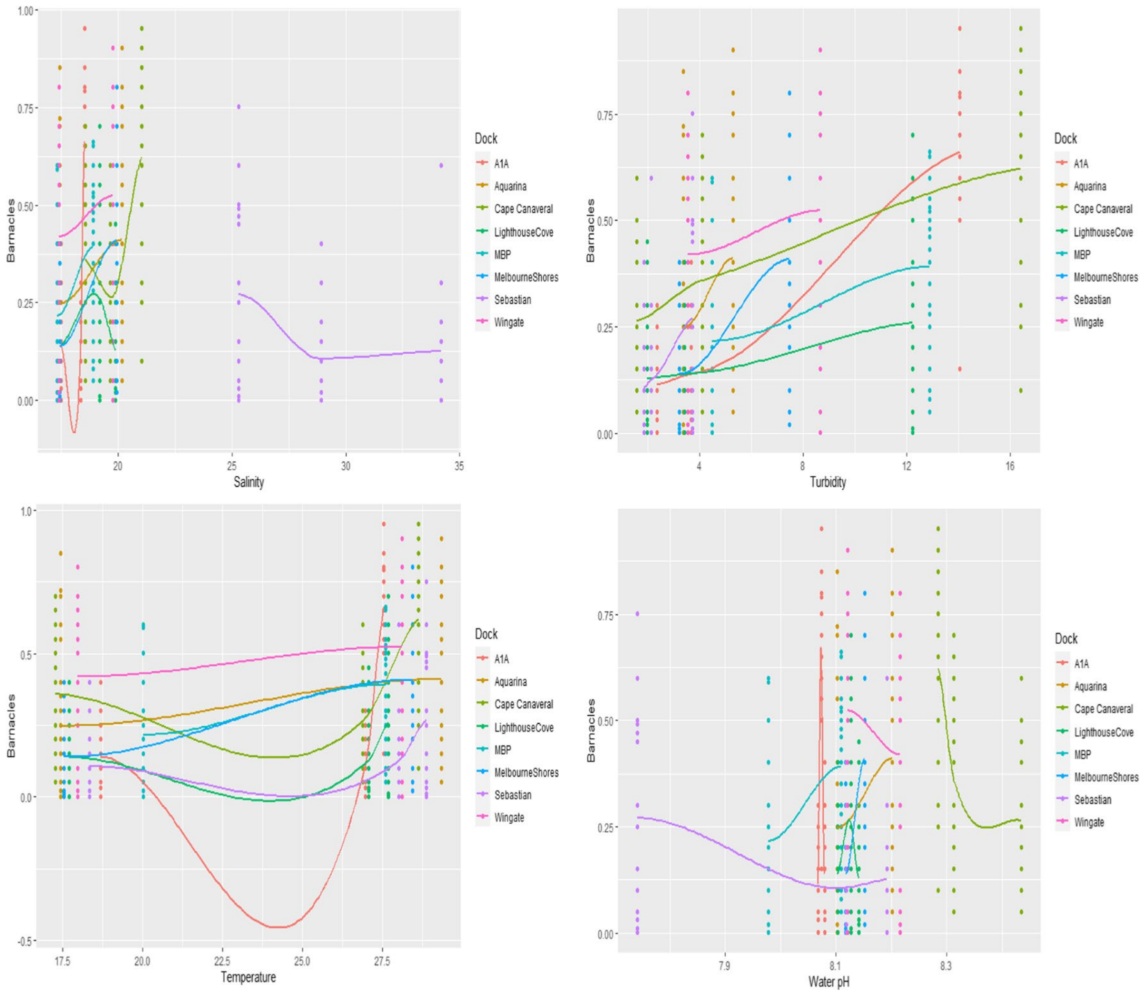

Fig. 14 Barnacle growth among docks in relation to environmental factors

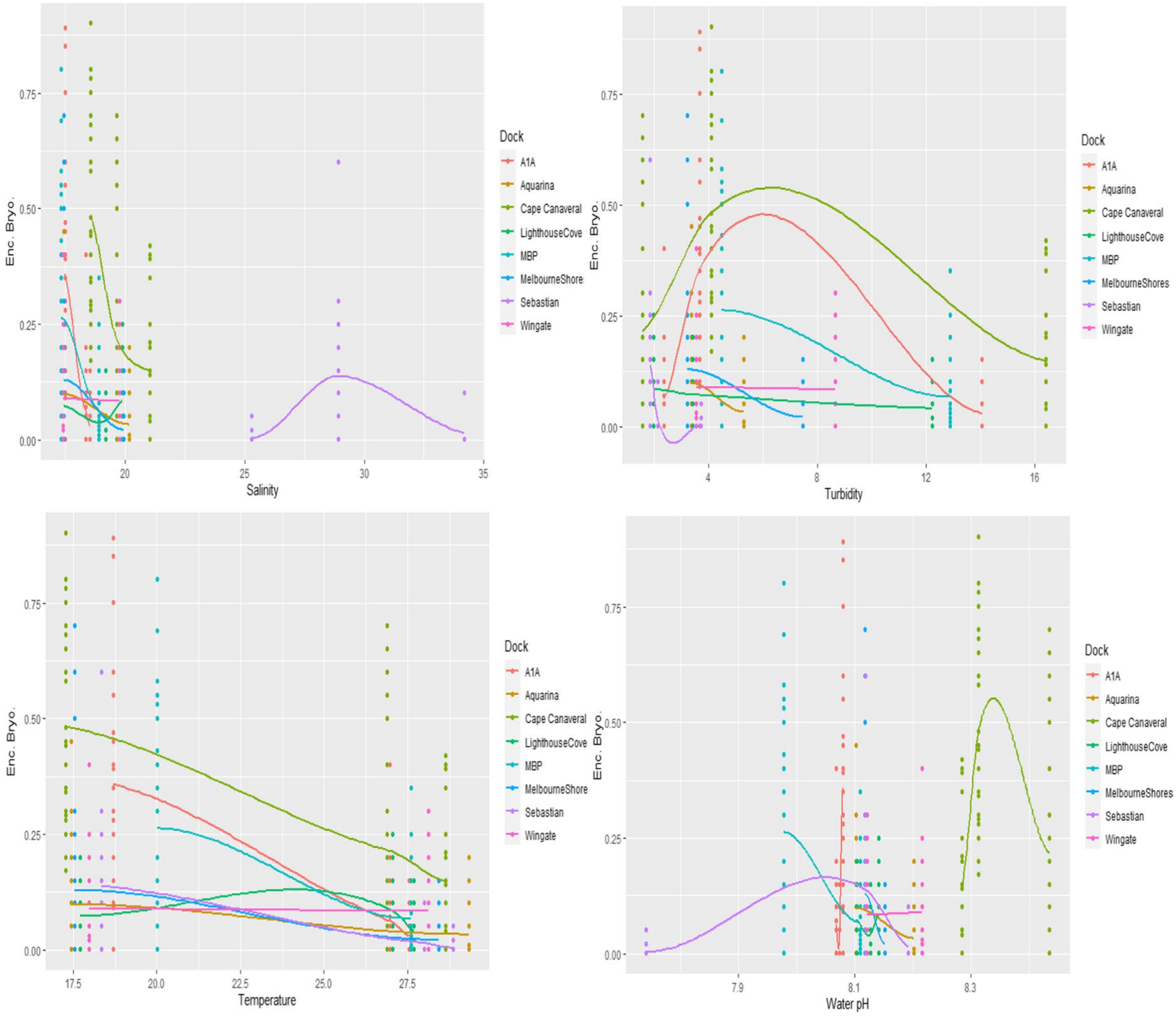

Fig. 15 EB growth among docks in relation to environmental factors

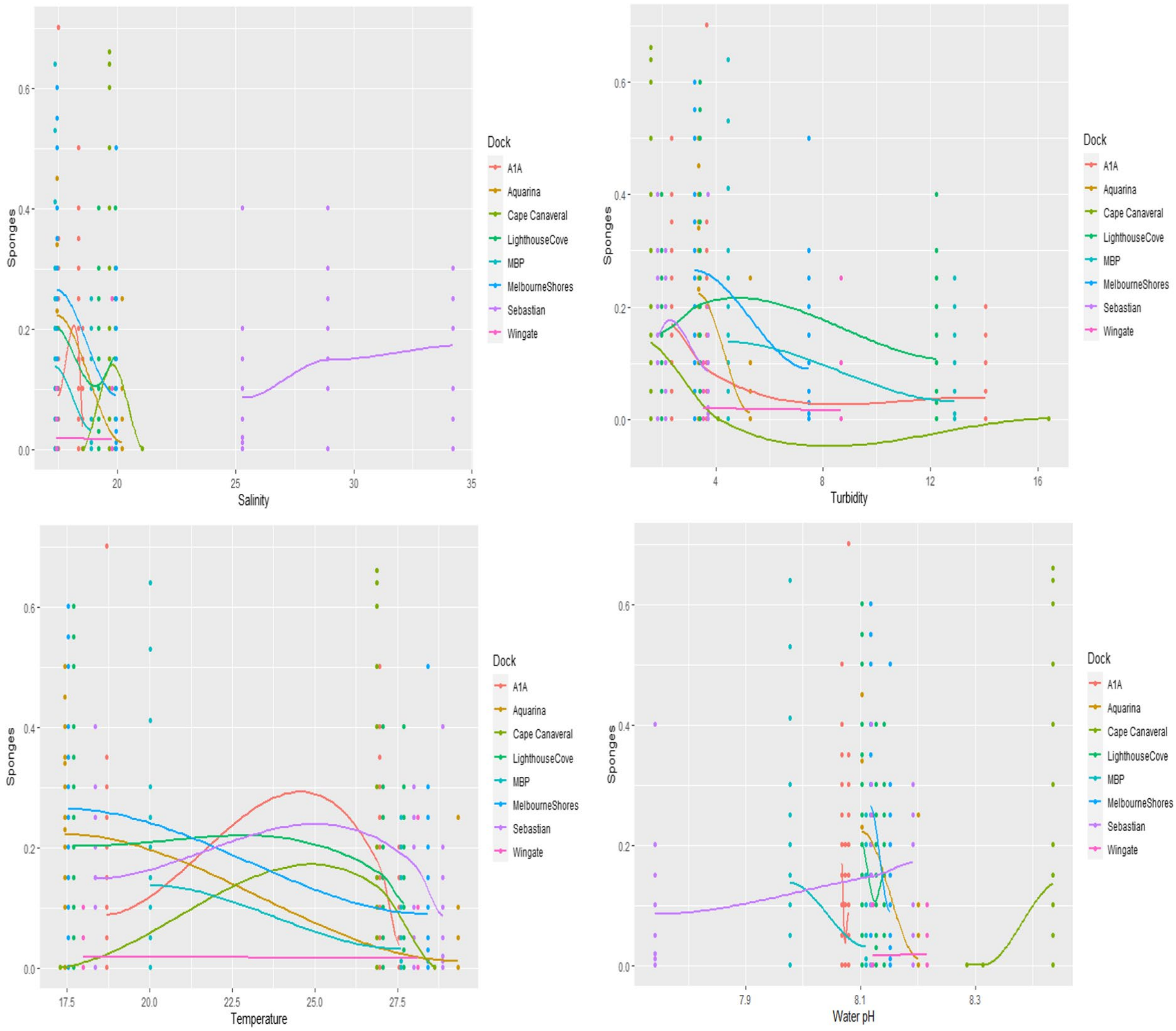

Fig. 16 Sponge growth among docks in relation to environmental factors

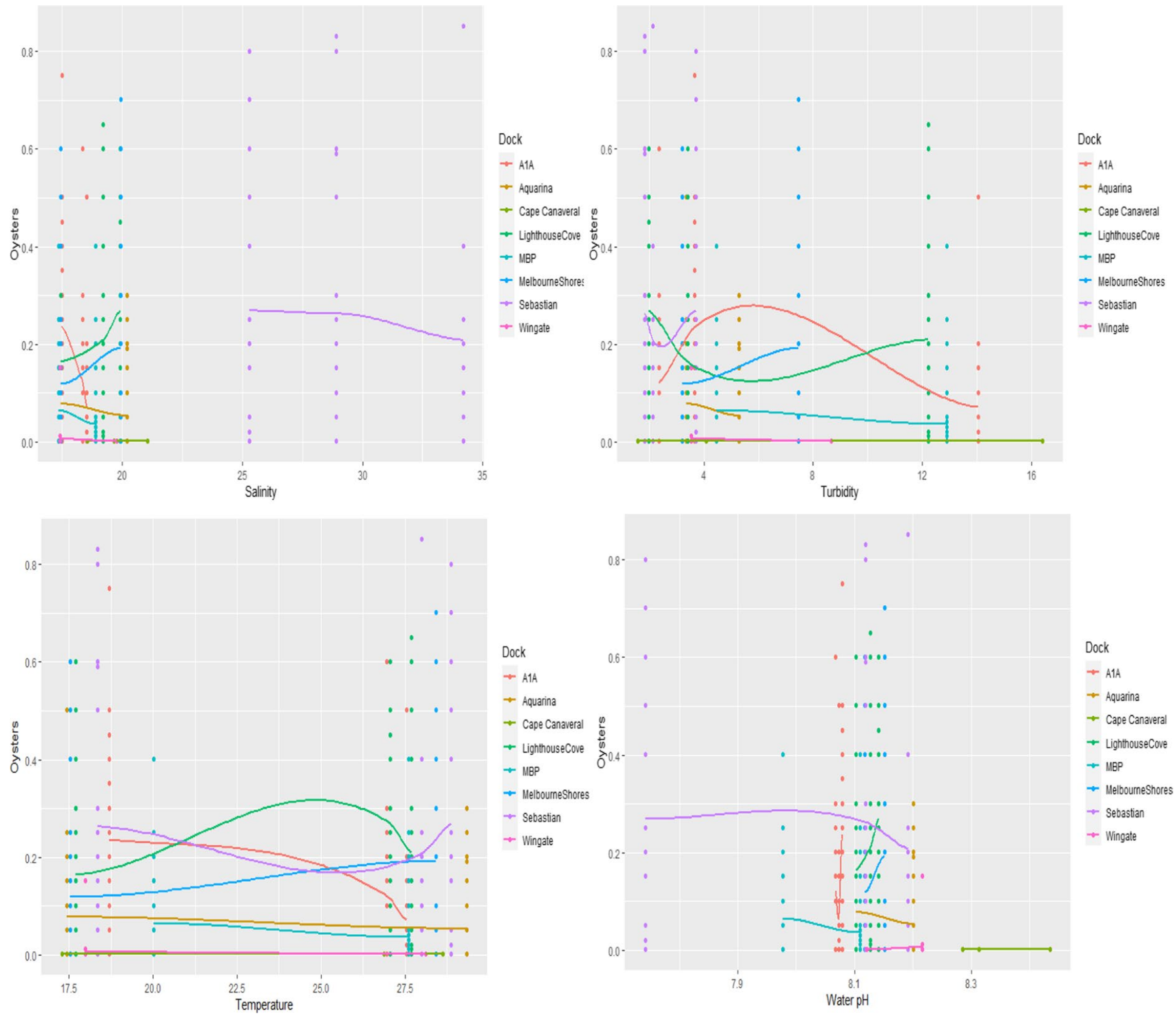

Fig. 17 Oyster growth among docks in relation to environmental factors

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Data Availability The data that support the findings of this study are not openly available and are available from the authors upon reasonable request.

Declarations

Conflict of Interest The authors declare no competing interests.

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