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Impact of Seawall Type on Mollusc Size and Diversity in South Water Caye Belize: A Case Study

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Impact of Seawall Type on Mollusc Size and Diversity in South Water Caye Belize: A Case Study

Introduction

It is estimated that approximately 70% of the world's population live on or near coastlines and this number is continuing to increase. (Bulleri et al. 2005) As the urbanization of coastal areas increases, the impact of humans on these fragile ecosystems has become more severe. In order to protect infrastructure from waves and erosion, various types of protective seawalls have been built and these walls have become increasingly more common due to the rise in sea levels and increase in frequency of storms. (Lai et al. 2018) Currently, in parts of Japan, Europe, Australia, and the United States more than half the coastline has been replaced by artificial structures. (Browne and Chapman 2011) Artificial structures include breakwaters, pontoons, jetties, pier pilings, and man-made sea walls. (Bulleri and Chapman 2004) However, simply building these structures with materials that are similar to natural seawalls does not necessarily suffice in supporting the same marine ecosystems. The topography, patterns of water flow, and turbulence, among other factors, may vary among natural and artificial substances. (Bulleri and Chapman 2004) Therefore, it is important to investigate the differences between artificial and natural surfaces to understand the extent to which these artificial substitutes act as suitable replacements for natural walls.

Minimal research has been conducted regarding the effects of building artificial seawalls in comparison to natural, particularly in the tropical rocky intertidal. (Lai et al. 2018) While not extensive, some research has been conducted in the temperate rocky intertidal and has shown that the intrinsic features of the wall surface impacts which species will dominate each wall type. (Bulleri et al. 2005) In addition, the level of wave exposure and the patterns of water transport play a major role in the assemblages in these areas. (Menge and Lubchenco 1981; Ravinesh and Bijukumar 2013) Thus, in temperate environments, the wall surface itself plays a critical role, but other factors need to be considered as well. In addition, while artificial sea walls in temperate rocky intertidal zones have been examined, minimal research has been conducted in the tropical rocky intertidal. (Lai et al. 2018)

In tropical environments, rocky intertidal shores are far less common than in the temperate latitudes. Tropical coastlines are more commonly lined with mangroves forests, beaches or mudflats. Although the rocky intertidal environment is less common in the topical latitudes, it does provide a solid substrate for a large range of marine organisms including various species of molluscs, barnacles, anthozoans, crabs, and microalgae. (Sibaja-Cordero and Cortez 2008) These animals are often endemic to the tropical rocky intertidal and therefore these habitats can be important sites for biodiversity. The tropical rocky intertidal varies greatly from the temperate in that sessile species are generally more uncommon and inter-individual contact is rare and typically only takes place only in crevices. Additionally, the assemblages most abundant in the temperate environment are scarce in the tropical rocky intertidal. For example, while mussel species may dominate the landscape in the temperate environment, they tend to be much smaller in the tropical intertidal and are usually only found in crevices. (Menge and Lubchenco 1981) Therefore seawalls in the tropical environment could potentially provide protection to smaller organisms if holes and crevices are created throughout the walls. (Menge and Lubchenco 1981) The differences between temperate and tropical rocky intertidal environments make it difficult to assume that the results of studies conducted in the temperate environment will translate to the tropical environment, which furthers the argument that there is a demand for research to be done in tropical areas.

Among the few studies done on natural assemblages in the tropical rocky intertidal, Williams (1994) noted that the structure of the community in these areas is impacted by a variety of factors including seasonal weather changes, the removal or addition of certain species, and the amount of shade or exposure. Williams found that predation is a more dominant factor in community structure on physically benign shores and competition is more important on shores with harsher conditions. (Williams 1994) However, in the summer with its more extreme conditions, both consumers and prey tend to be stressed. In contrast, moderately exposed shores are specifically structured by herbivory, especially algae. Under less severe conditions or when herbivores are removed, sessile species and algae seem to dominate. (Williams 1994) It is unknown how the community structure differs on artificial or natural seawalls in the tropical rocky intertidal. With the increasing number of artificial seawalls in many marine habitats, it is important to directly compare these habitats to investigate the effects of manmade seawalls on the ecosystem.

This paper presents an initial survey of three different types of man-made seawalls comparing them to the natural rocky intertidal on the coast of South Water Caye, Belize. The goal of this research was to investigate the number, size, and diversity of mollusc species present on each wall in order to conclude whether one type of artificial wall provides an assemblage of organisms that more closely mirrors those on a natural seawall. Taking into account the limited amount of time spent on the island and the limited resources, the long-term purpose of this research was to set a baseline to observe the diversity changes over time on the various types of seawall.

Materials and Methods:

Location and Types of Seawall: This study was conducted on South Water Caye, Belize (16.8152° N, 88.0818° W), a 6.0-ha (15-acre) island located about 32 km (20 mi) SW of Dangriga and 1.6 km (1 mi) north of the Smithsonian's Caribbean Coral Reef Ecosystems research facility on Carrie Bow Caye (16.8°N, 88.1°W). All data were collected March 10-17, 2019 on the northwest side of the island, where there is one long seawall composed of three different types of materials, as well as one, single natural rocky intertidal area. These were the only seawalls, natural and artificial, on this island at the time of the study.

The types of seawall (Figure 1) include a vertical concrete wall (Type 1), a slanted wall composed of rocks and chunks of concrete placed in front of a concrete wall (Type 2), a vertical wall of smooth stones cemented together (Type 3), and the natural rocky wall (Type 4). Given the different materials in each of these walls, each had different wave exposure relative to their location and height. Wall 4 was the most submerged and the furthest from the sandy beach. The other walls transitioned from one to the next as they were each positioned along the same, long seawall. Of these three, wall 2 had the most gradual incline from the base submerged in water to the top of the wall. Wall 1 and 3 were both almost completely vertical with wall 1 being the smoothest. Each wall, including wall 4, was within walking distance of the others. Although the exact age of each artificial seawall is unknown, walls 1 and 2 have been present for more than 6 years while wall 3 is less than 2 years old.

Measuring Mollusc Characteristics: In order to determine if wall type impacted the size or number of molluscs that were found submerged in front of it, three transects were laid perpendicular to the walls for a distance of 60cm. Each transect was approximately 20 cm from the previous transect. Along each transect, the number of molluscs was recorded and the length of each mollusc was measured on their longest anterior-posterior axis. .

In addition to the transects placed sub-tidally in front of each wall type, a number of measurements were taken on the intertidal vertical portions of each wall. Researchers placed a 0.5m^2 grid (Fig 1) onto the wall and recorded the length of each mollusc within that grid. This process was repeated two more times for each wall type, for a total of three grids sampled on each wall type. In addition to the size data, the number and diversity of molluscs on each wall were also measured. For this process, the 0.5m^2 grid was placed on a different location on each wall type. Then all molluscs within the sampling grid were removed and identified to the species level when possible. Again, this process was repeated twice more for each wall type so that there were three separate samples taken for all wall types. The number of crevices within each 0.5m^2 grid was counted in order to quantify the structures of the different walls. The depths of the crevices were also measured and recorded. To better understand the overall diversity of mollusc on each wall, data for each wall type were pooled and then Species Richness, Species Evenness, the Shannon Diversity Index and the Jaccard's Index of similarity were calculated and compared. To determine if wall type had a significant effect on the number and size of molluscs present on and in front the wall an ANOVA was calculated followed by a Tukey's post hoc tests.

Results:

As can be seen in Figure 1, there are large structural differences between the types of seawall present at this location. Wall types 1 and 3 were almost completely vertical, while types 2 and 4 had sloped horizontal orientations. The materials used to create the walls also varied. Wall 1 was a simple concrete wall, while walls 2 and 3 were a mixture of concrete, natural rock, and coral skeleton. Wall 4 consisted only of natural rock and coral skeleton. This variation in construction material created a difference in the number and size of crevices that were available for molluscs to inhabit. Wall 1 had a much larger number of crevices available, but these crevices were very small in size (Table 2). Walls 2 and 4 had fewer crevices overall, but they had a similar number of and sizes of crevices. Although crevice width was not measured, general observations indicated that the width of crevices on Wall 1 were much smaller than all other wall types.

Molluscs in Front of the Walls: The size of the molluscs in relation to distance from the wall was recorded approximately 60 cm in front of each wall. For all wall types, mollusc size did not change based on the distance from the wall. However, there were some significant differences between wall types and the species found sub-tidally in front of the wall. The natural environment (wall type 4) had significantly larger molluscs in front of it (ANOVA ($F(3,195) = 42.22$, $p<0.01$), as the average size of mollusc on Wall 4 was 18.33 cm and the average on the other wall types ranged from 6.8-9.2cm in length. In addition, there was a significant effect of wall type on the number of molluscs found in front of each type of wall, with more molluscs found in front of the Type 1 concrete wall (ANOVA ($F (3,195) = 16.93$. $p<0.01$)). Wall 1 had an average of 97.5 molluscs in the sub-tidal area in front of it while the other walls had an average number of 19.5-44 molluscs in front of them.

Molluscs on the Walls: When examining the molluscs found on each wall, there were significant differences based on wall type. The first effect was seen in the size of mollusc on each wall type, with wall 3 hosting the largest average size and wall 1 the smallest (Fig. 2). All wall types were significantly different from one another (ANOVA ($F(3,344)= 43.35$, $p<0.01$) except for the intermediate (Type 2) and the natural (Type 4) wall, which contained molluscs of similar size (Figure 2). In addition to mollusc size, diversity of molluscs was significantly impacted by wall type. Species Richness was highest on wall 2 and lowest on wall 4. Species Evenness was found to be highest on the wall 3 and lowest on wall 1 (Figure 3). In contrast, the Shannon Diversity Index was highest for wall 1, indicating that the diversity of species on wall 1 was more evenly distributed. In order to compare the overall similarity of species on each wall type, Jaccard's Index was used and indicates that the natural wall (Type 4) is the least similar to all other wall types (Table 1). However, it also indicates that walls 1 and 3 were the most similar. When examining species that were endemic to a particular wall type, we found that wall 1 had one endemic species, and walls 2 and 4 had two endemic species (see Table 3). There were no species endemic to wall 3.

Discussion:

Each wall varied in terms of diversity. This could indicate that the structure of the walls directly impacts the diversity of the community on each wall. Species Richness (total number of different species) was highest on the artificial walls and lowest on the natural seawall. This indicates that the physical structure of the artificial sea walls is sufficient to host a number of mollusc species. When looking at the data more closely we see that Species Evenness (Figure 2) was lowest on Wall 1 and highest on Wall 3. This value indicates that although Wall 1 may have had slightly more species, these species were not distributed evenly across all species present. As can be seen in Table 3, two species (*Tectarius coronatus* and one of the unknown species) were present in very large numbers on wall 1. Both of these species are small in size and therefore more likely to be able to fit into the smaller crevices present on wall 1.

The Shannon diversity index gives us more insight into species abundance as it is a measure of diversity that accounts for both the evenness of species and the overall abundance in each location. As can be seen in Figure 2, the concrete wall (Type 1) had the highest Shannon Diversity Index and the natural wall (Type 4) had the lowest. These data indicate that the natural wall had fewer species overall and had a few dominant species rather than a diverse assemblage of different species, while the concrete wall had a larger number of species and also had a few that were dominant. Walls 2 and 3 had a more even distribution of species overall. According to Jaccard's Index, which is a measure of the similarity of species between different environments, the concrete (Type 1) and pseudo (Type 3) walls were the most similar, followed by the pseudo and intermediate (Type 2) walls. The natural wall (Type 4) was the least similar to the other walls.

It is not surprising that the natural wall was the most different in species assemblage as it had the shallower slope and was present for the longest period of time in the habitat. The shallow slope allows for more of the wall to be covered with water and therefore it will support species who need less air exposure. Walls 1-3 had a steeper slope and therefore are more likely to support species who can tolerate the increased desiccation and heat stress that comes from exposure to air. Wave exposure and patterns of wave transport have been found to affect the assemblages on sea walls. (Bulleri and Chapman 2004). In fact, tidal height has previously been suggested to be one of the primary factors leading to species zonation on walls. (Williams 1994) In this study, the wave exposure of the natural wall varied greatly from the other walls as the natural wall was the most submerged. This variation could have contributed to the natural wall having the lowest similarity to the other walls with the Jaccard's Index.

In addition to the importance of tidal height, Bulleri and Chapman (2004) found that intrinsic features of the wall surface lead to variability in their assemblages. Artificial seawalls of cement, similar to wall type 1 in this study, have fewer complex surfaces to which organisms may attach in comparison with the natural rocky intertidal. (Bulleri and Chapman 2004) Although wall type 1 had a large number of crevices, these were quite small in depth and all crevices were similar in shape and size. Thus, these crevices were able to support only a few dominant species. Wall types 2-4 had wider and deeper crevices of varying shapes and thus could support a different species in these different crevices. Browne and Chapman (2011) found that simply adding crevices to artificial sea walls temporarily enhanced the number of species in that area; however, over a longer time span sessile species claimed the added spaces, thus making the area unavailable to other species. In contrast, creating deeper crevices was more efficient in increasing the number of species long term. (Browne and Chapman 2011)

Although there did not appear to be a correlation between the distance from the wall and mollusc size, there were significant differences in the species and number of molluscs found in front of each wall. Generally, the natural wall had the largest molluscs in front of it and the concrete wall had the greatest number of molluscs. This demands further research to explore the effects of artificial surfaces on the marine ecosystem extending beyond the walls themselves.

Based on this case study, artificial seawalls appear to be able to host diverse assemblages of molluscs, although assemblages are different from those found on natural seawalls. The age of the seawall, in addition to is structure, could affect the species composition. In this study, wall type 3 was the newest of the artificial walls, and it differed the most from the natural seawall. The concrete wall, type 1, was the oldest artificial wall, but the structure of this wall seemed to have been the dominant factor in its assemblage diversity. Thus, structure and age of the wall need to be considered in more detail in future studies. We would predict that older walls with deeper crevices and a shallower slope would be more similar to natural sea walls in structure and therefore could host a more natural species assemblage. Another factor to consider would be the change in molluscan diversity during different season. Ravinesh and Bijukumar (2013) found higher diversity during the monsoon season but an unchanged richness during monsoon and post-monsoon seasons. The present study was conducted during the dry season in Belize and it is therefore important to repeat this work during the rainy season.

From the baseline data gathered in this study, it is clear that artificial seawalls can host a number of molluscan species. However, the molluscs species found on the walls differ based on the structure, slope, and age of the wall. Future research into each of these factors is needed to determine which components have the largest impact on molluscan diversity and which can be altered to create artificial walls that serve the dual functions of preventing erosion and preserving biodiversity. With the advent of climate change and concomitant rise in sea level, it is clear that more seawalls will be built in many tropical areas, but it may be possible to build these in a manner that has a smaller impact on natural biodiversity.

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Tables & Figures

Table 1

Jaccard's Index heat map showing similarity between wall types.

Wall Type	1	2	3	4
1	*	0.44	0.67	0.375
2		*	0.5	0.33
3			*	0.2
4				*

Table 2

Crevice size and number on each wall type

Wall Type	Average Number of Crevices	Average Crevice Depth (cm)
1	712.5	1.5
2	405	3
3	78	2
4	335	2

Table 3

Species found on each wall type. Species listed as A, B, and C were not able to be identified, but were clearly different from one another. (* indicates that those species are endemic to that wall type)

Wall type	*Nerita tessallata*	*Nerita versicolor*	*Nerita peloronta*	*Tectarius coronatus*	*Echinolitorina ziczac*	*A*	*B*	*Acanthina spp*	*C*	*Acanthopleura granulata*	*Dardanius fucosus*
1	6	2	3	31	2	16*	0	0	0	0	0
2	4	1	0	75	71	0	1*	4	1*	0	0
3	0	1	1	22	10	0	0	4	0	0	0
4	19	0	0	3	7	0	0	0	0	1*	1*

Figure 1

Seawalls examined in this study (1) concrete wall, (2) rocks and chunks of concrete placed in front of a concrete wall, (3) smooth stones held together with cement, and (4) natural rocky intertidal area. The 0.5m^2 grids used to delineate sampling sites can be seen in each image.

Figure 2

Average mollusc size on each type of seawall. Different letters denote significantly different sizes as determined by an ANOVA (F(3,344) = 43.353, p<0.01) with Tukey's-b post-hoc tests to compare individual means.

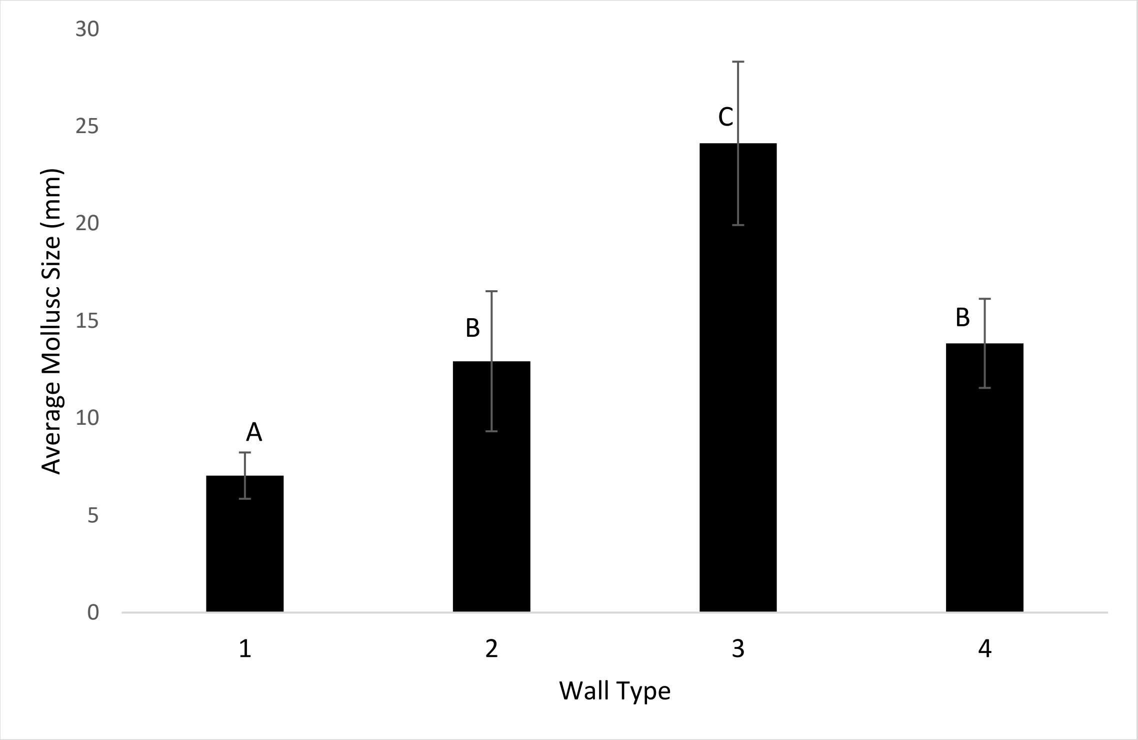
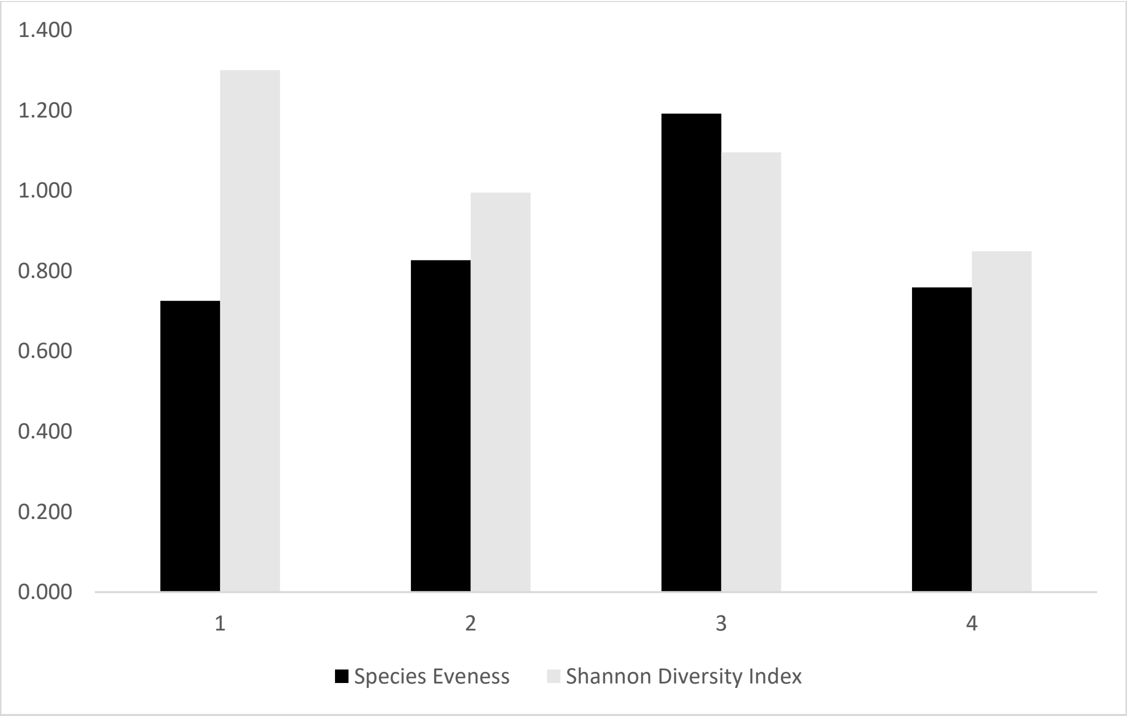


Figure 3

Species Richness (dark bars) and Shannon Diversity Index (light bars) calculations for each seawall type.



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