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Assessment of Coral Health and Fish diversity in the Fringing Reefs of Porvenir Island and Korbisky Island, Guna Yala, Panama

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ABSTRACT

Coral reefs are the most diverse and productive ecosystems on Earth, serving as important habitats to millions of organisms; however, they are disappearing at alarming rates. The major influences causing their decline are the combined effects of global climate change and increased industrialization, urbanization, and agriculture. Previous studies have correlated high coral coverage with high fish diversity; therefore, as coral reefs disappear, so too does fish diversity. This study assesses the health of the fringe reefs of Porvenir Island and Korbisky Island in Guna Yala, Panama by recording the live coral, bleached coral, diseased coral, and algae cover of each reef and recording all fish species seen within 1m to the right of the transect. Ten 15x1m belt transects were taken at the Porvenir fringe reef and set 5m apart and parallel to the shoreline, and five 15x1m belt transects were taken at the Korbisky fringe reef. There is significantly more live coral coverage in the Porvenir reef than the Korbisky reef ($p=0.0213$, $df=223$, $t=-2.04$); however, the Korbisky reef is more diverse (Korbisky reef: $H=2.212$; Porvenir reef: $H=2.060$). Additionally, there is no difference in the diseased coral coverage and bleached coral coverage between the two reefs (Bleached: $p=0.398$, $df=223$, $t=+0.26$; Diseased: $p=0.0924$, $df=223$, $t=+1.33$). Based on these results, we can conclude that live coral cover, diseased coral cover, and bleached coral cover do not play a role in fish diversity because the Porvenir fringe reef has more live coral coverage, but less fish diversity than the Korbisky fringe reef.

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INTRODUCTION

Location of Study

Panama (7,550,000 ha) is a narrow country in southern Central America that connects North America and South America and separates the Pacific Ocean from the Caribbean Sea. It is bordered by Costa Rica on the west and Colombia on the east. The southern side of the country, located along the Pacific Ocean, is often more dry than the northern, Caribbean side of the country. The Pacific waters are also more productive, nutrient-rich, deep, and cool than the Caribbean Sea (Leigh et al. 2014). As a consequence, fewer coral reefs are found on the Pacific side of the country. Additionally, since Panama is located in the tropics, it does not experience four distinctive seasons; instead, there is a dry (December-May) and wet (June-November) season. Data collection for this study took place in early-mid November on the Caribbean coast in Guna Yala during an El Niño event. During an El Niño event there is less than normal rainfall (Windsor 1990).

Guna Yala (320, 600 ha), previously known as San Blas, is located along the northeast coast of Panama along the Caribbean Sea and borders Colombia (Guzman et al. 2003). It is one of five comarcas (reserves) in Panama, meaning that is an autonomous territory run by the indigenous people of the area, the Guna. The Guna lived in the forests of Panama and Colombia for centuries, but began to inhabit the Caribbean coast and islands in the mid-1800s. Since then they have been heavily dependent on the marine resources of the area—fish, corals, and invertebrates (Guzman et al. 2003). The comarca was established in 1938 and allowed the Guna to independently govern their territory outside the laws of the Panamanian government (Guzman et al. 2003).

In addition to the mainland, Guna Yala also consists of 365 islands surrounded by coral reefs, and the coast is fringed by mangrove forests and seagrass beds (Guzman et al. 2003). The coral reefs are very important to the Guna. They have practiced coral mining for decades and use them (genus *Acropora*, *Siderastrea*, and *Diploria*) to create a solid, structurally sound base for their homes. However, the reefs in Guna Yala are well preserved as a result of the rules that protect, conserve, and support sustainable development of natural resources (Rivera et al. 2012). They contain the greatest diversity of coral species and are considered the best developed reefs in Panama (Guzman et al. 2003; Rivera et al. 2012). Porvenir Island, located about a 30 minute boat ride east of the mainland, was the location of this study. It is surrounded by coral reefs and has an anchorage site on the leeward side of the island. A small hotel and airstrip are located on the island. Korbisky Island is smaller than Porvenir Island and also inhabited by people.

What are coral reefs?

Coral reefs are the most diverse and productive ecosystems on Earth, serving as important habitats to millions of organisms, even though they only cover 1% of the world (Knowlton 2001; Mumby and Steneck 2008). They are from the phylum Cnidaria and class Anthozoa; however, they can further be classified as either hard corals or soft corals (octocorals). Hard corals have a hard, internal calcium carbonate skeleton, whereas soft corals do not. Both hard and soft corals are living structures (animals) composed of the coral polyp and intracellular photosynthetic microalgae, zooxanthellae. The symbiotic relationship between the polyp and zooxanthellae is extremely important. The zooxanthellae provide the coral with nutrients to grow and the coral provides the zooxanthellae with shelter and nutrients. However, corals can also capture their own food (microorganisms) with their stinging tentacles. Most corals are a yellow-brown color and this coloration is from the zooxanthellae. Some corals, though, have special pigments within them to protect them from the sun's UV rays and the pigments range in color from blue to purple to pink, which explains the bright colors of some corals (Alieva et al. 2008).

Coral reefs are very delicate ecosystems that require specific growing conditions. They are found between 30°N-30°S mainly in Southeast Asia around Indonesia and the Philippines, around Australia, and in the Caribbean Sea. They occupy shallow, tropical and subtropical waters ranging from 25-29°C (Towle et al. 2015). The zooxanthellae require these conditions so they receive adequate sunlight for photosynthesis. Temperatures above 29°C create unfavorable growing conditions for the coral.

The importance of coral reefs

The ecosystem services that coral reefs provide are innumerable and crucial. They are nurseries for many fish species (Nagelkerken et al. 2000), buffer shorelines from wave energy and prevent erosion and flooding, are habitats for animals and plants that could potentially be used to synthesize cures for cancer, Alzheimer's, and arthritis, and support local economies through tourism. Reef fish use at least 93 species of coral for shelter, favoring *Acropora* and *Porities*. Some species use just a single coral species as refuge; however, the majority use more than 20 different species (Coker et al. 2014). Corals, especially branching ones, are highly occupied due to the micro-habitats they create with their branches and crevices. Corals also contain numerous invertebrates that are used in modern medicine. For example, a cancer therapy drug is synthesized from algae, the anti-cancer agent Ara-C is developed from sponge extract, and a product known as Dolostatin 10, isolated from sea hare from the Indian Ocean, is under clinical trials for use in breast and liver cancer, tumors, and leukemia treatments (Bruckner 2002). The chance of finding a new drug from marine ecosystems, especially among coral reefs, is 300 to 400 times more likely than developing one from a terrestrial ecosystem (Bruckner 2002).

The reefs also save communities from spending hundreds of thousands of dollars a year for the services they provide and help local communities make money. They absorb wave energy and either break the wave or slow the wave down due to friction, thus protecting the coast from flooding (van Zanten et al. 2014). According to van Zanten et al. (2014), the coastal protection value of coral reefs in the US Virgin Islands is about $1.2 million dollars a year. De Groot et al. (2012) compiled data from over 300 studies and concluded that coral reefs are the most economically important biome in the world. Their value per hectare per year is about $350,000 and the most economically important service of reefs is tourism which brings in about $96,300 per hectare per year. Heavily visited reefs though, can make up to $1 million a year per hectare (de Groot et al. 2012). Additionally, reefs provide the world with many edible resources, such as lobsters, crabs, fish, and octopus. Coral reefs support a quarter of all small-scale fisheries globally, including about 6 million fishermen, and millions more rely on them for food (Graham 2014). As observed, coral reefs are extremely necessary biomes that harbor millions of species, protect the coast from wave energy and erosion, and provide the world with numerous resources; therefore, it's important to monitor their health.

Coral Reefs and Biodiversity

Many reef fish are indicator species, representing the overall health of the coral reef. For example, a direct result of decreases in coral cover is loss of biodiversity (Mumby and Steneck 2008; Wilkinson 2008; Pratchett et al. 2011). Mumby and Steneck (2008) found that loss of habitat complexity led to an increase in foraging efficiency of predators, which decreased the density of small-bodied fish. Similarly, Wilson et al. (2006) concluded, through a meta-analysis of 17 independent studies, that 62% of fish species decline in abundance after a reef loses at least 10% of its live coral cover. The most impacted fish are corallivores—organisms that rely on live coral tissue for food (Pratchett et al. 2011). In the Great Barrier Reef, Pratchett et al. (2006) altered coral cover by reducing coverage by 16-36% and found that the decline in fish diversity was 1.8-2.3 times the proportion of coral loss. However, the coral-fish relationship is a two way street.

Coral reef fish can also impact the health of corals (Magdaong et al. 2014). Magdaong et al. (2014) discovered that coral cover increased in the Philippines between 1981 and 2010 and attributed this success to a decrease in fishing and the initiation of reef protection and marine protected areas. Destructive fishing practices have negative trophic cascading effects. When just one species is overharvested, the entire ecosystem becomes unbalanced. For instance, when a coral reef grazer like the parrotfishs' (Scaridae) populations decrease, the macroalgae, which they graze on, begin to proliferate and compete with the coral for sunlight. If the macroalgae outcompete the corals, a phase shift occurs and the reef changes from a coral dominant to algae dominant ecosystem (Steneck et al. 2014).

Fish, though, are not the only organisms affected by decreases in healthy coral cover. Invertebrate diversity also is reduced as live coral cover decreases due to habitat loss (Idjadi and Edmunds 2006). Idjadi and Edmunds (2006) concluded that reefs with high coral diversity provide a greater variety of habitats and refuges for invertebrates compared to reefs with low coral diversity.

Threats to coral reefs

Unfortunately, coral reefs are disappearing globally at alarming rates—approximately 19% of the original area of global coral reefs has disappeared and 20% are under threat of loss in 20–40 years (Wilkinson 2008). The cause of such rapid degradation is the combined effects of global climate change and increased industrialization, urbanization, and agriculture (Mumby and Steneck 2008; Pratchett et al. 2011). Many consequences arise from these physical stressors such as coral bleaching, the spread of coral diseases, and massive colony deaths; these all lead to decreased species richness within the reefs (Kaczmarsky et al. 2005; Mumby and Steneck 2008; Wilkinson 2008). In the past 27 years, coral cover has decreased by 50% in the Great Barrier Reef, Australia and more than 50% in the Caribbean (Sale and Hixon 2015). Along the coast of Panama, coral cover has been reduced as much as 70% in several areas (Guzman 2003). Therefore, it is imperative to study and analyze the factors that are endangering coral reefs and the numerous species that rely on these ecosystems in order to save and preserve such rich environments.

Global climate change is rapidly affecting coral reefs worldwide. As atmospheric CO_2 and other greenhouse gas (GHG) levels rise, even the most protected coral reefs will not be able to avoid rising water temperatures and ocean acidification (Sale and Hixon 2015). Increased water temperatures ($\geq$30°C) causes the coral polyp to stress and expel the zooxanthellae. If the zooxanthellae are not present, the corals lose their main nutrient supply/food source, and the corals eventually die. The expulsion of the zooxanthellae is known as coral bleaching because when the algae leave, the coral loses its color. Ocean acidification occurs when atmospheric CO_2 and GHG levels rise and the ocean acts as a carbon sink, absorbing excess CO_2 from the atmosphere. This absorption of CO_2 decreases the amount of free floating carbonate ions in the water, which corals require to construct their calcium carbonate skeleton, and decreases ocean pH—hence acidification. Increasing ocean acidity decreases coral skeleton density, slows coral growth/calcification, and forces corals to spend more energy and resources on growing rather than reproduction (Hoegh-Guldberg et al. 2007). Lastly, stronger and more frequent storms are a growing side-effect of global climate change. These storms not only physically damage coral reefs, but also cause changes in salinity and turbidity within the coral reef ecosystems. Stronger storms can break branching coral colonies due to increased wind speeds and wave energy. The waves also stir up the sediment in reefs, leading to increased turbidity. High rainfall leads to increased runoff which adds freshwater to the shallow marine waters that corals inhabit, decreasing salinity and increasing nutrient levels (Harmelin-Vivien 1994). Additionally, after a cyclone passes through a reef, algal dominance can occur, which creates unfavorable conditions for coral growth and physically damages reefs due to increased wave energy and action (Harmelin-Vivien 1994).

In addition to GHG emissions, elevated nutrient inputs—phosphorus and nitrogen—cause rapid algal growth which lead to harmful algal blooms that cause eutrophication. These blooms increase turbidity and sea surface temperatures, both of which reduce coral growth (D'Angelo and Wiedenmann 2014). Therefore, it is important to regulate fertilizer use near the coast and prevent the dumping of raw sewage into oceans.

Coral diseases

Increased human presence along shorelines leads to more pollution, nutrients, and sediments entering the surrounding aquatic environments. All of these factors negatively affect coral reefs, which are very fragile ecosystems (Pratchett et al. 2011). Not only do they decrease the water quality for coral reefs, but they also stimulate the creation and spread of coral diseases. Kaczmarsky et al. (2005) stated that coral diseases are often assumed to be caused by direct or indirect anthropogenic stresses, such as increased nutrient levels, pollution, and sedimentation (Parks 2002, Bruno et al. 2003). In the Caribbean Sea, coral diseases are on the rise due to greater physical human contact, dredging, ship-strikes, sediment loading, and toxic exposures to soluble pollutants (Goreau et al. 1998). The most common diseases found in the Caribbean include black band disease (BBD), white band disease (WBD), yellow band disease (YBD), dark spot syndrome (DSS), and aspergillosis (Goreau et al. 1998; Bruno et al. 2003).

The direct causes of coral diseases are largely unknown, but there have been many observations and correlations seen between nutrient enrichment, a direct anthropogenic impact, and coral diseases (Kaczmarsky et al. 2005). For example, BBD is caused by elevated water temperatures, runoff, sediments, toxins, and sewage (Parks 2002) and YBD and aspergillosis affect corals more severely when there is a significant increase in nutrients (Bruno et al. 2003). Additionally, WBD is caused by a bacteria that most likely comes from human activity, such as sewage dumping (Anonymous 2014). Even though DSS is not caused by nutrient enrichment, it is indirectly exacerbated by humans since it is caused by increased water temperatures, a consequence of global climate change (Borger 2005). However, excessive nutrient inputs and enrichment not only affect the corals, but also the organisms that rely on corals as a habitat or food source (Wilson et al. 2006, Mumby and Steneck 2008).

Helping coral reefs

Based on the above research, it is evident that more laws need to be created and enforced in order to manage anthropogenic activities that affect local coastal areas and coral reefs. These delicate ecosystems need to be protected for ecological, economic, aesthetic, and intrinsic reasons because when coral reefs are degraded due to human presence, the corals are not the only organisms impacted. Therefore, in order to protect coral reefs and the thousands of organisms that rely on these ecosystems, marine protected areas need to be established around coral reefs, water quality standards should be raised, the use of chemicals—pesticides, herbicides, insecticides, etc.—should not be allowed within a certain distance from coastal shorelines, and better waste management practices should be implemented and enforced.

RESEARCH QUESTION

What are the differences in live coral cover, coral disease cover, bleaching, and fish species diversity in the fringe reef of Korbisky Island and the fringe reef of Porvenir Island, Guna Yala?

Null Hypotheses:

1) There is no difference in live coral cover between the Korbisky Island fringe reef and the Porvenir Island fringe reef in Guna Yala.
2) There is no difference in coral disease cover between the Korbisky Island fringe reef and the Porvenir Island fringe reef in Guna Yala.
3) There is no difference in bleached coral cover between the Korbisky Island fringe reef and the Porvenir Island fringe reef in Guna Yala.
4) There is no difference in fish species diversity between the Korbisky Island fringe reef and the Porvenir Island fringe reef in Guna Yala.

Alternative Hypotheses:

1) There is a difference in live coral cover between the Korbisky Island fringe reef and the Porvenir Island fringe reef in Guna Yala.
2) There is a difference in coral disease cover between the Korbisky Island fringe reef and the Porvenir Island fringe reef in Guna Yala.
3) There is a difference in bleached coral cover between the Korbisky Island fringe reef and the Porvenir Island fringe reef in Guna Yala.
4) There is a difference in fish species diversity between the Korbisky Island fringe reef and the Porvenir Island fringe reef in Guna Yala.

JUSTIFICATION

Even though they cover a very small percentage of the earth (less than 1%), coral reefs are crucial habitats. They are extremely diverse and provide innumerable ecosystem services for the world—buffer shorelines from waves, provide habitat for spawning and nursery grounds, attract tourists from all over, and are a source of new medicine. Approximately a quarter of all aquatic species rely on coral reefs as a source of food and shelter. Consequently, coral reefs are important for economic, aesthetic, intrinsic, and ecological values. In addition, coral reefs are important to many local cultures. The Guna have relied on coral reefs for food and use corals for structural support for their homes. Sadly though, these vital environments are decreasing in abundance worldwide due to anthropogenic activities such as global climate change, overfishing, and coastal development. Therefore, studying the health of coral reefs is necessary and tracking the spread of coral diseases, which are exacerbated by pollution and nutrient input, is also important to monitor.

By measuring the coverage of live/healthy coral and comparing it to diseased and bleached coral, I can assess the health of a fringing reef around Porvenir Island and Korbisky Island, which haven't been analyzed. If a lot of bleaching is present, it would indicate that the water temperature has increased, creating thermal stress for the coral polyp. Additionally, if many diseases are found, it could be attributed to the local pollution from the hotel and nearby anchored boats, and perhaps encourage the hotel to dispose of their waste more carefully and monitoring of the anchored boats. This study is also important since it assesses the health of reefs that are visited biannually by the School for International Training Panama Program and could provide baseline data for a future Independent Study Projects which could show how the health has improved or decreased since this study.

METHODS AND MATERIALS

Fringe reef location selection

To select the Porvenir fringe reef site, a kayak was taken to the nearest leeward reef off of Porvenir Island, Guna Yala Comarca (UTM: 17 P, 0725444 m E, 1057122 m N). It was approximately 200m from the island's shore. Upon reaching the edge of the reef, a suitable sample area with high hard coral coverage, low soft coral coverage, and at a depth no deeper than 2 meters was found by the observer (Kaczmarsky et al. 2005). At the first appropriate site in the reef, a tape measurer was anchored to the bottom of the ocean floor and then the observer swam parallel to the island for 15 meters while laying out the tape measurer (Kaczmarsky et al. 2005, Raymundo et al. 2009, Seeman et al. 2014). Nine other 15 meter transects were laid out parallel to the first transect, each spaced 5 meters apart from each other.

The Korbisky fringe reef was located 1.89km from the first reef site to the southwest (UTM: 17 P, 0723899 m E, 1056141 m N). The site was chosen by the observer because it was the first reef encountered within kayaking distance that was long enough to be sampled. The reef was quite narrow and situated between two islands and received a strong breeze (Figure 1).

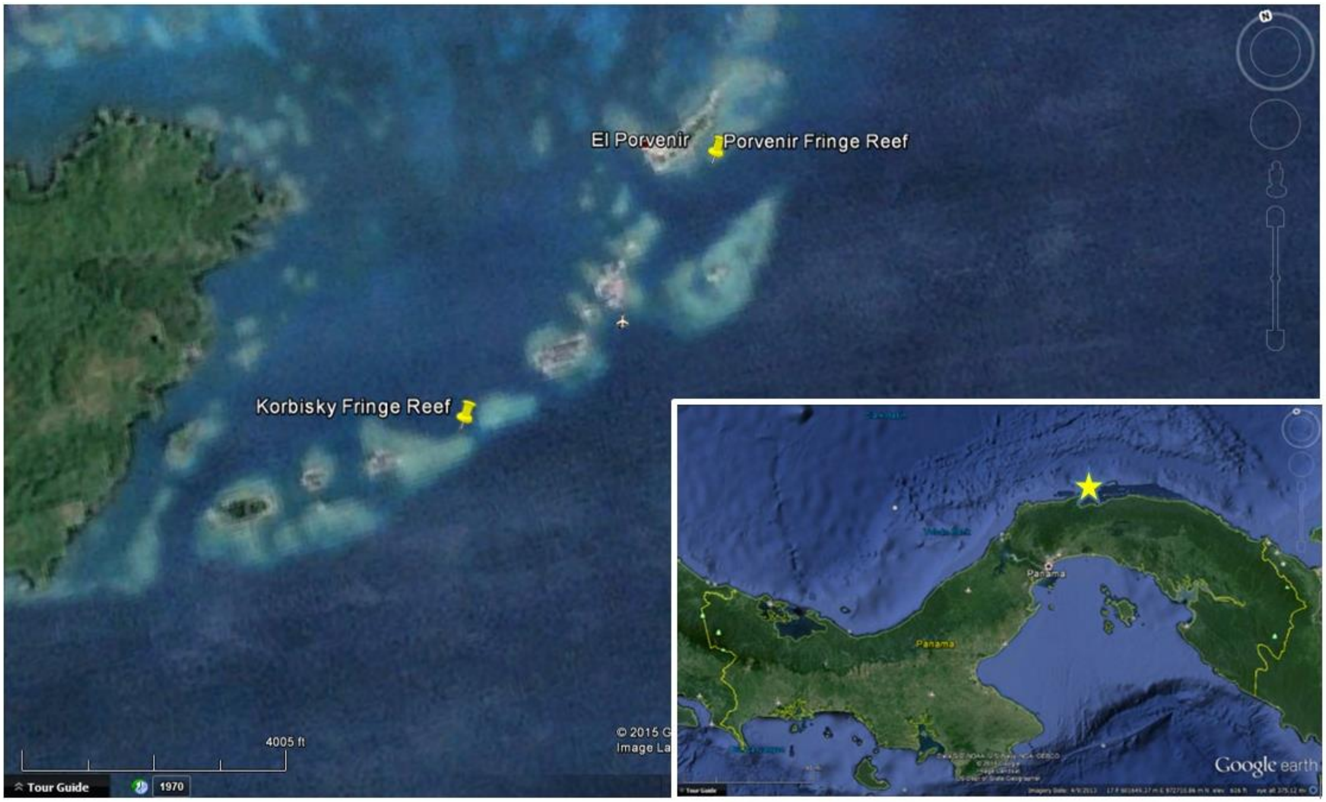

Figure 1. Location of the two fringe reefs in Guna Yala, Panama.

Fish morphospecies diversity

After laying out a 15 meter transect parallel to shore, the observer swam back to the start of the transect and waited five minutes before recording the fish species that were along the transect (Pratchett et al. 2011). Any fish that the observer saw that was within the water column and approximately one meter to the right of the tape measurer was counted. The approximate volume of each sample site for fish species diversity was ~30m^3 (15 meters long, one meter wide, and two or less meters high). The physical appearance of each fish was recorded and the number of individuals that were morphologically similar were counted. Frequently seen fish species were identified to the species level using a Caribbean fish identification book—Humann and Deloach (2014). For fish that could not be identified with the Humann and Deloach guide, fish were grouped together based on their physical appearance, taking into account body shape, color, and fin and tail shape.

Coral coverage sampling

Once the fish morphospecies had been recorded, the observer swam back to the start of the transect and used a 1x1 meter quadrat with crosshairs spaced 10 centimeters apart from each other, so that each square was 10x10 cm and represented 1% of the quadrat (Jokiel et al. 2015). The quadrat was then be placed at the 0 m mark with the bottom left corner at 0 m and the percent coverage of healthy/living, dead, diseased, and bleached coral in the quadrat was recorded. Percent coverage of algae and soft corals were also recorded. Coral diseases were identified in the field if possible, or a picture was taken for identification back on land with a guide. Then the quadrat was moved to the 1 m mark and percent coverage was calculated for the same categories. Recording percent coverage continued until the full 15 meters were sampled, so a total of 15 m^2 were sampled for each belt transect. The same coral coverage sampling method were used for the nine other transects in each reef. A total of 150 m^2 was sampled and analyzed at the Porvenir reef and 65 m^2 was sampled at the Korbisky reef, so a total of 215 m^2 were evaluated between the two reefs. Fewer samples were taken at the Korbisky reef due to weather conditions.

Statistical analysis

The coverage of live/healthy, dead, diseased, and bleached coral was calculated for each individual transect. Then the percent cover of each coral type was calculated for the entire Korbisky and Porvenir reefs. A t-test was run to see if there is a significant difference in coral cover and number of individuals and morphospecies found in the two reefs. A scatter plot was used to show if there was any correlation between algae cover and live/healthy coral cover. Additionally, a Shannon-Weiner Diversity Index was calculated for each transect in each reef to indicate where more species are commonly found and which reef—Korbisky or Porvenir—is more diverse. Lastly, a multivariable test (ANOVA) was run to see if the average number of morphospecies found in a transect and the average percent of live versus dead versus diseased corals at each site differed between the two reefs (Raymundo et al. 2009).

RESULTS

Live coral coverage

There is significantly more live coral coverage in the Porvenir reef than the Korbisky reef (p=0.0213, df=223, t=-2.04). In the 150 m^2 sample area of the Porvenir reef, approximately 10.59% is live coral coverage, whereas only 6.43% of the 75 m^2 sample area of the Korbisky reef is live coral cover (Table 1). The observed distribution of live coral in the Porvenir reef is significantly different from the expected distribution (χ^2_9=23.75, p<0.05). The most live coral coverage is in Transect 9 and 10, which are farthest from Porvenir Island's coast (Table 2).

Table 1. Percent Coverage of live hard coral, dead coral or rock, diseased coral, bleached coral, algae, and soft coral found at the Porvenir fringe reef and the Korbisky fringe reef.

	Live Hard Coral (%)	Dead Coral/Rock (%)	Diseased Coral (%)	Bleached Coral (%)	Algae (%)	Soft Coral (%)
Porvenir Fringe Reef	10.59	79.40	0.028	0.024	9.93	0.11
Korbisky Fringe Reef	6.43	91.87	0	0.02	0.99	0.1

Table 2. The number of fish observed along each transect and the percent cover of live coral in each $15m^2$ belt transect.

Transect Number	**Number of Fish**	**Live Coral Cover (%)**
Porvenir Fringe T1	45	9.31
Porvenir Fringe T2	29	8.18
Porvenir Fringe T3	43	10.56
Porvenir Fringe T4	44	9.42
Porvenir Fringe T5	46	6.88
Porvenir Fringe T6	40	4.95
Porvenir Fringe T7	39	10.43
Porvenir Fringe T8	55	9.18
Porvenir Fringe T9	60	12.55
Porvenir Fringe T10	57	24.42
Total:	**458**	
Korbisky Fringe T1	58	3.67
Korbisky Fringe T2	59	6.03
Korbisky Fringe T3	82	18.07
Korbisky Fringe T4	38	1.65
Korbisky Fringe T5	59	2.75
Total:	**296**	

Of the nine coral species present—*P. porites, A. tenuifolia, P. astreoides, P. strigose, O. annularis, A. palmate, A. cervicornis, D. clivosa,* and *F. fragum*—at the Porvenir fringe reef, the most commonly found is *Porites porites* (finger coral) (Table 3). *P. porites* makes up 75.09% of the live coral coverage present at the reef and the next two most abundant coral species found are *Agaricia tenuifolia* (thin leaf lettuce coral), which covers 13.66% of the fringe reef, and *Porites astreoides* (mustard hill coral), which covers 8.40% of the fringe reef (Table 3). These three species—*P. porites, A. tenuifolia,* and *P. astreoides*—are found within every belt transect in the fringe reef. *P. porites*'s observed distribution is significantly different from its expected distribution, meaning that it is not evenly distributed throughout the fringe reef. It is most abundant in Transects 3 and 10, 8.55% and 21.35% coverage of each transect, respectively (χ^2_9=29.25, $p<0.05$). Additionally, *P. porites* coverage is not evenly distributed along each transect (χ^2_{14}=38.42, $p<0.05$). It is most commonly found and densest near the edges in Quadrats 1 and 2. On the other hand, the observed distribution and coverage of *A. tenuifolia* and *P. astreoides* throughout the fringe reef are not significantly different from the expected distribution, so no preference is observed (A. tenuifolia: (χ^2_9=11.65, $p>0.05$; P. astreoides: χ^2_9=1.27, $p>0.05$). Their distribution is also not significantly different from their expected distribution along each transect as their coverage moves inward, where the waves are more abundant and strong (A. tenuifolia: χ^2_{14}=6.92, $p>0.05$; P. astreoides: χ^2_{14}=13.35, $p>0.05$).

Table 3. Species of coral found in the Porvenir fringe reef and their percent coverage of the total amount of living hard coral cover.

Scientific Name	**Common Name**	**Coverage (%)**
Porites porites	Finger coral	75.09
Agaricia tenuifolia	Thin leaf lettuce coral	13.66
Porites astreoides	Mustard hill coral	8.4
Pseudodiploria strigosa	Symmetrical brain coral	0.99
Orbicella annularis	Boulder star coral	0.69
Acropora palmata	Elkhorn coral	0.6
Acropora cervicornis	Staghorn coral	0.28
Diploria clivosa	Knobby brain coral	0.19
Favia fragum	Golfball coral	0.094

In the Korbisky fringe reef, the observed distribution of live coral coverage is significantly different than the expected distribution (χ^2_4=27.92, p<<0.05). The most live coral coverage is in Transect 3 (Table 2). The three most abundant hard coral species in the Korbisky fringe reef are *Porites porites*, *Agaricia tenuifolia*, and *Pseudodiploria strigosa*, making up 56.31%, 16.08%, and 4.84%, respectively, of the total live hard coral coverage (Table 4). None of these species are found in each transect. Fire coral is very abundant in the Korbisky reef (8.44% of live coral cover). *P. porites* coverage is not distributed as expected throughout the reef. They favor the edge of the reef, mainly occupying Quadrats 1 and 2 in each transect (χ^2_{14}=194.32, p<<0.05). *A. tenuifolia* and *P. strigosa* also favor the edge of the reef; highest coral coverages are found in Quadrats 1 and 3 and 2 and 3, respectively (A. tenuifolia: χ^2_{14}=46.60, p<0.05; P. strigosa: χ^2_{14}=28.05, p<0.05).

Table 4. Species of coral found in the Korbisky fringe reef and their percent coverage of the total amount of living hard coral cover. Fire coral (*Millepora alcicornis and M. complanata*), a soft coral, was included because it was very abundant.

Scientific Name	Common Name	Coverage (%)
Porites porites	Finger coral	56.31
Agaricia tenuifolia	Thin leaf lettuce coral	16.08
**Millepora alcicornis/M. complanata*	Fire coral	8.44
Pseudodiploria strigosa	Symmetrical brain coral	4.84
Acropora cervicornis	Staghorn coral	3.65
Orbicella annularis	Boulder star coral	3.56
Porites astreoides	Mustard hill coral	2.61
Siderastrea siderea	Massive starlet coral	2.09
Dichocoenia stokes	Elliptical star coral	1.23
Orbicella faveolata	Mountainous star coral	0.62
Favia fragum	Golfball coral	0.28
Diploria clivosa	Knobby brain coral	0.28

Diseased and bleached coral cover

There is very little bleached coral coverage at the Porvenir reef and Korbisky reef (Table 1). At both reefs, approximately 0.02% of the areas sampled are bleached and there is no significant difference in bleached coral cover between the two fringe reefs (p=0.398, df=223, t=+0.26). Bleaching is only present in *P. porites* and *A. tenuifolia*.

Of the total 150m^2 sampled in the Porvenir reef, only 0.028% of the reef is covered by disease, and 0% of the corals in the Korbisky reef is diseased. Corals with diseases are only present in the Porvenir reef (Table 1). There is no significant difference, however, in the total diseased coral coverage between the Porvenir reef and Korbisky reef (p=0.0924, df=223, t=+1.33). The only disease noted was white band disease in *Acropora cervicornis*. It was identified to be white band disease and not bleaching because there was a clear band across the branches and a bit of tissue was missing. There is no tissue loss when bleaching occurs. Bleaching is simply the whitening of coral, not the breaking down of it.

Fish diversity

There is a significant difference in the number of fish found at each of the reefs (p=0.0279, df=13, t=+2.1). In the Porvenir reef, a total of 458 individuals were found, and 296 individuals were found in the Korbisky reef (Table 2). Twenty-eight species of fish live in the two reefs—7 species are found only in the fringe reef, 11 are found only in the Korbisky reef, and 10 are found in both of the reefs (Table 5). The two most abundant fish in both the Porvenir and Korbisky reef are the bluehead wrasse (*Thalassoma bifasciatum*) and a dark brown damselfish (unidentifiable species). In the Korbisky reef, the bluehead wrasse is most abundant (n=110) then the brown damselfish (n=49) and in the Porvenir reef, the brown damselfish is most abundant (n=137) and then the bluehead wrasse (n=107) (Table 6 and Table 7).

Table 5. The location where each species of fish is found. They are either present in just the Porvenir reef, just the Korbisky reef, or can be found within both.

Fish Species Found in Both Reefs	**Porvenir Reef Fish Species**	**Korbisky Reef Fish Species**
Black/brown damsel	Red parrotfish	brown, white stripe, yellow fins
Bluehead wrasse (*Thalassoma bifasciatum*)	Silver body, yellow underfin	blue, gray, red parrot
Sergeant major (Abudefduf saxatilis)	Brown, yellow, brown wrasse	yellow, white stripes (vertical)
reef parrotfish (Sparisoma amplum)	Bicolor damsel (Stegastes partitus)	green, black, white, red wrasse
Slippery dick (*Halichoeres bivittatus*)	white, yellow fins and head, black dots btw body and tail	Foureye butterflyfish (Chaetondon capistratus)
Purple top, yellow stomach	gray, orange top damsel	Indigo hamlet (Hypoplectrus indigo)
Threespot damselfish (*Stegastes planifrons*)	Camo-fish (similar to blenny)	Princess parrotfish (Scarus taeniopterus)
Yellowtail damselfish (*Microspathodon chrysurus*)		silvery wrasse
Speckled damsel (*Pomacentrus bankanensis*)		camo-fish
Redlip blenny (Ophioblennius macclurei)		Spotfin butterfly (Chaetodon ocellatus)
		Brown chromis (Chromis multilineata)

Table 6. List of fish species found along each transect in the Porvenir fringe reef close to Porvenir Island and the diversity of each transect.

Fish Species	**T1**	**T2**	**T3**	**T4**	**T5**	**T6**	**T7**	**T8**	**T9**	**T10**
Bluehead wrasse	15	5	6	16	8	8	14	14	15	6
Sergeant major	8	1	10	11	3	0	0	2	4	15
Reef parrotfish	2	0	0	0	5	2	3	6	8	3
Slippery dick	0	3	2	3	5	9	3	4	6	3
Red parrot	0	0	1	0	0	0	0	0	0	0
Silver body, yellow underfin	0	2	0	0	0	0	0	0	0	0
Purple top, yellow stomach	0	1	0	0	0	0	2	0	2	2
Brown, yellow, brown wrasse	0	3	0	0	0	0	0	0	0	0
Threespot damselfish	5	1	4	2	0	1	0	0	0	6
Black/brown damsel	15	11	18	6	17	11	13	19	15	12
Yellowtail damselfish	0	2	1	5	1	2	3	2	0	4
Brown chromis	0	0	1	1	2	1	0	6	3	3
Redlip blenny	0	0	0	0	3	0	0	0	0	0
Bicolor damsel	0	0	0	0	2	6	1	1	4	3
White, yellow fins and head, black dots btw body and tail	0	0	0	0	0	0	0	1	0	0
Gray, orange top damsel	0	0	0	0	0	0	0	0	3	0
Diversity (H)	1.42	1.86	1.60	1.64	1.87	1.78	1.57	1.78	1.97	2.08

Table 7. List of fish species found along each transect in the Korbisky fringe reef close to Korbisky Island and the diversity of each transect.

fish	T1	T2	T3	T4	T5
Brown damsel	15	14	10	5	5
Brown, white stripe, yellow fins	1	0	0	0	0
Blue, gray, red parrot	1	0	0	0	0
Bluehead wrasse	25	23	38	10	14
Threespot damselfish	2	3	8	1	0
Sergeant major	2	3	7	0	6
Yellow, white stripes (vertical)	3	0	0	0	0
Green, black, white, red wrasse	4	0	0	0	0
Reef parrotfish	3	6	3	0	0
Foureye butterflyfish	1	0	3	2	2
Redlip blenny	1	2	2	0	0
Yellowtail damselfish	0	4	2	0	0
Slippery dick	0	4	8	2	7
Indigo hamlet	0	0	1	0	1
Princess parrotfish	0	0	0	3	0
Brown, black dot damsel	0	0	0	1	3
Silver wrasse	0	0	0	12	0
Camo-fish	0	0	0	2	0
Spotfin butterfly	0	0	0	0	1
Silvery wrasse	0	0	0	0	18
Purple top, yellow bottom	0	0	0	0	2
Diversity (H)	1.72	1.72	1.75	1.84	1.92

By calculating a Shannon-Wiener Diversity Index for each reef, it is determined that the Korbisky reef (H=2.212) is more diverse than the Porvenir reef (H=2.060). Additionally, within the Korbisky reef and Porvenir reef, the number of fish are not distributed as expected (evenly) (Korbisky: χ^2_4=16.40, p<<0.05; Porvenir: χ^2_9=17.15, p<0.05) (Figure 2). A one-way analysis of variance (ANOVA) was calculated to determine if the number of fish varied between the Porvenir reef and Korbisky reef. There was no significant difference in the number of fish found along each transect in the Korbisky reef or along each transect in the Porvenir reef (Korbisky reef: H=0.527, P=0.971; Porvenir reef: H=3.964, P=0.914).

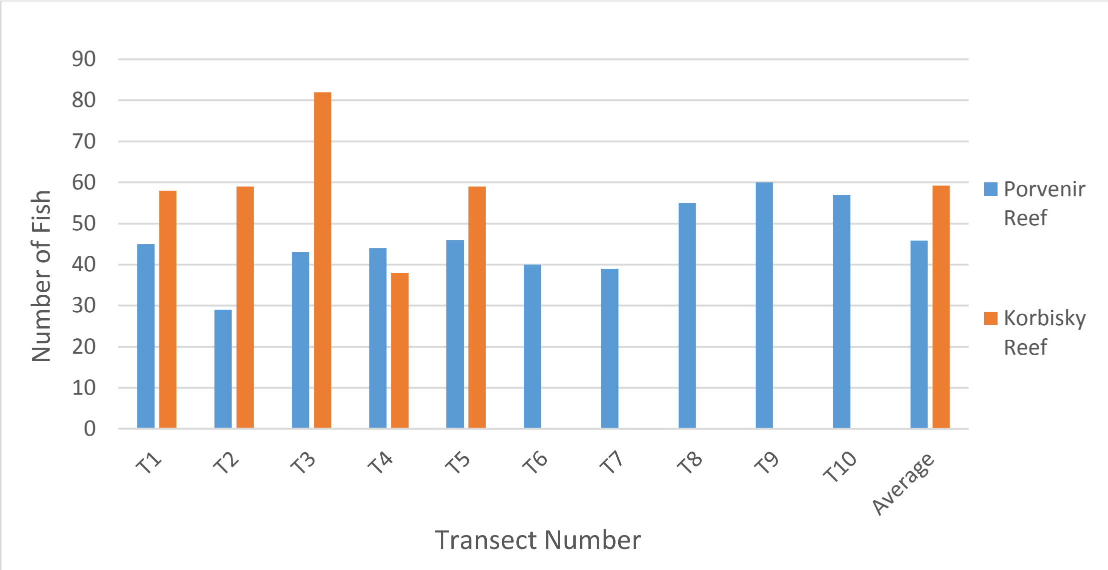

Figure 2. The number of fish observed along each transect at the Porvenir reef and Korbisky reef.

Relationship between coral cover and other parameters

A weak, positive logarithmic correlation is seen between the number of fish present along each transect and the percent cover of live coral cover in the Porvenir reef (R^2=0.32) (Figure 3). A stronger, positive logarithmic correlation is present between the number of fish present along each transect and the percent cover of live coral cover in the Korbisky reef (R^2=0.883) (Figure 4). A logarithmic relationship implies that when one factor changes (increases or decreases), the other factor changes proportionally to the logarithms of the other numbers. There is no correlation between coral coverage and algae coverage in the Korbisky reef and the Porvenir reef (Figure 5 and Figure 6). A linear relationship best fits the data and results in the highest R^2 value.

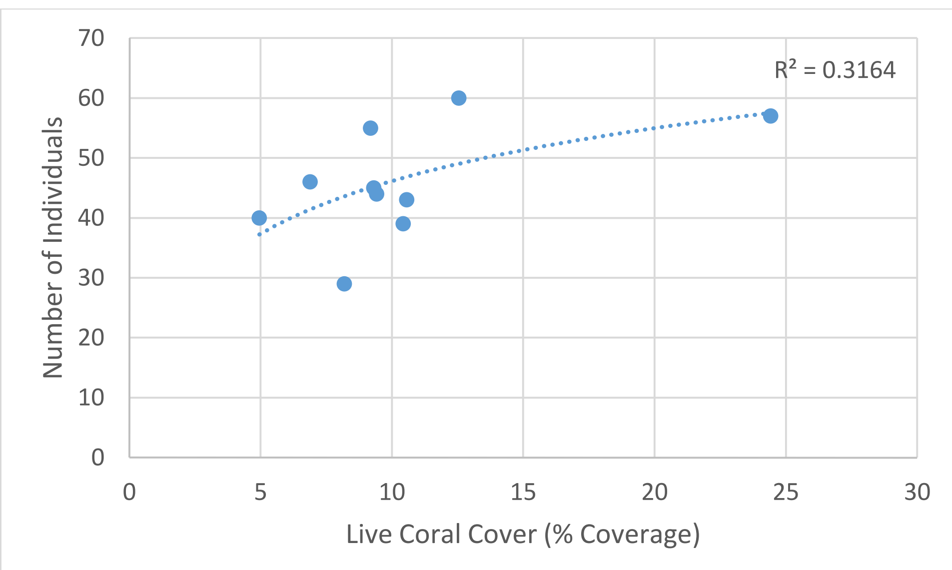

Figure 3. Logarithmic correlation between the numbers of fish found along each transect and the percent cover of live coral at the Porvenir reef with an R^2 value of 0.316.

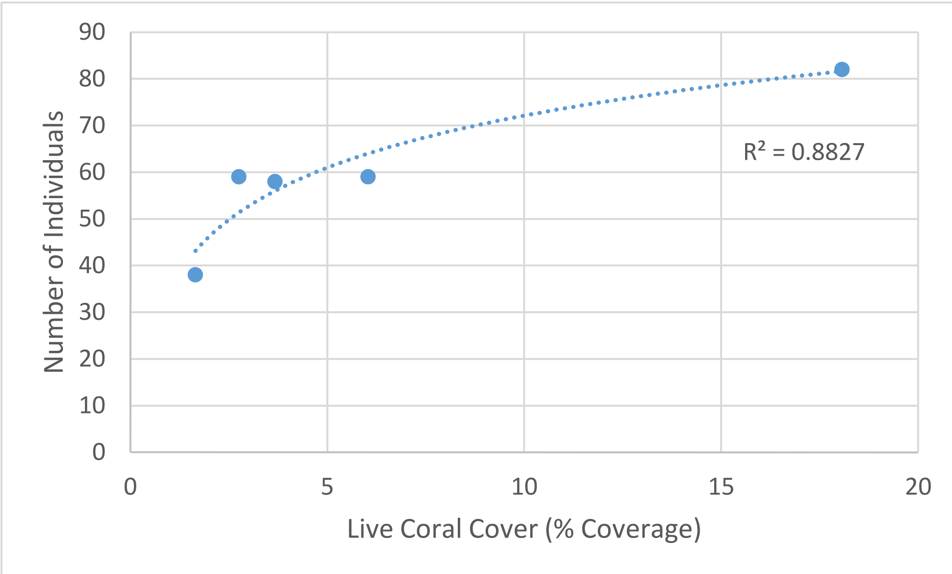

Figure 4. Logarithmic correlation between the numbers of fish found along each transect and the percent cover of live coral at the Korbisky reef with an R^2 value of 0.883.

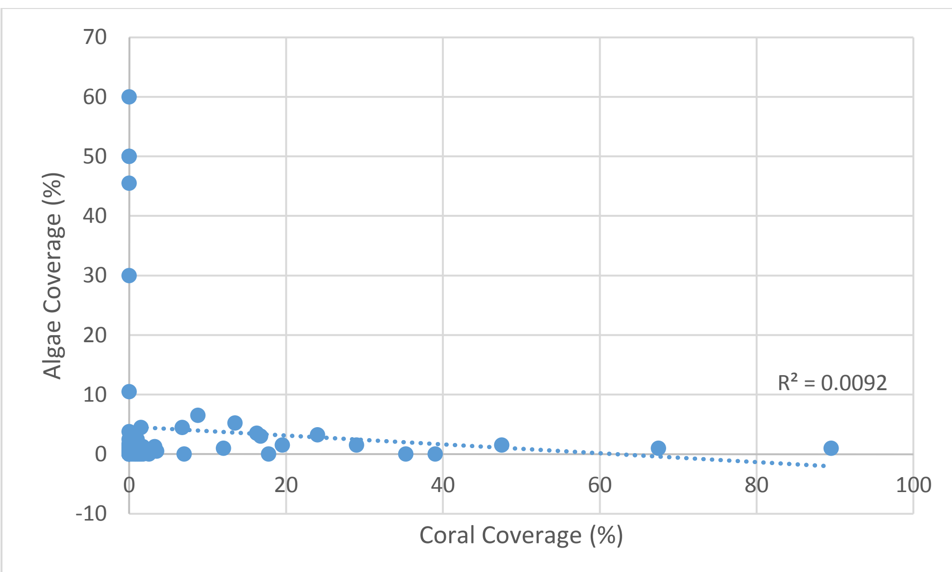

Figure 5. Linear correlation between live coral coverage (%) and algae coverage (%) in the Korbisky reef with an R^2 value of 0.0092.

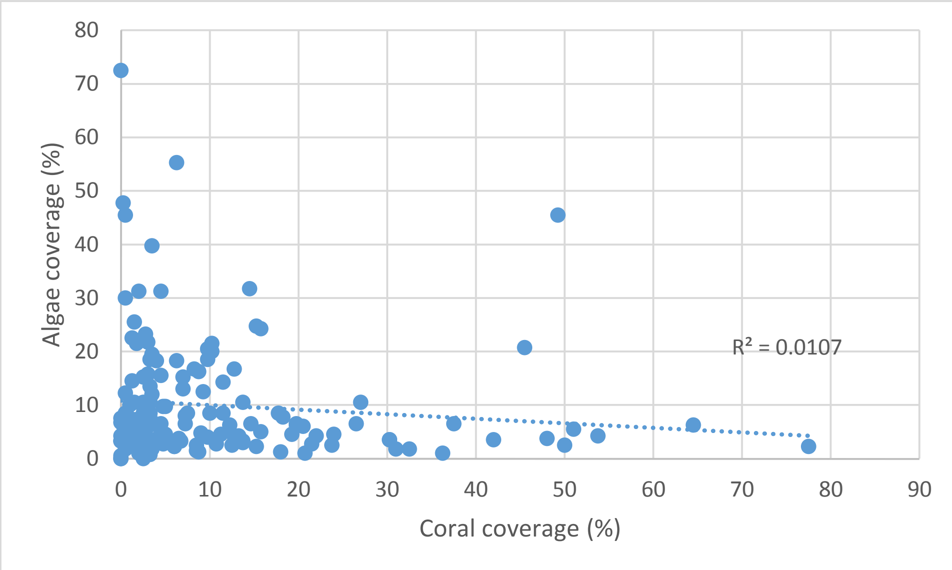

Figure 6. Linear correlation between live coral coverage (%) and algae coverage (%) in the Porvenir reef with an R^2 value of 0.0107.

Sources of Error

There were multiple sources of error in this study. The transects may not have been exactly parallel to shore or to each other, so a distance of 5 meters may not have always been kept. It was very hard to keep the transects straight due to the curvature of the reef and the waves. The waves also made it difficult to count the coral, disease, bleached, and algae cover because not only was the observer constantly moving back and forth, but also the quadrat would move whenever a big wave came. So, when placing the quadrat back, it may not have been in the exact same place it was before it moved. Additionally, when recording the fish diversity, the observer could've missed fish or double counted fish. Lastly, when recording algae cover in the Korbisky reef, turf algae was not counted as algae since it lightly covered the rock and rubble, which made it difficult to count the coverage.

DISCUSSION

Based on the results, there is no significant difference in diseased coral and bleached coral coverage between the Korbisky reef and the Porvenir reef; however, there is a significant difference in live coral cover and fish species diversity between the Korbisky reef and Porvenir reef. Therefore, two null hypotheses are rejected and two are accepted.

There is a significant difference in the coral cover between the Porvenir reef and the Korbisky reef. During the sampling period, the Porvenir reef and Korbisky reef both experienced wave action due to the daily storms; however, there was more constant wave energy impacting the Korbisky reef. The Porvenir reef, on the leeward side of Porvenir Island, is somewhat sheltered by the island, whereas the Korbisky reef has no island between it and the waves coming from the ocean and offshore. Wave action often limits hard coral growth (Harmelin-Vivien 1994; Williams et al. 2013). Williams et al. (2013) concluded that reefs exposed to increased wave energy contain decreased overall hard coral cover due to the physical stress and damage. Additionally, reefs that receive wave action are often dominated by encrusting corals (*Porites*, *Montastrea*, and *Montipora*) and are rarely covered by branching corals, such as *Acropora* (Williams et al. 2013). Similar to their study, both the Korbisky reef and Porvenir reef that were sampled in this study are dominated by *Porites porites* and low *Acropora* coverage is present. More *Acropora* coverage was recorded in the Korbisky reef; however, more *Acropora* colonies are present in the Porvenir reef, but were not sampled because they were either past the 15m transect or between transects. Lastly, Williams et al. (2013) concluded that shallow reefs are more prone to wave action; therefore, less hard coral cover is present. The Korbisky reef (depth: ~0.5m, but 2m at the edge/start of the transects) was shallower than the Porvenir reef (~1.0-1.5m), which could be another factor that explains why there is significantly less coral coverage in the Kobrisky reef than the Porvenir reef.

Both reefs though had lower coral cover compared to a coral reef assessment in Guna Yala in 2003 (Guzman). Guzman (2003) sampled four Panama reefs—Guna Yala, Bocas del Toro, Isla Grande, and Bahia Minas—and analyzed the long-term changes in live coral cover in each reef. Guna Yala had about 40% live coral coverage in 1983 and then it decreased to about 20% by 2001. In this study though, the two reefs sampled have about 10% or less live coral coverage. It would be beneficial and interesting to see if the live coral coverage of the entire Guna Yala region has decreased since 2001 or if it's just locally low coral coverage.

The dominance of *P. porites* in both the Korbisky reef and Porvenir reef is very common in shallow waters (Kahng 2014). In Hawaii, the genus *Porites* covers more than 50% of the entire archipelago and more than 50% of live coral coverage is *Porites* cover in both the Korbisky reef and Porvenir reef (Kahng 2014). In a 2003 study, it was concluded that *Agaricia agaricites*, *Porites astreoides*, *Diploria* spp., and *Siderastrea siderea* mainly covered reef flats in eastern Panama and *A. tenuifolia*, *D. clivosa*, *and Millepora complanata* (fire coral) are commonly found species in shallow areas of 2 m or less along central Panama's Caribbean coast (Guzman). Additionally, a study off the coast of Jamaica also recorded high coral cover of *P. porites*, *P. astreoides*, and the genus *Agaricia*, three of the commonly found corals in the reefs of this study (Ford et al. 2014).

There is no significant difference in diseased coral cover between the Korbisky reef and Porvenir reef. Both had less than 0.06% diseased coral cover. Most diseases are caused by anthropogenic activities, such as increased nutrient inputs, dredging, and shit strikes (Goreau et al. 1998; Pratchett et al. 2011; Vega Thurber et al. 2014). Recently, some islands in Guna Yala have started recycling, composting, and disposing their waste in a sanitary landfill (Howe and McDonald 2015). And according to a recent study (Fruitema 2015), the Guna have a long-standing cultural awareness of garbage disposal and the negative impacts it can cause to the environment if not disposed of properly. This environmental consciousness could account for the very little to no coral diseases in the reefs surrounding Porvenir Island and Korbisky Island. Coral diseases though could increase in the Porvenir area due to increasing physical human contact, such as snorkeling, tourism, ship-strikes by the numerous sailboats and yachts, and increased pollution and direct sewage disposal into the Caribbean (Goreau et al. 1998). It is surprising, however, that there are not more cases of white band disease and some cases of black band disease since both are caused by dumping sewage directly into the surrounding waters of the reef and white band and black band have been observed in Caribbean reefs all along Panama's coast since the 1980's (Parks 2002; Guzman 2003, Anonymous 2014). Many bathrooms are built directly over the ocean in the Porvenir area, and when waste is not burned, it is sometimes dumped directly into the ocean if it is not recycled.

There is also no difference in bleached coral coverage between the Korbisky reef and Porvenir reef. The Porvenir reef has 0.004% more bleached coral coverage than the Korbisky reef. Bleaching occurs due to increased sea surface temperatures (Li and Reidenbach 2014).

When the water temperature rises 1-2°C for an extended time period of 3-4 weeks, bleaching happens. The NOAA Coral Reef Watch satellite data however shows little variation in sea surface temperature in the eastern Caribbean during the data collection days and it was not a fine enough of scale to observe the temperature near Porvenir and Korbisky Island. Temperature during the data collection days was in the high 20s (°C), around 27-28°C.

There could have been slightly more bleaching at the Porvenir reef for a few reasons. The main species that showed signs of bleaching was *P. porites*. Because *P. porites* cover is much greater in the Porvenir reef, it would make sense that a slightly higher percentage of *P. porites* would be bleached. The *P. porites* at the Porvenir reef are at about 1m depth, whereas the *P. porites* at the Korbisky reef are at a depth of 2m. Decreased water circulation within bays and lagoons can cause increased water temperatures (Li and Reidenbach 2014). Davis et al. (2011) conducted a study in the Red Sea and concluded that reefs that are protected from direct wave energy and impacts have the most water temperature variability. Because the Porvenir reef is behind Porvenir Island and closer to shore, it is more protected than the Korbisky reef and could potentially have warmer waters than the Korbisky reef on calmer days during the dry season. The Korbisky reef could also have slightly less bleaching due to the increased wave action it receives. Ocean winds decrease sea surface temperatures due to evaporative cooling and mixing of the warm surface waters and cooler deeper waters (Manzello et al. 2007).

A study done by Whelan et al. (2007) similarly concluded that *P. porites* were sensitive to increased sea surface temperatures and exhibited high bleaching coverage after a thermal stress anomaly in 2005 in the Caribbean. Over 92% of the *P. porites* in the Tektite Reef, Virgin Islands National Park, St. John were bleached. The high amount of bleached *P. porites* indicates their sensitivity to increased sea surface temperatures, and could explain why bleaching was only seen in *P. porites* and *A. tenuifolia* in the reefs of this study. It is also more common for branching and encrusting corals to experience bleaching than massive and submassive corals (McClanahan 2004). A reef off the coast of Navassa Island in the Caribbean experienced bleaching in 2006 and the most susceptible corals to bleaching were *Agaricia* spp. and *Montastraea faveolata* and *P. porites* were intermediately affected (Miller et al. 2011). These two articles (Whelan et al. 2007; Miller et al. 2011) support the findings of this paper, demonstrating that *P. porites* and *A. tenuifolia*, two of the most commonly found coral species in the two reefs sampled, are susceptible to bleaching more frequently than other species.

Lastly, there is a significant difference in the number of fish found within the Korbisky reef and Porvenir reef and the Korbisky reef has a greater fish diversity than the Porvenir reef. The higher number of fish individuals and the higher diversity (H) within the Korbisky reef are not consistent with the findings of many previous studies (Wilson et al. 2006; Pratchett et al. 2011; Graham and Nash 2013; Holbrook et al. 2015). In many previous cases, increased biodiversity is strongly correlated with live coral coverage; however, the Korbisky reef has less live coral coverage and more fish species diversity.

Live coral cover is important to thousands of reef fish. The corals, especially branching corals, offer structural complexity and create micro-niches for fish and invertebrates (Graham and Nash 2013). Graham and Nash (2013) determined that there was a strong positive relationship between structural complexity and fish density and biomass. They concluded that increased structural complexity offers more refuge from predation, which leads to increased fish density and biomass. The greater surface area also provides more feeding sites, which increases species richness (Bell and Galzin 1984). Therefore, it is unexpected to see that the Korbisky reef, which had less coral coverage, has more fish species and individuals present.

However, there was a study done in the coral reefs of Farquhar Atoll, which is part of the Seychelles Islands, which concluded that live coral cover is not necessarily indicative of fish biomass and individuals (Friedlander et al. 2014). Coralline crusted algae and turf algae were the most dominant benthic cover and live coral was the least dominant cover. However, they recorded lots of fish biomass and high fish diversity. They attribute this to the non-industrial fishing and low pollution levels that occur within the atoll, concluding that fish diversity and biomass can be preserved even when coral reefs decline due to global climate change if no-take protected areas are created around coral reefs. Furthermore, the high abundance of parrotfish within the atoll regulated algae growth which allowed for crustose coralline algae to dominate, which maintain healthy reefs. Therefore, the low coral cover, but high fish diversity at the Korbisky reef, could be due to the subsistence fishing that occurs within Guna Yala and not industrial fishing.

There is a correlation along each transect though, when the data are not compiled, and the number of species along each transect is positively correlated with live coral coverage. This corresponds with many previous studies where more coral coverage offers more habitat for more species (Holbrook et al. 2015). The two most abundant species in each reef are the bluehead wrasse (*Thalassoma bifasciatum*) and a dark brown damselfish (unidentifiable species). These species are commonly found in shallow Caribbean reefs and seen together (Black et al. 2014; Humann P and Deloach N 2014). Damselfish are very territorial and aggressive fish, known to defend their territory by attacking intruders (Black et al. 2014). Wrasses are common damselfish intruders due to their high habitat overlap.

Finally, there is no correlation between algae cover and live coral cover. Previous studies have found that there is a strong, negative correlation between the two—as coral cover increases, algae cover decreases (Mumby and Steneck 2008; D'Angelo and Wiedenmann 2014). The algae competes against the coral fighting for sunlight; however, in both the Korbisky reef and Porvenir reef, there was no correlation. Turf algae is very abundant in the Korbisky reef, as opposed to the clumped watercress algae (*Halimeda opuntia*) in the Porvenir reef. Perhaps no correlation was found in the Korbisky reef, because the turf algae, which is light brown and lightly covering the rubble, dead coral, and rock, was not counted as algae, but rather dead coverage.

CONCLUSION

Upon analyzing the results, the fringe reef around Porvenir Island has significantly more live coral cover than the fringe reef around Korbisky Island, but the Korbisky reef has significantly more fish species diversity than the Porvenir reef, and there is no difference in the diseased coral coverage and bleached coral coverage between the Korbisky reef and Porvenir reef. There are, however, similarities between the reefs—the most abundant fish species are the bluehead wrasse (*Thalassoma bifasciatum*) and a solid dark brown damselfish (unidentifiable species), most live coral coverage is on the outside of the reef in Quadrats1-3, live coral cover does not correlate with algae cover, and they statistically have similar amounts of diseased coral coverage and bleached coral coverage. The main difference between the reefs is the total live coral cover and fish diversity. Based on previous studies, it appears that there is increased live coral cover in the Porvenir reef because it is more sheltered, located behind Porvenir Island. The increased fish diversity in the Korbisky reef could be attributed to the high amount of turf algae cover (however, it was not recorded as algae cover in this study) and the greater coral species diversity. However, in this study we can conclude only that there is no correlation between live coral cover and fish species diversity and that coral bleaching and diseases are not prevalent in the Porvenir and Korbisky fringe reefs. A future study to determine how overall coral coverage has changed in Guna Yala since 2003 would be interesting and beneficial to the reefs of Guna Yala, since it has the most diverse reefs in Panama.

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