Belize Coastal Ecology Assessment

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Abstract

Over the course of two-weeks, George Mason University researchers assessed fish and encrusting organism community diversity within three key ecosystems in Belize: 1) coral reefs, 2) seagrass beds, and 3) mangroves. Additionally, encrusting community diversity was assessed between artificially placed habitats in the form of dock pilings and naturally occurring Red Mangrove prop roots. Diversity indices were calculated in order to determine if any links between level of development in surrounding area (i.e., low, intermediate, or high) and Marine Protected Area status could be identified. The objective of this study was to create a complete picture of the current state of Belizean coastal ecosystems, as the country is currently emerging as one of the world's top tourist destinations.

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Overview

1.1 Introduction

Coastal areas represent some of the most vulnerable ecosystems in the world as a result of continued urban development as demonstrated by 40% of the world population living within 100km of a coast (United Nations, n.d.). Historic civilizations, such as the Mayans approximately 2,500 years ago, settled coastal areas throughout Central America as a result of proximity to marine food resources (Claudino-Sales, 2019). While access to marine resources for food is still an important factor for coastal inhabitation, the present-day tourism industry provides substantial economic incentive to develop coastal areas (Diedrich, 2007). The development of these city-centers along coasts, particularly for tourism infrastructure (e.g., lodging, restaurants, and beach access), tend to increase the abundance of impervious surfaces. These surfaces then contribute to elevated levels of runoff into surrounding waters, a big problem for coastal areas with photosynthetic organisms dependent on oligotrophic (i.e., low nutrient) water (Arnold and Gibbons, 1996 and Victor et al., 2006).

In addition to the increase in impervious surfaces, as development continues, urban sprawl begins to encroach on and displace multi-functional habitats such as mangroves patches. Not only do these newly developed areas become covered with impermeable substrate, but the services previously provided by the mangroves such as shoreline stabilization, pollutant filtration, and wildlife habitat are also lost. Natural shoreline stabilization via mangrove roots is estimated to save coastal communities $3679 per hectare of shoreline per year in coastline stabilization against natural weather events (e.g., hurricanes), as well as natural erosion from tides and boat wake (Bosire et al., 2008). When these habitats are removed for development, coastal communities are left with a need for alternative tools to combat shoreline retreat, many solutions of which have demonstrated to provide sub-par protection when compared to natural mangrove habitat (Hochard et al., 2019). Beyond the protection provided to inland communities, mangroves also serve as protection to seaward communities by acting as a sink for inland pollutants such as chemicals, nutrients, and sediment transported over the land. Especially in regions lacking long shelfs, elevated sediment loads can cause major problems for nearshore ecosystems like seagrass beds and coral reefs as these communities depend on oligotrophic waters for energy production (i.e., photosynthesis) (Victor et al., 2006). Finally, mangrove patches provide habitat for terrestrial and marine wildlife, a function that would most certainly be lost for marine organisms, if not also some terrestrial groups, when converted to urban zones. Specifically, some reef fishes utilize the shelter offered by submerged prop roots as nursery habitat for juvenile fish that would otherwise be subject to higher levels of predation on the less protected reef (Mumby et al., 2009 and Dorenbosch et al., 2005).

While mangrove ecosystems receive the most direct destruction via urbanization, surrounding coastal ecosystems including seagrass beds and coral reefs also demonstrate the potential to be impacted. Unlike the mangrove trees that are able to persist following high sedimentation events due to the location of leaves (i.e., above the water), seagrass beds and corals grow entirely submerged and rely on high water clarity to absorb enough sunlight to photosynthesize (Victor et al., 2006). In instances where surface runoff transports high levels of nutrients (e.g., from surrounding farmland) instead of sediment, an indirect effect occurs wherein alga are prompted to bloom now that the previously limiting resource (i.e., nutrients) is in excess in the environment. These algal blooms have the potential to impact coastal ecosystems by growing as a surface film and blocking the light for seagrass and corals, or by generating harmful toxins released as they grow.

Both mangroves and seagrasses are important nursery habitats for fish species that recruit on to the reefs (Mumby et al., 2009). The reduction of mangroves via human development has the potential to harm the health of coral colonies, however, there is evidence that even dead coral structures may still provide habitat for fishes (Wilson et al., 2010 and Nelson et al., 2016). The combination of all of these factors create a complex and conflicting narrative for describing the effects of human development on coastal ecosystem health. In order to further explore this narrative, a group of George Mason University researchers conducted a case study to investigate the implications of recent coastal development on an otherwise healthy coastline in the Central American country of Belize. Establishing baseline measures of ecosystem health in this region is critical to quantify future change driven by anthropogenic-linked stressors, such as increases in water temperatures and pollution.

In Belize, nearly one-third of the gross domestic product is linked to activities surrounding the Belize Barrier Reef System, so maintaining the health of this ecosystem is extremely important (Cho, 2005). In an effort to conserve this unique ecosystem, 963 km^2 of World Heritage property was established spread across seven locations in various habitats including mangroves, seagrass beds, and coral reefs (Claudino-Sales, 2019). Conserving coastal ecosystems in Belize is important to maintain ecological function and ecosystem services.

Marine Protected Areas (MPAs) in Belize fall into two categories: no-take and multiple use. A no-take MPA exhibits more stringent regulation and does not allow the removal of any resource from the area, whereas a multiple use MPA can vary in stringency and allows for differing levels of fishing, recreation, tourism, and research (Cho, 2005). In Belize, two government organizations are charged with regulating MPAs, the Fisheries Department and the Forestry Department. If an area is designated a Marine Reserve, then the Fisheries Department governs activities and draws power from amendments to the Fisheries Act (Regulations of 1983 and 1988). If an area is designated as either a National Park, Wildlife Sanctuary, Natural Monument, or Nature Reserve, then the Forestry Department governs the activities and is granted power through the National Parks Systems Act. These protections were designed to guide the use of Belize's coastal resources to ensure the development of Belize's coastline follows a sustainable trajectory of growth. However, these government frameworks are not always regulated to their full extent, with many of Belize's protected areas being considered "paper parks" (Young et al., 2008 and Barcott, 2008).

While well-regulated no-take MPAs provide considerable protection to the reef ecosystem from extractive practices, frequently, these areas allow for recreational activities such as snorkeling and diving, which can still damage the reefs. High traffic of divers and snorkelers can cause permanent damage from intentional or unintentional touching or stepping on corals, as well as damage to reefs due to poor anchor placement (Farrel and Marion, 2001 and Diedrich et al.,

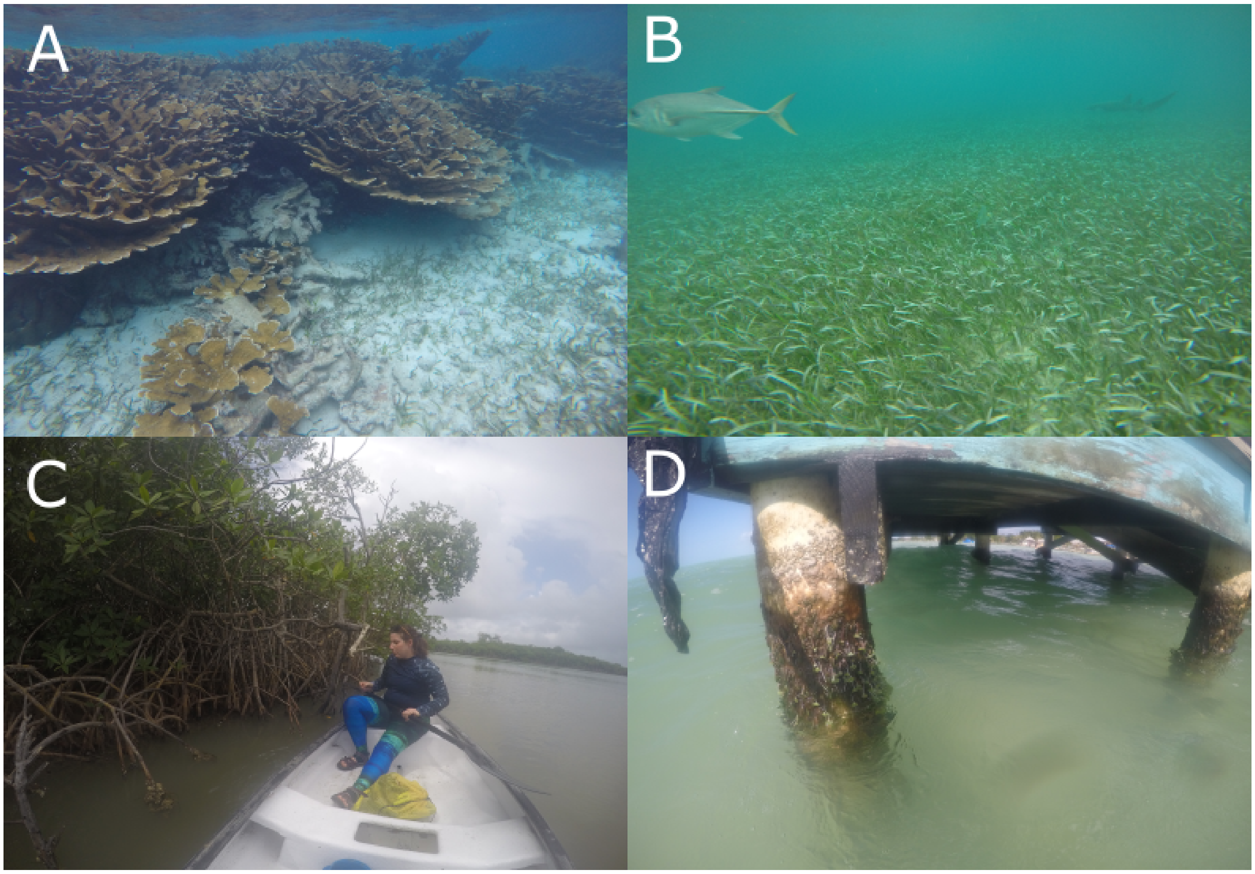

Figure 1.1: Examples of coral (A), seagrass bed (B), mangrove (C), and dock (D) survey locations.

2007).

The purpose of this research was to identify how development impacted three key tropical coastal habitats: coral reefs, seagrass beds, and mangrove fringes. Generally, ecosystems with high diversity are considered more resilient to environmental change, such as that associated with human development, therefore diversity was the primary proxy used to assess ecosystem health. Other factors were also considered at each location, including level of development and water quality. In order to evaluate the link between development and habitat health (i.e., diversity) three categories of development were defined: 1) high (i.e., "developed"), 2) intermediate, and 3) low (i.e., "pristine") development. The connection between factors were then evaluated using a hypothesis testing approach.

1.2 Study Locations

Data were collected from multiple sites throughout Belize, representing either coral, seagrass, mangrove, or artificial (i.e., dock) habitats (Figure 1.1) in high, intermediate, and low development areas (Figure 1.2 and 1.3). Additionally, three areas (i.e., Shark Ray Alley, Gale's Point, and Half Moon Caye) surveyed are under some form protection by the Belizean government. Two sites were categorized as "pristine", or low development areas, including Half Moon Caye Natural Monument (designated in 1982; Cho, 2005) and Long Caye (non-protected area). Only one site was categorized as exhibiting intermediate development, neither "pristine" or "developed", which was the Gale's Point Wildlife Sanctuary (protected area). The sites catego-

Table 1.1: Sampling locations with associated development level, protection status, protection type, and year established Information adopted from Cho (2005).

Name	Development Level	Protection	Protection Type, Year Established
Secret Beach	High / "Developed"	No	N/A
Coral Gardens	High / "Developed"	No	N/A
Shark Ray Alley	High / "Developed"	Yes	Hol Chan Marine Reserve, 1987*
Gale's Point	Intermediate	Yes	Gale's Point Wildlife Sanctuary, 1998*
Half Moon Caye	Low / "Pristine"	Yes	Half Moon Caye Natural Monument, 1982
Long Caye	Low / "Pristine"	No	N/A

rized as "developed", or high development areas, included Secret Beach in San Pedro (non-protected area), Coral Gardens offshore of San Pedro (non-protected area), and Shark Ray Alley (within Hol Chan Marine Reserve, designated in 1987; Cho, 2005) (Table 1.1).

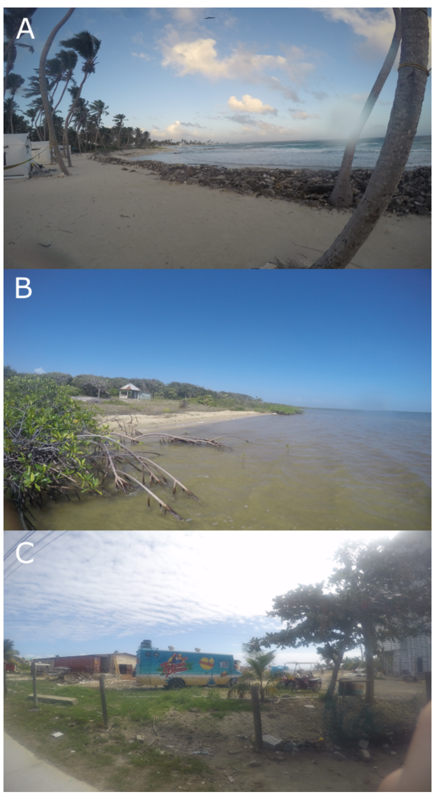

Figure 1.2: Examples of low (A, Half Moon Caye), intermediate (B, Gale's Point), and high (C, Ambergris Caye) development areas surveyed.

1.3 Research Areas

This study focused on three overarching areas of research, 1) fish community diversity, 2) epiphyte (i.e., encrusting flora and fauna that require host substrate to grow on) community diversity, and 3) habitat health of seagrass beds and coral reefs, in order to provide empirical data to describe the impacts of human development in Belize. The following chapters illustrate the findings within each research area, and contribute to the much needed coastal health baseline of Belize - a country rapidly transitioning from a fishing to a multi-million dollar tourism-based economy (Belize Tourism Board, 2018). Water quality parameters (i.e., temperature, salinity, pH, and chlorophyll a) were measured following established protocols (Appendix A) at all sampling locations in order to determine if there were differences between areas of different levels of development. We expected a significant difference between water quality parameters in areas of low, intermediate, and high levels of development.

$\mathbf{H_{01}}$: There is no difference between water quality parameters in areas of low, intermediate, and high levels of development.

$\mathbf{H_{A1}}$: There is a difference between water quality parameters in areas of low, intermediate, and levels of development.

We did not find a significant difference between water quality parameters in areas of low, intermediate, and high levels of development (Kruskal-Wallis, $P>0.01$).

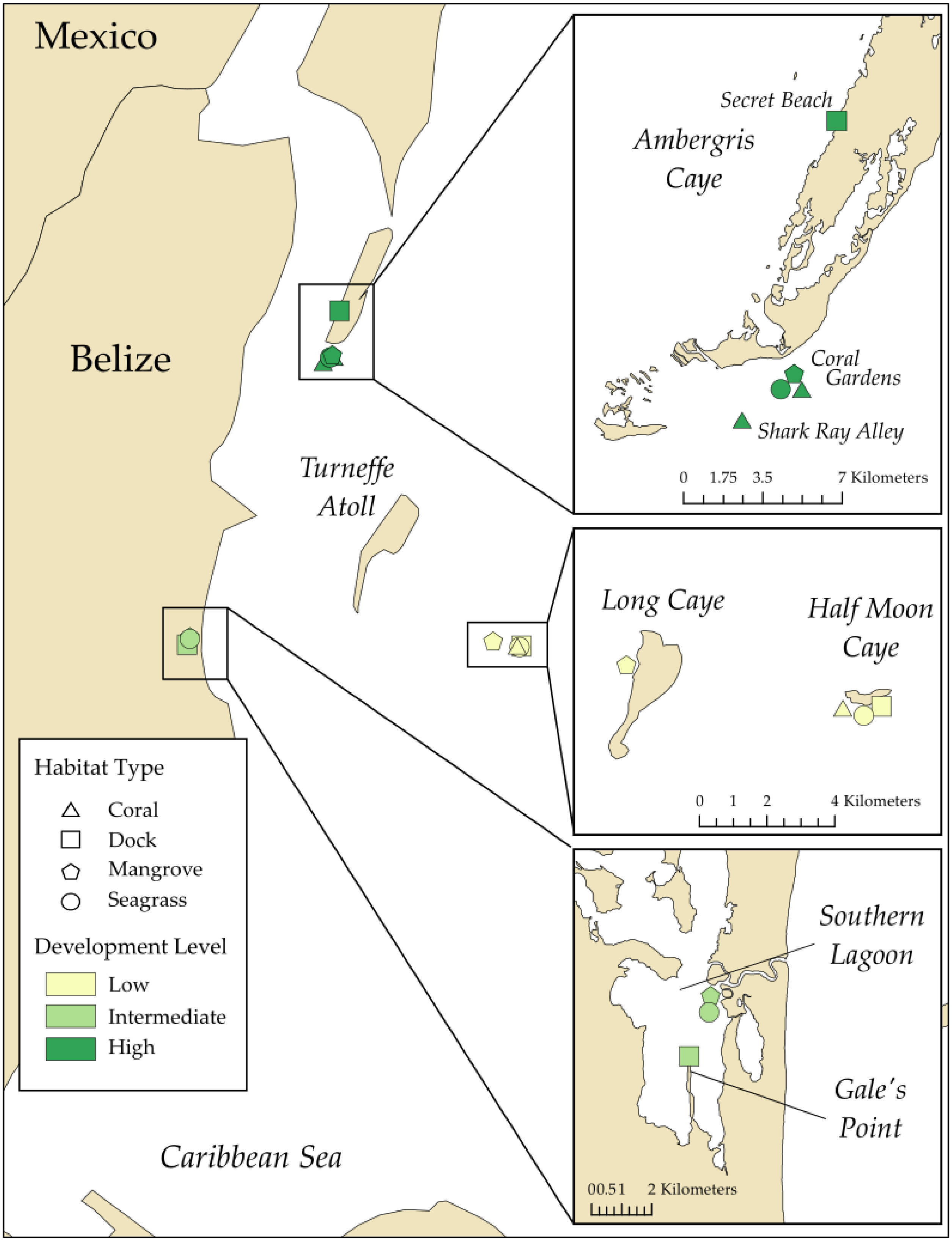

Figure 1.3: Locations of coral (triangle), dock (square), mangrove (pentagon), and seagrass (circle) habitat sampled across low (yellow), intermediate (light green), and high development (dark green) areas in coastal Belize.

Chapter 2

Fish Communities

Fish community composition, abundance, and biodiversity have the potential to be altered by human activities that place unnatural pressures on an environment (McClanahan et al., 2007, Roberts, 2001, and Bilkovic & Roggero, 2008). While MPAs are commonly linked to higher fish abundances, we wanted to know if the level of development and protection status impacted these communities in terms of composition, abundance and biodiversity.

Fish communities were assessed at three coral reef sites, Shark Ray Alley, Coral Gardens, and Half Moon Caye (Figure 1.3) in order to test differences in fish community composition, abundance, and biodiversity. Each site represented an ecosystem subject to one of three combinations of development and protection: high levels of development with added government protection at Shark Ray Alley, high levels of development with no government protection at Coral Gardens, or low levels of development with added government protection at Half Moon Caye.

Fish observations were completed at mangrove patches near Coral Gardens and on Long Caye (low development with no government protection), but were excluded from analysis due to visually unclear survey data that made fish taxa identification too low. Observations were also made in seagrass beds at Coral Gardens and Half Moon Caye, but were excluded due to lack of fish presence.

2.1 Fish Hypotheses

First we tested the fish abundance and biodiversity in the three sites. We expect that areas with close proximity to development would have lower abundance and biodiversity than pristine areas with lower development (Hypothesis One). These indicators would likely be higher in MPAs where fishing pressure is low comparatively to open access areas such as that of Coral Gardens.

$\mathbf{H_{01}}$**:** There will be no difference between fish abundance and diversity between the three sites (developed MPA, developed unprotected, and pristine MPA).

$\mathbf{H_{A1}}$**:** There will be higher fish abundance and diversity in the pristine environment of Half Moon Caye.

Next, we tested if there was a difference in fish community composition between the three sites. Fish spawning habitat can be impacted by shoreline development, which may lead to different community structure offshore (Sundblad & Bergstrom, 2014). Thus, we expected that there would be a difference in fish community composition between the three sites among the developed and pristine areas.

$\mathbf{H_{02}}$**:** There will be no difference in community composition between three sites (developed MPA, developed unprotected, and pristine MPA)

$\mathbf{H_{A2}}$**:** There will be a difference between the three sites in fish composition

2.2 Fish Methods

Four fish transects were conducted haphazardly, following established survey methods (Appendix B), along coral reefs at roughly 2-3 minute transects with one observer writing fish categories and one observer recording on video. This method is appropriate for estimating and comparing population densities and community compositions, but is less accurate when extrapolating to biomass because there is no spatial component (Halpern, 2004). Surveys were conducted swimming above the patch reef, but due to the shallow reef crests at Half Moon Caye and Shark Ray Alley, surveys were conducted at the reef-sand edge. Additionally, fish survey transects were conducted at seagrass beds at Half Moon Caye and Coral Gardens, following the same protocol used in the coral reefs (Appendix B). However, there were no fish counted at Coral Gardens and very few at Half Moon Caye, which made analysis not feasible. Surveys were also conducted along mangrove fringes near Coral Gardens and at Long Caye, following mangrove specific protocols (Appendix C), but video quality was too low due to high turbidity at Coral Gardens and therefore these locations were also excluded.

Videos were reviewed and all fish were tallied and identified in general taxa groups (Appendix D). Then, a PERMANOVA with SIMPER analysis was conducted to determine community composition and which taxa contributed to those differences the most. Then, Kruskal-Wallis was done on abundance and Shannon-Wiener Index values to determine if there was a difference in abundance of taxa or diversity at each of the sites.

2.3 Fish Results

There was a significant difference in community composition between the three sites, with wrasses, damselfish and grunts making up the majority of those differences (Figure 2.1). In post-hoc analysis, there was no difference between Coral Gardens and Shark Ray Alley community composition. However, there was no significant difference in the biodiversity between the three sites ($P>0.05$). Fish abundance was also different between the three sites with Half Moon Caye having a higher abundance of fish species (Figure 2.2).

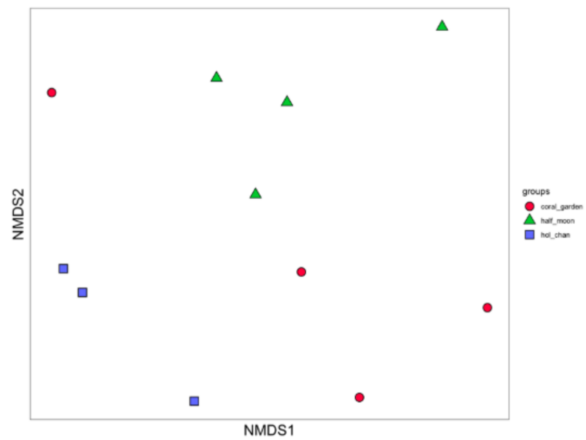

Figure 2.1: nMDS plot displaying a significant difference of fish community composition between the three sites ($P<0.01$).

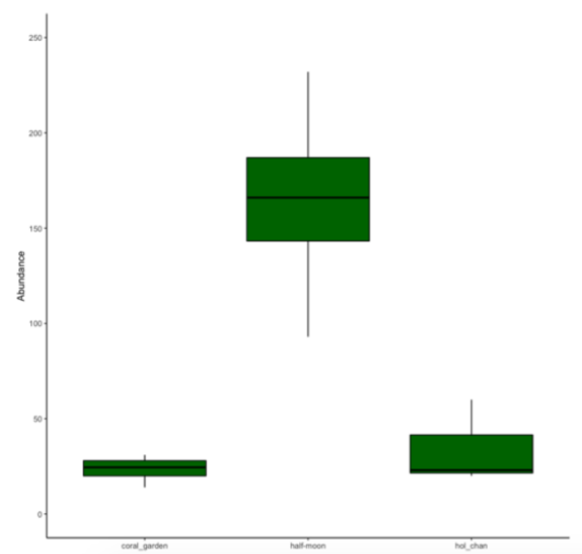

Figure 2.2: Boxplot of fish abundance within the three sites($P<0.05$).

Chapter 3

Epiphyte Communities

The mangrove areas assessed for this study focused on Red Mangrove trees (*Rhizophora mangle*), which are characterized by long prop roots that extend into marine waters (Figure 3.1). The roots of these trees provide numerous services for the surrounding ecosystem, including acting as shelter for fishes avoiding predation and a stabilizer for the shoreline. While these trees are equipped to survive development driven environmental changes such as increased flooding, sedimentation, and nutrient loading, the other organisms colonizing the mangrove prop roots may not be as well suited. Chapter 2 focused on impacts of development on the nektonic communities (i.e., fishes) in Belize, while this chapter focuses on the observed differences between the sessile species that colonize prop root habitat (e.g., Figure 3.2). First, epiphyte communities occurring on mangrove prop roots (i.e., natural substrate) were compared between locations categorized as either a low, intermediate, or high development level. Second, epiphyte communities occurring on natural substrate and dock pilings (i.e., artificial substrate) (Figure 3.3) were compared between locations categorized as either a low, intermediate, or high development level. Third, these data were combined so that epiphyte communities occurring on either natural or artificial substrate were compared, regardless of development level.

3.1 Epiphyte Hypotheses

First, we tested if there was a difference between epiphyte community composition on mangrove prop roots when compared between locations with low (i.e., Long Caye), intermediate (i.e., Gale's Point), and high (i.e., Coral Gardens) development levels (Hypothesis One), and if so, which species were most responsible for the observed differences.

$\mathbf{H_{01}}$**:** There is no difference in epiphyte community composition occurring on mangrove prop roots between areas of low, intermediate, and high development.

$\mathbf{H_{A1}}$**:** There is a difference in epiphyte community composition occurring on mangrove prop roots between areas of low, intermediate, and high development.

We expected areas with higher levels of development to have different epiphyte communities occurring on the prop roots than that of lower development areas, as these areas likely experienced harsher living conditions such as greater influxes of nutrients or sediments from surface runoff. These harsher living conditions could then limit the types of organisms able to persist in each location. Alga species are generally considered more tolerant of poorer water conditions than organisms such as sponges, so we expected to see more alga than sponges in the high development area.

Second, we tested if there was a difference between epiphyte taxa richness (Hypothesis Two), as well as epiphyte taxa frequency of occurrence

Figure 3.1: Red mangrove prop roots extended into the water at Long Caye.

(Hypothesis Three), occurring on natural substrate (i.e., mangrove prop roots) as well as artificial substrate (i.e., dock pilings) at low (natural at Long Caye, artificial at Half Moon Caye), intermediate (both at Gales Point), and high (natural at Coral Gardens, artificial at Secret Beach) development levels. In our study, frequency of occurrence was defined by the number of times a taxa group occurred at least once on a prop root or piling in a specific development category.

H_{02}: There is no difference between epiphyte taxa richness occurring on natural and artificial substrates between areas of low, intermediate, and high development.

H_{A2}: There is a difference between epiphyte taxa richness occurring on natural and artificial substrates between areas of low, intermediate, and high development.

H_{03}: There is no difference between epiphyte taxa frequency of occurrence observed on natural and artificial substrates between areas of low, intermediate, and high development.

H_{A3}: There is a difference between epiphyte taxa frequency of occurrence observed on natural and artificial substrates between areas of low, intermediate, and high development.

Finally, we tested if there was a difference between epiphyte taxa abundance (Hypothesis Four), as well as epiphyte taxa richness (Hypothesis Five), occurring between natural and artificial substrates across the development gradient (i.e., all sites combined).

H_{04}: There is no difference between epiphyte taxa abundance occurring on natural and artificial substrates.

H_{A4}: There is a difference between epiphyte taxa abundance occurring on natural and artificial substrates.

H_{05}: There is no difference between epiphyte taxa richness on natural and artificial substrates.

H_{A5}: There is a difference between epiphyte taxa richness on natural and artificial substrates.

Figure 3.2: Epiphyte community on artificial substrate (i.e., dock piling) at Half Moon Caye.

3.2 Epiphyte Methods

Prop roots along mangrove patch edges were surveyed at locations characterized by either low (Long Caye, n=17), intermediate (Gale's Point, n=15), or high (Ambergris Caye, n=18) development. GoPro video cameras recorded prop root communities from the base of the root to the high tide line, while surveyors either snorkeled beside the prop roots (low and high development sites) or viewed the roots from a canoe (intermediate development site). Videos were reviewed and epiphyte organisms were identified to general taxa groups.

Dock pilings were also surveyed at locations characterized by either low (Half Moon Caye, n=10), intermediate (Gale's Point, n=15), or high (Secret Beach, n=16) development. The same protocols used to assess epiphyte communities on mangrove prop roots were followed to assess epiphyte communities on dock pilings.

A PERMANOVA was conducted to determine if there was a difference between the taxa present in epiphyte communities on mangrove prop roots between development levels (Hypothesis One), followed by a SIMPER analysis to determine which species contributed most to the differences. Additionally, two Kruskal-Wallis tests were conducted to determine if there was a difference between epiphyte taxa richness (Hypothesis Two), as well as epiphyte taxa frequency of occurrence (Hypothesis Three), observed on nat-

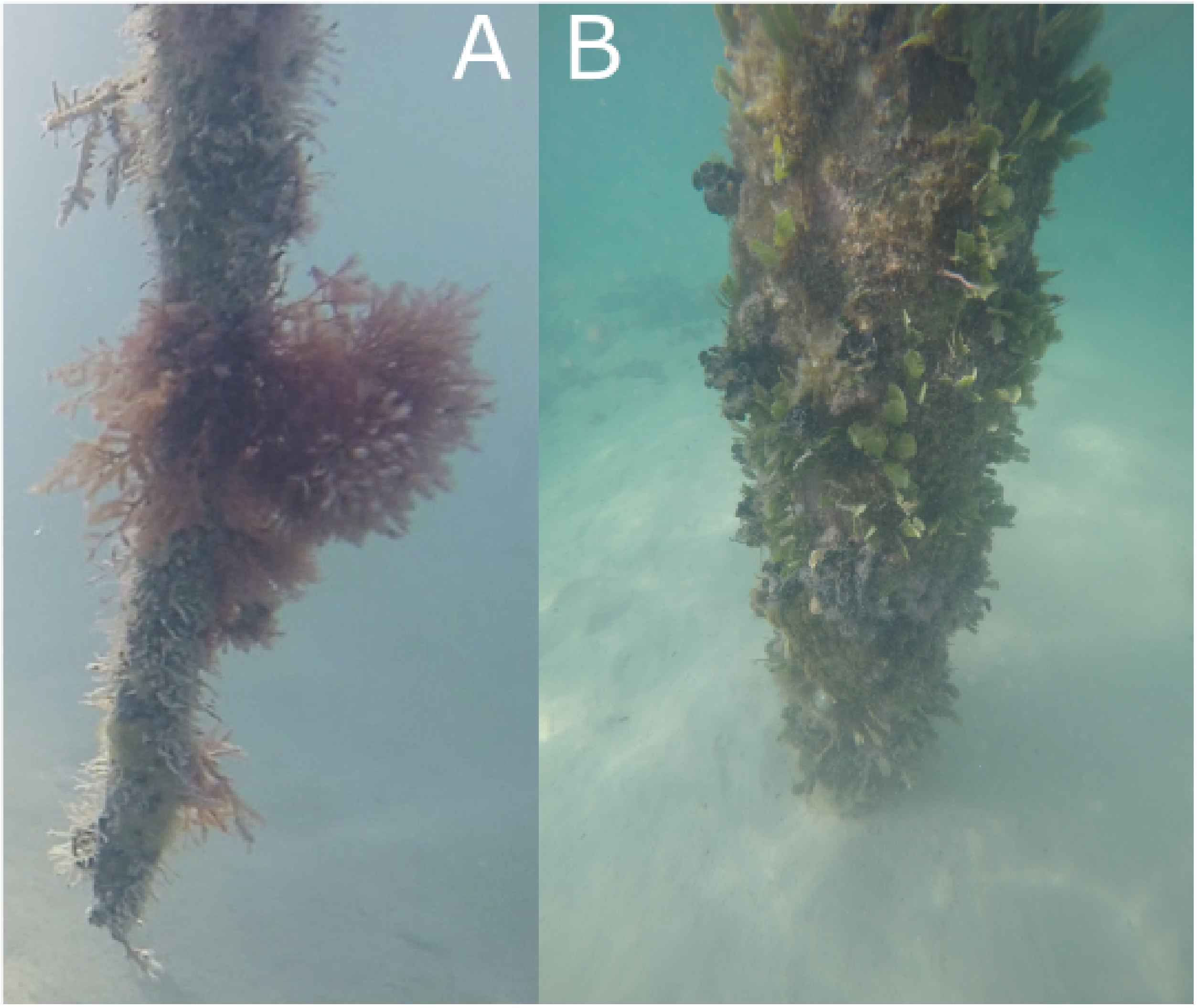

Figure 3.3: Examples of natural (A, Coral Gardens) and artificial (B, Half Moon Caye) substrates observed for epiphyte community surveys.

ural and artificial substrates between areas of low, intermediate, and high development. Finally, two Wilcoxon-Mann-Whiteny tests were conducted to determine if there was a difference between epiphyte taxa abundance (Hypothesis Four), as well as taxa richness (Hypothesis Five), growing on natural and artificial substrates.

3.3 Epiphyte Results

The PERMANOVA determined that there was a significant difference between total epiphyte community composition on prop roots across the development gradient (*Pseudo-F*=18.21, *P*=0.001), therefore we rejected our null hypothesis (H_{01}). The SIMPER analysis determined that the top five organisms contributing to the most differences between the three areas were barnacles big white, oysters, brown algae mat short, yellow-brown mystery sponge, and snails. The data were well-fit for display on a 2-D plot as observed in Figure 3.4, which illustrates that samples from the same development level were typically more similar to other samples from that

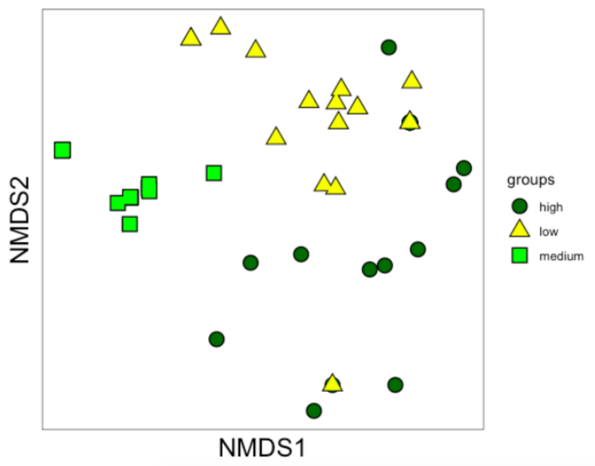

Figure 3.4: nMDS plot displaying a significant difference between epiphyte community composition across the development gradient (P<0.01).

same level, than samples observed at other development levels.

The two Kruskal-Wallis tests compared epiphyte taxa richness and frequency of occurrence observed on natural and artificial substrates, and both tests indicated that there were significant differences between locations (P<0.05; P<0.05), therefore we rejected both null hypotheses (H_{02} and H_{03}) for these groups in favor of our alternative hypotheses (H_{A2} and H_{A3}).

When comparing epiphyte taxa abundance, the Wilcoxon-Mann-Whitney test determined that there was no significant difference between taxa abundances occurring on natural and artificial substrate across the development gradient (P>0.01), therefore we failed to reject our null hypothesis (H_{04}). However, when comparing epiphyte taxa richness the second Wilcoxon-Mann-Whitney test determined that there was a significant difference between taxa richness occurring on natural and artificial substrate across the development gradient (P<0.01), therefore we rejected our null hypothesis (H_{05}) in favor of our alternative hypothesis (H_{A5}). Throughout the development gradient, artificial substrate supported the greatest number of different epiphyte taxa (Figure 3.5).

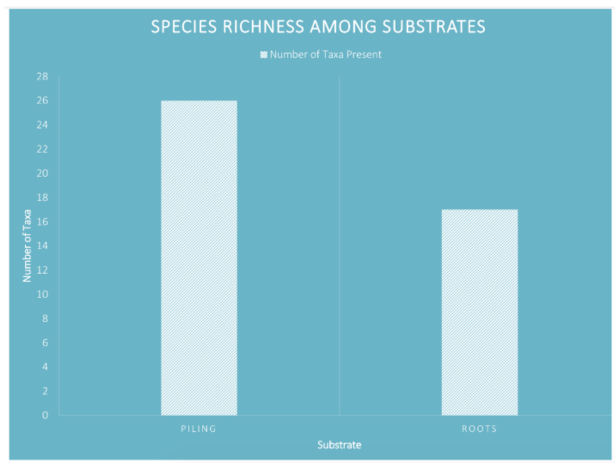

Figure 3.5: Total epiphyte taxa richness observed across all development levels (low, intermediate, and high) between artificial and natural substrates.

Chapter 4

Habitat Health

Conservation professionals widely acknowledge that habitat loss is one of the most influential drivers of species decline globally. Habitat loss can occur when an area is physically altered and converted from one type of landscape into another, but it can also occur when environmental factors force a habitat to be less suitable for the inhabitants living there. Global changes in climate are often referenced as causing range shifts in species, as the changes make previous habitat less suitable while making new habitat more optimal. This chapter of the study aimed to establish a baseline for seagrass bed and coral reef habitat health across low, intermediate, and high development level areas in Belize.

4.1 Habitat Hypotheses

In order to test if development impacted coral cover, coral health, and seagrasses between developed and pristine environments, habitat surveys were conducted. First, we tested the difference between live coral in the three sites (Hypothesis One).

$\mathbf{H_{01}}$**:** There is no difference in the percentage of living coral observed between areas within an MPA, outside an MPA, and pristine.

$\mathbf{H_{A1}}$**:** There is a significant difference of percent living coral observed between areas within an MPA, outside an MPA, and pristine.

We expected live coral cover to be highest in the pristine environment because there would be less runoff from the developed lands that could harm coral health.

Next, to assess coral health, we tested the difference in ratio of dead to live coral between the three sites. We expect that there would be a lower ratio of dead to live coral in the pristine sites because of the potential limited human impact to the area (Hypothesis Two).

$\mathbf{H_{02}}$**:** There will be no difference in the ratio of percent coverage of dead to alive coral between areas within an MPA, outside an MPA, and pristine.

$\mathbf{H_{A2}}$**:** The ratio of percent coverage of dead to alive coral at urban sites will be higher than the ratio at pristine sites.

Finally, we had hoped to test if there was a difference in seagrass coverage between areas of low, intermediate, and high development, but due to low visibility in the intermediate location and time limitations post-processing the quantitative sea grass bed analysis was excluded from the study. Instead, qualitative results are presented.

4.2 Habitat Methods

After each fish community transect was completed (Chapter 2), habitat health was assessed following established snorkeling transect survey protocols (Appendix B). Each survey was conducted by two researchers who haphazardly placed a 1-meter quadrat over the habitat of interest, either a coral reef or seagrass bed, along a 30-meter transect, photographing the transect each time it was aligned over the targeted habitat using a GoPro camera (e.g., Figure 4.1). Six

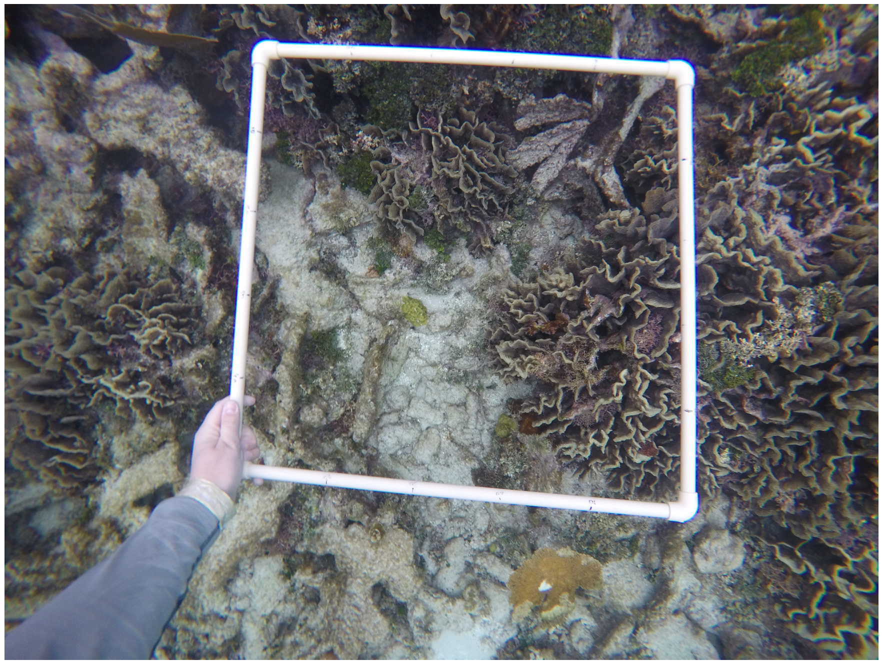

Figure 4.1: Coral reef transect at Shark Ray Alley within Hol Chan Marine Reserve.

quadrats were taken over the same 2-3 minute transect as the fish surveys in Shark Ray Alley, Coral Gardens, and Half Moon Caye (Figure 1.3). Seagrass transects were also attempted at Gales Point, however, high turbidity made it difficult to see or photograph quadrats so these data were not included in analysis. The photos were reviewed by two analysts to determine percent coverage of live, dead, bleached coral, or bare rock. A Kruskal-Wallis test was then conducted to analyze the difference between the sites.

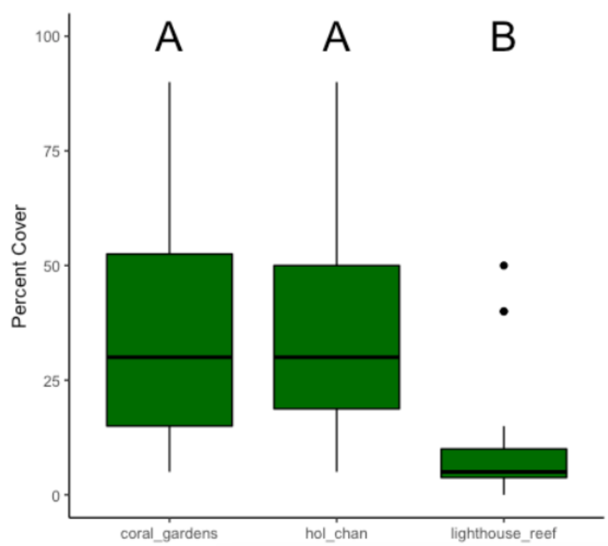

Figure 4.2: Distribution of percent living coral coverage observed within an MPA in a highly urbanized area, outside an MPA in a highly urbanized area, and inside an MPA in a low urbanization area with significant differences observed between locations labeled A and B.

4.3 Habitat Results

There was a significant difference between the percent of living coral observed between the three sites surveyed, with the pristine area of Half Moon Caye having the lowest percent of live coral ($P<0.05$) (Figure 4.2). Similarly, there was a significant difference between the ratio of dead to living coral at pristine and urban sites, with Half Moon Caye having the highest ratio ($P<0.05$).

Seagrass was present across all three devel-

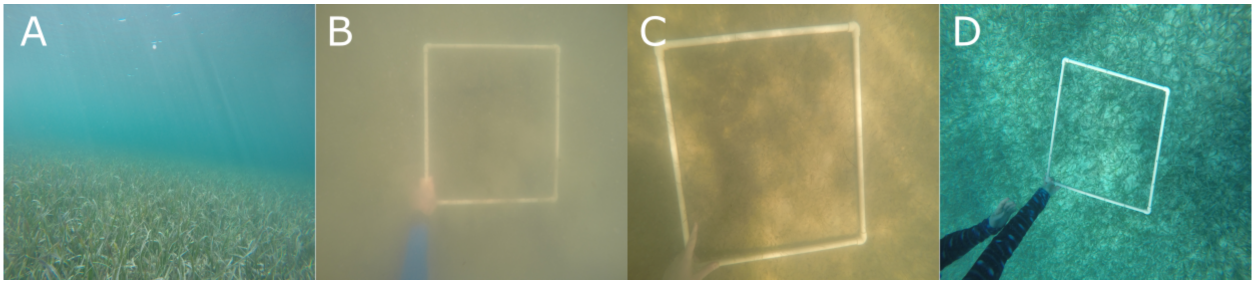

Figure 4.3: Seagrass habitats between low (A, Half Moon Caye), intermediate (B - minimum visibility, C - maximum visibility, Gale's Point), and high (D, Coral Gardens) development areas.

opment levels, with similarly high densities at the lowest and highest development areas - Half Moon Caye and Coral Gardens, respectively. The lowest density of seagrass was observed off Gale's Point in Southern Lagoon, an area known to host a large population of West Indian Manatees (*Trichechus manatus*) subspecies, the endangered Antillian (Caribbean) manatee (*T. m. manatus*). In addition to differences in quantity between sites, Half Moon Caye and Coral Gardens were dominated by thick leafed turtlegrass (*Thalassia testudinum*), while Gale's Point was dominated by thinner leafed manatee grass (*Syringodium filiforme*) with some possible shoal grass (*Halodule wrightii*). Visibility at Gale's Point was noticeably lower than visibility at either Half Moon Caye or Coral Gardens (Figure 4.3).

Chapter 5

Discussion and Conclusion

5.1 Discussion

Amongst the three research areas, fish communities, epiphyte communities, and habitat health, the proximity to development yielded various impacts. Surprisingly, results associated with the "pristine" habitat (i.e., Half Moon Caye) that was subjected to the lowest development and received government protection, did not consistently reveal indicators of "better" health. For example, although Half Moon Caye had the highest fish abundance, it also had the lowest percentage of live coral. Cox et al. (2017) found that MPAs alone do not restore coral cover and fish communities. One explanation is the proximity to shore and shallow water could result in snorkelers or shore divers stepping directly on corals or kicking them while observing. Both Coral Gardens and Shark Ray Alley were deeper, so perhaps less prone to sediment redistribution via kicking from snorkelers. Additionally, shallower water at Half Moon Caye allows for greater wave exposure, which has been found to significantly impact reef habitat and fish assemblages (Friedlander et al., 2003). Wave exposure may explain reduced coral health, but our fish abundance results are inconsistent with impacts of reduced fish abundance. Additionally, one review study explained that some MPAs had less coral cover and more macroalgae than heavily fished areas and that those areas tend to have high fish biomass (Pawlik et al., 2016). However, the relationship of macroalgae cover and fish biomass seems to be driven by fish excretion adding additional nutrients into the coral reef area (Burkepile et al., 2013).

Size of marine protected areas may also make a difference to fish abundance and community structure (Halpern, 2003). Size may be limited by nearby development, and therefore becomes a function of development, when there are competing interests to use the resources. Highly developed areas may opt for smaller MPAs, while areas surrounded by less development would have the space available for larger MPAs. Hol Chan, where Shark Ray Alley is located, is 4.2km^2, while Half Moon Caye is 39.2km^2, so the size difference between the two MPA sites may have also influenced the differences in fish abundance (Cox et al., 2017). In the future, controlling for MPA size, reef complexity, and depth may better reflect the differences in coral cover and fish communities, biodiversity and abundance. Fish communities were different between the three sites, but Coral Gardens and Shark Ray Alley were not significantly different (i.e., the two locations off of Ambergris Caye). One reason these sites did not differ may be because of the close proximity to one another. Additionally, the Hol Chan reserve, where Shark Ray Alley is located, has been established since 1982, which may have allowed for spillover of recovered fish species into non-marine reserve areas nearby.

While the fish communities demonstrated the potential to utilize multiple locations, as indicated by similarly comprised communities across locations, epiphyte communities demonstrated stark differences in composition between development areas (Figure 3.4). Certain epiphytic communities, such as photosynthetic or filter-feeding organisms, are known to thrive within specific environmental conditions wherein ample light and food is available, but clogging particles such as sand are minimized (Diaz and Rutzler, 2009). These organisms act as bioindicators for the general health of the surrounding system. This study found that filter feeding organisms such as sponges dominated in the low development mangrove fringe, which further supports this concept.

Our data supports the conclusion that the presence of development in the area surrounding a mangrove patch is associated with epiphyte community composition on prop roots. While there is a difference between communities at each site, environmental variables between sites did not vary (i.e., temperature, salinity, pH, and chlorophyll a) suggesting that other factors that were not measured may be driving the differences. In this study, the organisms contributing most to the differences in community composition between high and low levels of development (i.e., excluding intermediate development) were the yellow-brown mystery sponge, the brown algae mat short, and snails. Sponges rely on waters low in suspended sediments, as they are filter feeders and rely on pores to remain unclogged. Alternatively, algae taxa do not filter feed and can exist in highly turbid waters, as long as there is sufficient light penetrating for photosynthesis to occur. Various algal taxa were observed at all locations, further supporting that these organisms can persist in an array Due to Mechanical errors with the total suspended solids (TSS) reader, we did not record consistent readings for this measure. An increase in TSS is commonly associated with higher levels of development, as these areas frequently have more runoff from the increased amount of impervious surfaces in the surrounding landscape. In the future, TSS should be measured to determine if this parameter does vary between sites and correlates with differences in community composition. Overall, the results of this study indicated that pristine environments have a greater presence of sensitive epiphytic organisms, which suggests that development may be contributing to the lack of sensitive species in the more developed environments. Even though impacts of development may not be singularly evident based on other results in our study, epiphyte communities may be the first indication of problems in the environment, as they lack the capability to migrate to a more suitable habitat.

In the future, mangrove-specific creature guides may aid in the identification of organisms colonizing mangrove prop roots better than the reef creature guides utilized by this study. The lower the identifiable taxonomic unit reached, the greater potential researchers will have to identify if the organisms driving differences in diversity are also associated with ore or less "healthy" environments.

5.2 Conclusion

There are upcoming coastal challenges with the increase of tourism in Belize, between deforestation of mangroves, wastewater treatment, and visitation load on MPAs. However, with tourism being an over $500 million industry and rising (Belize Tourism Board, 2018), Belize will likely continue to pursue development of coastal areas to attract more tourists. It is possible to protect tourism industry interests while also supporting legal infrastructure to protect ecosystem services through sustainable development practices (Olsen, 2003).

In an emerging economy, it is important to evaluate and assess environmental resources in order to understand how development may impact those resources. Our analysis suggests that development is starting to impact the coastal environment of Belize. The results provide baseline information regarding the status of three key research areas; epiphytic organisms, habitat health, and fish communities. Belize is known for progressive environmental policies, and it has an opportunity to continue that legacy by recognizing impacts of development to coastal habitats and implementing best management practices in the future to prevent further degradation.

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Chapter 6

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Appendices

.1 Appendix A

Protocol: Water Quality

Introduction In situ measurements of physical parameters give a fast and comparable overview of the water quality of a water body. The data can be used on its own, or used to help explain other observations and collections made at the same time. It is good practice to include recording the physical parameters of the aquatic environment where any of our other sampling takes place.

Equipment: Fluorometer, Pen YSI

Procedure Insert the PEN YSI in the water until the line indicated and read the Temperature, pH, Salinity, and TDS (Total Dissolved Solids), and record readings in notebook Insert the Fluorometers in the water until the line indicated and read the Chl a in mg/L record reading in notebook

Notes The readings of temperature, pH and salinity can be used to determine if the measurements fall within the tolerance range of organisms of interest (e.g. fishes, corals). Measurements of TDS and Chl a give direct information on the amount of dissolved solids and phytoplankton in the water column respectively, but also indirect information on the amount of light that can penetrate to e.g. seagrasses or corals below it, and the level of anthropogenic impacts such as influx of sediment into the marine environment (increased TDS) or influx of nutrient to the marine environment (increased Chl a). Comparisons with other studies in similar regions can put readings into context.

.2 Appendix B

Protocol: Fish and Habitat Transects

Introduction This protocol is a visual survey of the organisms present in a specific aquatic habitat (Fish, invertebrates, corals, seagrasses). Following the protocol will allow for a quantitative survey of what species are present with what prevalence and what size. Each transect will be repeated three times, so that we have surveyed each habitat in triplicate.

Like scuba diving, snorkeling should be done using a buddy system. Keep an eye on the well-being of your buddy and stay together. All procedures will be performed in pairs of two. Let your buddy and your instructors know if you need a rest (cold, tired, leg cramp, etc.). If you are not finished with the protocol one of the instructors can take your place.

In addition to observing and recording in the field, video recordings and pictures will be taken. Use the video information to augment and improve the field recordings. Each team reviews the video/pictures they took. A picture of a slate with site and date information before each transect will facilitate remembering where what footage was taken when all materials get saved on computers in the afternoon. The afternoons and evenings will be used to analyze the videos and pictures. Same day processing is best to not let the material pile up and to have the transect fresh in your memory.

Equipment Snorkel gear
30-meter measuring tape
10-20 transect flags
Floating buoy with line and weight
Writing Slates plus pencils (2)
Go-Pro Camera (2)
ID pocket guides
Quadrat
2 short lines with weights

Procedure Choose the area of your first transect and do a 15-minute reconnaissance snorkel. Determine what the dominant types of fishes and organisms (including corals, seagrasses, macroinvertebrates) are and ID them using your pocket guides or the full guide back on the boat or shore. Determine what size categories of fishes would be appropriate for this survey (for example 2 categories, one larger than slate, one smaller than slate). Determine if individual fishes can be counted or if abundance categories need to be established, and choose appropriate ones if so. Practice what a 2.5 meter distance is using measuring tape.

Prepare one slate by writing the (more or less) five most dominant fishes as rows and the size categories as columns. Leave room to write in additional species (or descriptions)

Prepare one slate by writing the (more or less) five most dominant corals/habitat types, with nr 1-10 as columns. Leave room to write in additional species (or descriptions)

The first team of snorkelers sets the transect. They bring the measuring tape, the floating buoy with line and weight, and 10-20 transect flags.

Team 1: stake one the end of the measuring tape in the ground with a flag, then roll out 30 meters of measuring tape staking in a red flag every 3 meters until 10 flags are planted. At the end of the 30 meters, the floating buoy will be anchored with the line and weight. The measuring tape can be collected and removed.

Team 2: waits 10 minutes for fish to settle back.

The first swimmer of team 2 holds the slate and pencil and watch, and records start time. Then swims slowly at constant swimming speed over the flags that indicate the transect towards the floating buoy. Along the way, record all fishes and their size category and abundance seen along the transect within a distance of 2.5 meters from the transect (so 2.5 meters to the left and to the right, making your transect belt 5x30 meters). Record end time when finished.

The second swimmer of team 2 follows the first swimmer closely and films the transect with a go-pro camera.

Team 3: attaches the two lines with weights on opposite corners of the quadrat. the quadrat will be placed on the bottom near each flag (the quadrat can hover the length of the lines above the bottom in high relief areas)

One member of team 3 will record the percent cover of habitat type (coral species, seagrass, sand, etc.) within the quadrat.

The second member of team 3 will take a photo of the quadrat (right above it) with a go-pro camera

Repeat this at every flag until 10 quadrats are recorded and photographed. The photographer can take additional photo close-ups to help ID the coral species, or to provide additional information by photographing macroinvertebrates or relief of the coral.

Team 3 timing note: the first quadrat can be done right after team 1 is finished setting the first flag. The second quadrat can be done after team 2 has passed the second flag.

Team 1 picks up the flags and buoy from the field behind team 3.

Repeat this transect in the same general area two more times, so that we have triplicate transects in each habitat. Rotate team roles with each transect (team 1 becomes team 3, team 2 becomes team 1 and team 3 becomes team 2). You can switch roles within a team as well.

Transfer information from the slates to the notebooks

Review video recordings and photos in the evenings and use the video information to augment and improve the field recordings. Each team reviews the video/pictures they took. A picture of a slate with site and date information before each transect will facilitate remembering where what footage was taken.

.3 Appendix C

Protocol: Mangrove Fringe

Introduction This exercise measures fish and invertebrate communities associated with mangrove prop roots. These roots create a structurally complex habitat and provide refugia from predators for fish and hard substrate for invertebrates.

Equipment Snorkel gear, buoys/lines/weights, tape measure, slates, Go-Pros, ID pocket guides, YSI.

Procedure 1- Locate a continuous mangrove area where the mangrove plants extend to the shoreline. The shoreline should be snorkeling depth.

2- Inventory fish species, fish size categories (range, morphological differences) and invertebrate morphospecies (filamentous algae, green fleshy algae, red sponge, white encrusting tunicate, blue tunicate, white anemone, etc) on the proproots. Describe and photograph. Note start-stop time.

3- Select 3 x 30m survey sites along mangrove fringe, 1m away from roots. Measure water quality.

Team 1, fish survey: take video and count individuals per species. Count individuals per size category (¡10cm, ¿30cm). Note start-stop time.

Teams 2 and 3, invertebrate survey: approximately every other meter, closest root: take picture, measure

Follow up. Evaluate footage, input data, and journaling.

.4 Appendix D

Table 1: Fish taxa observed in coral reef assessment.

Name
Angelfish
Bass
Blenny
Butterflyfish
Chromis
Chub
Damselfish
Gobie
Grouper
Grunt
Hamlet
Hog
Jack
Sharks
Parrotfish
Snapper
Squirrelfish
Surgeonfish
Trigger
Wrasse