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Marine Animalia Organism Diversity and Reef Condition on Two Reef Sites at Big Creek Beach and Boca del Drago, Bocas del Toro, Panamá

Bri Tiffany
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May 2015

Abstract

Ocean acidification, climate change, overfishing, and coastal development are endangering coral reefs across the globe. In Bocas del Toro, Panamá, coral reefs are especially threatened by the rapid growth in tourism and the subsequent anthropogenic effects caused by an increased human presence. To evaluate reef condition in this area, a study comparing percent coverage of live and dead coral as well as the diversity of marine Animalia organisms was conducted at one reef site in Big Creek beach and one reef site in Boca del Drago, Isla Colón, Bocas del Toro. It was predicted that dead coral cover would be greater than live coral cover at both sites, and marine Animalia diversity would differ between sites and depend on coral reef condition. Percent coverage of live and dead coral was determined using counts from a 1x1m^2 quadrat with cross hairs, and compared within each site utilizing an equal variance two-tailed t-test. Marine organisms at each site were counted using the same 1x1m^2 quadrat with cross hairs, and their diversity calculated and compared through the Shannon-Wiener Biodiversity Index, the Evenness index, the Jaccard Index, and the Effective Number of Species unit. Results showed that while Boca del Drago had a higher percent coverage of live coral than did Big Creek beach, the percent coverage of dead coral was still significantly higher than that of live coral at both reef sites. The diversity of marine Animalia organisms was higher at the Boca del Drago reef, but was not correlated with the higher percent coverage of live coral observed. Further research is needed to determine the reason behind this increased diversity at the Boca del Drago site.

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Introduction

Coral reefs are some of the most biodiverse and productive ecosystems on Earth. However, ocean acidification, climate change, overfishing, and coastal development are endangering coral reefs all across the globe. Reefs are important for not only the marine organisms that rely on the habitat that these unique ecosystems provide, but also because of the key symbiotic relationship that exists between mangroves, seagrasses, and coral reefs themselves. Mangroves and seagrasses filter nutrients and sedimentation from land runoff, and in turn coral reefs act as a buffer to dissipate wave energy before it reaches seagrass beds and mangrove stands—thereby protecting the coastline from erosion due to destructive wave energy (McEntree 2012). Coral reefs are also an important part of our own societal structure, as they provide many goods and services that are critical to the social and economic welfare of hundreds of millions of people (Cinner et al. 2009). In example, coral reef fisheries are a key protein and economic resource for numerous human communities—communities that are frequently located in developing countries (Cinner et al. 2009, McEntree 2012). Furthermore, the biodiversity of coral reefs is a valuable scientific and medical resource that has provided chemical materials and compounds with applications from treating cancer to aiding in bone grafts (Moberg and Folke, 1999). Finally, coral reefs also have a variety of cultural, aesthetic and recreational values for local communities and tourists.

Despite their great biological and economic significance, coral reefs are disappearing at alarming rates. This loss in live coral directly corresponds to reduced taxonomic distinctness and substantial reductions in species richness (Graham et al. 2006). The importance of deteriorating physical structure of corals to these patterns on species demonstrates the long-term impacts of overall coral loss, and the key relationship between species diversity and coral reef health (Graham et al. 2006)

The location of both of my reef study sites, the Bocas del Toro Archipelago, is located on the Northwest Caribbean coast of the Republic of Panamá in the province of Bocas del Toro. Around 18,000 people live scattered throughout the island chain, and the population consists of Afro-Antilleans, indigenous populations, Panamanians, Chinese-Panamanians, North Americans, and Europeans (Die, 2012). Tourism in the Bocas del Toro region has exploded in recent years, and the region is currently considered a development priority zone at the national level (Guzman, 2005). In 2010 alone, more than 60,000 tourists visited the Bocas del Toro province (Die, 2012). Land development has increased significantly during the last decade with an increase in sedimentation and a negative impact on coral reefs, mangroves, and seagrass beds in result (Guzman, 2005). Furthermore, pressure from commercial and artisanal fisheries has led to the collapse of several economically important marine organisms such as sea cucumbers, lobsters, and conches (Guzman, 2005).

Literature Review

Global Threats to Coral Reefs

Coral reefs are threatened globally by ocean acidification, climate change, overfishing, and coastal development. Ocean acidification is caused by an increased amount of CO_2 dissolved in the ocean—which drives the carbonate system to lower the overall pH (Kleypas et al. 2006).

This increased acidity in the ocean represents a key threat to coral reefs, as it reduces the calcification rate of framework builders (Anthony et al. 2008). In fact, more than 30% of the CO_2 emitted to the atmosphere by human activities is taken up by the ocean, lowering the pH of waters to levels that have the potential to prevent calcium carbonate accretion by organisms such as coral reefs (Anthony et al. 2008). For 650,000 years prior to the Industrial Revolution, atmospheric CO_2 concentrations remained between 180 to 300 parts per million by volume. However, the rate of current and projected CO_2 increase is approximately 100x greater than the past, resulting in the irreversible increase in atmospheric CO_2 in the atmosphere (Klepas et al. 2008). Consequently, CO_2 levels are predicted to increase and present further challenges for coral-reef building organisms throughout the 21st century (Anthony et al. 2008). In fact, it is suggested that calcification rates of coral reefs will decrease by up to 60% within the 21st century (Kleypas et al. 2008).

Increased CO_2 in the atmosphere is leading not only to ocean acidification, but to general climate change as well. Global surface temperature has increased approximately 0.2°C per decade in the past thirty years, and is expected to continue to increase even with efforts to reduce carbon dioxide emissions (Hansen et al. 2006). This leads to rising sea surface temperatures associated with CO_2 increase—which causes a subsequent increase in frequency and severity of coral bleaching events with negative consequences for coral survival, growth, and reproduction (Anthony et al. 2008). Coral bleaching occurs when corals are stressed by changes in conditions such as temperature, leading them to expel the symbiotic algae living in their tissues, causing them to turn completely white (Douglas, 2003). While corals can survive a bleaching event, these events generally result in depressed growth and increased mortality (Douglas, 2003). Since the early 1980s, incidences of coral reef bleaching and mortality have occurred almost annually in one of the world's subtropical or tropical seas (Baker 2008). This bleaching is episodic, with the most severe events occurring with phenomena such as El Niño (Baker 2008). These episodes have resulted in significant coral cover loss in multiple locations, and have changed coral community structure in many others (Baker 2008).

In addition to climate change and ocean acidification, global overfishing is also having a negative impact on coral reefs. Since the onset of industrialization, records reveal a rapid decline of native species diversity in coastal ecosystems (Worm et al. 2006). Currently, 53% of the world's fisheries have fully exploited their species, and 32% are overexploited, depleted, or recovering from depletion (FAO 2010). A majority of the top ten marine fisheries, accounting for about 30% of all capture fisheries production, are fully exploited or overexploited (FAO 2010). And unless the current situation improves, stocks of all species currently fished for food are predicted to collapse by 2048 (Worm et al. 2006). This type of extreme overfishing can be detrimental to coral reef environments due to its tendency to change the habitat by removing functionally important species (Wilson et al. 2010). Fishing has the ability to change the size distribution of fish communities directly, by decreasing abundance of large individuals and increasing abundance of small individuals. Overfishing of herbivorous fishes can also lead to increased levels of algae growth—which can smother the coral reef and affect its ability to effectively photosynthesize (Conklin and Smith, 2005).

Coastal development is another major threat to coral reefs across the tropics. The growth of coastal communities can generate a wide range of risks to surrounding coral reefs. For one, the physical act of construction can destroy sensitive habitats such as wetlands or other shore environments. Wetlands, sea grasses, and mangroves are an important buffer between land and sea, and their destruction can result in increased runoff to coral reefs. This runoff causes the water to become nutrient-rich, which frequently leads to an increased population of algae and phytoplankton—also known as suffocating algae blooms. Coral reefs are communities adapted to waters with low nutrient content, and increased levels and additions of nutrients favors organisms that disturb the reef ecosystem and the sensitive balance that exists within them (Wood 1993).

Threats to Coral Reefs in Bocas del Toro Region

Since 1980, coral cover in the entire Caribbean has declined by an average of 80% (Cramer at al. 2012). Surveys of fossil reefs have revealed that these drastic declines in Caribbean coral communities are unprecedented over the past 200,000 years despite historical fluctuations in sea level and climate In the Isla Bocas area specifically, changes in coral and molluscan communities demonstrate that reefs near Bocas del Toro have experienced substantial ecological change . Transformations observed in molluscan size and trophic structure signal an overall deterioration of reef environmental conditions This shift in trophic structure of gastropod communities at offshore sites towards that of higher nutrient and higher turbidity levels suggests that degraded conditions are expanding offshore. The timing of these shifts in structures implicates local Bocas del Toro anthropogenic disruptions such as fishing and deforestation as the ultimate causes. Land clearing and human population have both increased rapidly over the last one hundred years in the Bocas del Toro region. This widespread land clearing began at the turn of the 20th century for banana production and has rapidly increased for tourism since the 1990s. This development and population increase has led to amplified runoff of sediments, nutrients and pollutants to surrounding coral reef environments (Cramer et al. 2012).

The poor management of the coastal zone within Bocas del Toro has quickened the degradation of the marine habitats in the region (Guzman, 2005). In fact, it was found that most of the reef habitats with the highest diversity were located outside the marine protected area of Bastimentos within the Bocas region. This lack of legitimate protection for marine ecosystems is the main basis for indirect habitat degradation in Panama (Guzman, 2005). Overall, the coral reefs in the Bocas del Toro region are not as healthy as they once were—majorly due to anthropogenic activities. Furthermore, it is implicated that the environmental stress on reefs in this region will continue to increase (Cramer at al. 2012).

Global Threats to Marine Organisms

In addition to a global loss of corals and degradation of reef health, there is a corresponding loss of taxonomic distinctness within marine species and substantial reductions in species richness (Graham et al. 2006). Some of the main threats to marine organisms include inadequate protection, habitat destruction, and invasive species.

Much of the habitats of marine organisms are not protected. Though it covers 70% of our planet's surface, only 2.8% of the ocean has been protected (Magiera 2013). Furthermore, the majority of the world's marine reserves are protected only in name. The vast majority of these reserves suffer from little or no management at all. Fewer than 10% are achieving their management goals and objectives, and 90% are open to fishing. Adequate protection is needed, and reserves must improve their management. Wherever reserves have been properly established (and have existed for several years with full protection) they have been successful (Roberts & Hawking 2000).

It is crucial to not only protect the habitat of marine organisms, but to keep them free from invasive species as well. Invasive species are a global threat, frequently causing both economic and environmental damages in the ecosystems they invade. It has been shown that an increased number of species invasions over time coincides with the loss of native biodiversity (Worm et al. 2006). Invasive species have been an issue ever since people began travelling in ships and transporting organisms across the seas. However, the rate of establishment for foreign organisms has been increasing dramatically. In six studied ports in the U.S., Australia, and New Zealand, new estuarine and marine species have been establishing once every 32 to 85 weeks (Bax et al. 2003). While many of these species may not harm the native species, some come to dominate the already-existing flora and fauna. One example is *Kappaphycus alvarezii* (a red alga that is native to the Philippines) that has become invasive in several marine habitats across the tropics (Doty, 2001). This species has become particularly invasive in Kane'ohe Bay, O'ahu. It was introduced to this area in the seventies, and has since completely overgrown the reefs in this site—to the point where the reefs can no longer house and feed marine organisms (Jin, 2013). *Kappaphycus* is currently considered to be the most severe threat to marine life in this area, and measures are actively being taken by The Nature Conservancy of O'ahu to remove this alga and keep the coral reefs clear (Jin, 2013).

<u>Threats to Marine Organisms in Bocas del Toro Region</u>

Specifically in the Bocas del Toro region, marine organisms are threatened by the overall deterioration of reef conditions that is currently occurring in the area (Cramer et al. 2005). They are rapidly losing healthy habitat, and populations of several species—including the *Nephropidae* lobster species , the *Isostichopus badionotus* sea cucumber species, and the *Meoma ventricosa* conche species are decreasing as a result (Guzman, 2005). Marine organisms in Bocas del Toro are also being threatened by invasive species—the Pacific Red Lionfish in particular. Lionfish possess a broad range of traits that make them particularly successful invaders and adept at avoiding predation from native organisms, including venomous spines, a camouflaged pattern, low parasite load, efficient predation, high reproductive rates, and rapid growth. The invasion began when two species of Indo-Pacific lionfish were introduced to Florida coastal waters during the 1980s, and have since spread rapidly (Albins and Hixon 2011). First seen in the Bocas archipelago in 2009, the species now exists throughout the Caribbean coast of Panamá at depths of up to 300 feet (Smithsonian 2011). A study in the Bahamas concluded that a single lionfish can reduce native fish populations on a coral reef patch by nearly 80% in just five weeks). One lionfish was observed to eat twenty small reef fish in only thirty minutes (Holian 2012). Scientists believe that one of the reasons lionfish are such efficient predators is because they have an untraditional visual profile—native fish allow the predator to come very close and are quickly eaten (Holian 2012). Their reproduction rates are also impressive. One female can lay up two million eggs in one year, and they appear to be capable of reproducing throughout the year (Holian 2012). With these high reproductive and predation rates, it is likely that the lionfish will continue to be a threat to marine organisms in the Bocas del Toro region.

<u>Association between Marine Organism Diversity and Reef Condition</u>

The degradation of reef habitat and loss in live coral directly corresponds to reduced taxonomic distinctness and substantial reductions in species richness (Graham et al. 2006). Experiments that manipulated species diversity or genetic diversity found that diversity enhanced ecosystem stability—and that regional biodiversity loss impaired filtering and detoxification services provided by suspension feeders, submerged vegetation, and wetlands. Furthermore, overall water quality has been shown to decrease exponentially with declining diversity (Worm et al. 2006), which can negatively impact the health of the coral reefs. It has also been shown that losses of marine diversity are highest in coastal areas chiefly as a result of conflicting uses of these coastal environments (Gray 1997).

Research Question and Objective

The question directing my research is, how diverse are the marine Animalia organisms and what is the overall condition of one reef site in Big Creek beach and one reef site in Boca del Drago? One of the main objectives of my study was to measure and compare organism diversity between these two sites. My other main objective of study was to assess reef condition based on a calculated live and dead coral percent cover. Finally, to further analyze reef condition and marine Animalia diversity, I determined if there was any sort of correlation or causation between the two.

Methods and Materials

Two coral reefs, one in Big Creek beach and one in Boca del Drago, were selected as research sites. Big Creek beach is a fringing reef located just a few kilometers north of the main tourist site of Bocas town. One main road runs along Big Creek beach, making it easily accessible. The beach is relatively narrow, and the road is located extremely close to the waterfront. Several building structures are located along this road. However, the area is not yet highly developed and much forest area remains. The reef that runs along Big Creek beach is located at N 09° 21.79′; W 082° 14.36′. The reef is nearly continuous, with some small breaks of sand in between coral areas. Almost all of the reef is within one to two meters of shore, and is exposed during the day when tides are low. The reef in Big Creek beach is a fringing reef. The second site, Boca del Drago, is located approximately sixteen kilometers northwest of Bocas Town. Drago itself is a small beach community with one main hostel and several restaurant establishments. The Boca del Drago beach is also narrow, with a small road running partway alongside it. For the most part, the area remains undeveloped as well—though tourism and population in this area is increasing. The fringing reef studied in Boca del Drago is located at N 09° 24.95′; W 082° 19.78′. Both locations were determined through the use of a GPS. Data was collected on nine field days from April 12 to April 20, 2015. At each site, 125 quadrat samples were taken using a $1x1m^2$ quadrat with cross hairs. Sampling began at approximately 10AM each morning.

At Big Creek beach, the coral reef was within approximately 5m of shore and exposed during the day when tides were low. As reefs were exposed, all data at Big Creek beach was collected while walking through water. The first quadrat was placed on the approximate beginning of the reef and, using the cross hairs method, live coral, dead coral, algae, Animalia organisms on reef, sand, and sea grass were counted and recorded on waterproof paper (Sellers et al. 2015). Any Animalia organisms seen on the reef were also described and later identified using a taxonomic guide. To randomize the location of subsequent sampling points along the Big Creek beach reef, I walked two meters forward and placed the quadrat to the right (sample two), collected data, walked an additional two meters forward and placed the quadrat to the left (sample three), and repeated this right-left process until 125 samples were obtained on the Big Creek beach reef site.

At Boca del Drago, the coral reef was within approximately 100m of shore. Water depth was relatively shallow, approximately 1-2m, and all data was collected while snorkeling. The first quadrat was again placed at the approximate beginning of the reef and the same cross hairs method was applied to count and record live coral, dead coral, algae, Animalia organisms on reef, sand, and sea grass (Sellers et al 2015). Any Animalia organisms on the reef were described and later identified using a taxonomic guide. The same method of randomization used in Big Creek beach was used to obtain 125 samples—but this time data was collected while snorkeling around the Boca del Drago reef site.

Maps of the study sites were created in Google Earth and the location of each reef highlighted through GPS and memory of the study site. To analyze data, percent coverage of each category (live coral, dead coral, algae, marine Animalia organisms on reef, sand, and seagrass) was calculated based off of counts collected using the cross hairs method (Sellers et al. 2015). Percent coverage of live and dead coral at each site was compared using an equal variance two-tailed t-test ($p < .05$) in order to prove statistical significance. The Shannon-Wiener Diversity Index (SWI) and the Evenness Index of both the Big Creek beach reef site and the Boca del Drago reef site were also calculated to determine the diversity of species within each site (Atlaf et al. 2014). From the SWI value, the effective number of species (ENS) was also determined. Additional indexes, the Jaccard index and the corresponding unit known as Jaccard distance, were used to identify community similarity and dissimilarity between Boca del Drago and Big Creek beach (Haley and Johnston 2014). Finally, a regression analysis was performed to highlight any correlation that might exist between percent coverage of live coral and number of marine Animalia organisms. All graphing and calculations were done in Microsoft Excel.

Results

After initial surveys, it became clear that the reef was an entirely dead coral reef ecosystem and likely had been dead for an extended time period due its physical appearance (Appendix 1). However, multiple living marine organisms and algae species still utilized this coral reef., and represents an ecosystem of mixed live and dead coral (Appendix 2).

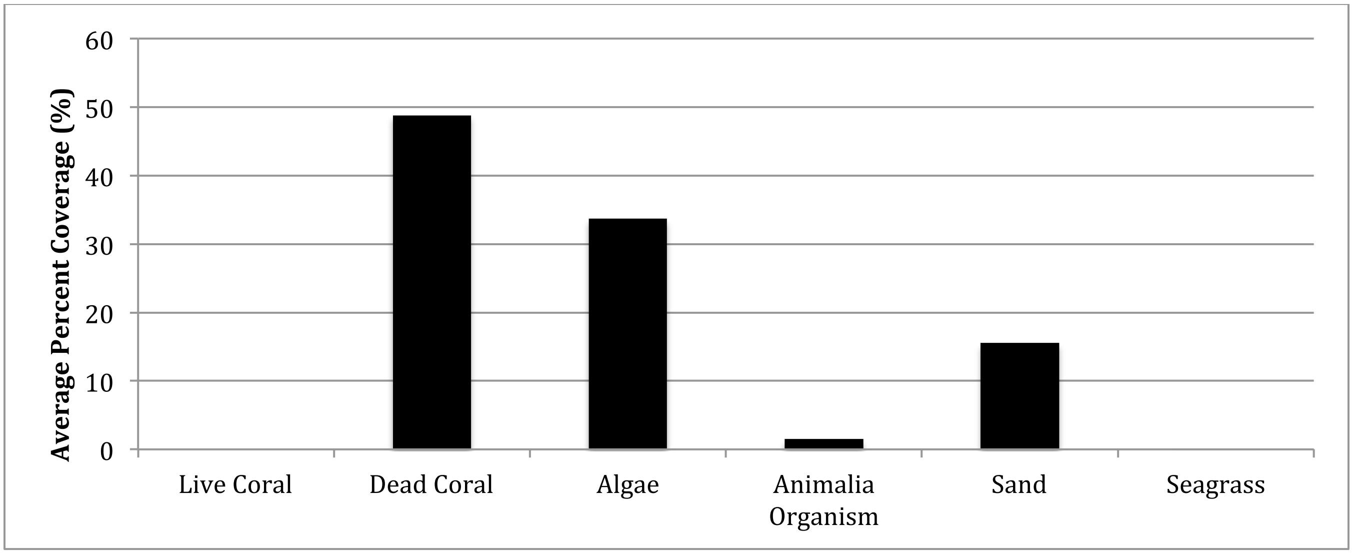

Figure 2: Average percent coverage of organisms at Big Creek beach reef

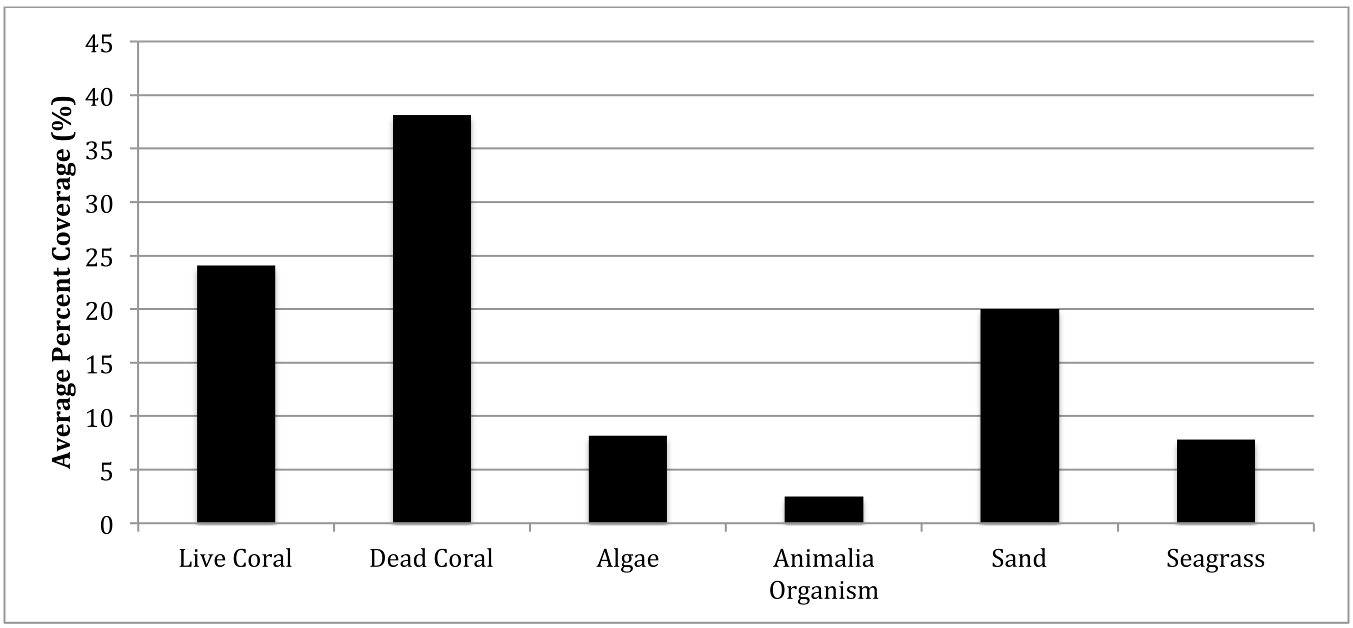

Figure 3: Average percent coverage of organisms at Boca del Drago reef

Average percent coverage was calculated for both Big Creek beach and Boca del Drago from 1x1m^2 quadrat crosshair samples. On average at Big Creek, coverage was 0.0% live coral, 48.79% dead coral, 33.72% algae, 1.51% Animalia organism, 15.6% sand, and 0.05% seagrass. On average at Boca del Drago, coverage was 24.06% live coral, 38.12% dead coral, 8.19% algae, 2.50% Animalia organism, 20.0% sand, and 7.79% seagrass. Dead coral had the highest percent coverage of any organism at both sites.

Big Creek Site	Boca del Drago Site
p = 6.16E-46	p = 1.49E-6
Mean Live Coral = 0.0%	Mean Live Coral = 24.06%
Mean Dead Coral = 48.79%	Mean Dead Coral = 38.12%

Figure 4: p-values for equal variance, two-tailed t-test between percent coverage of live and dead coral at both Big Creek and Boca del Drago. $p < 0.05$. Ho = no significant difference in percent coverage of live and dead coral within each site. Mean percent coverage of live and dead coral included.

A two-tailed t-test with equal variance was calculated to compare the percent coverage of live and dead coral within each site. Statistical analysis using this test ($p < 0.05$) led to the rejection of the null hypothesis that there is no significant difference in percent coverage of live and dead coral within each site. Big Creek beach had a statistically significant p-value of 6.16E-46 and Boca del Drago also had a statistically significant p-value of 1.49E-6. The mean percent coverage for live and dead coral at Big Creek beach was 0.0% and 48.79% respectively. The mean percent coverage for live and dead coral at Boca del Drago was 24.06% and 38.12% respectively.

H	E	ENS
0.91	0.47	2.48

Figure 5: Shannon-Wiener Diversity Index (H), Evenness (E), and Effective Number of Species (ENS) for Big Creek reef site

H	E	ENS
2.10	0.76	8.17

Figure 6: Shannon-Wiener Diversity Index (H), Evenness (E), and Effective Number of Species (ENS) for Boca del Drago reef site

J	D_j
0.05	0.95

Figure 7: Jaccard Index (J) and Jaccard distance (d_j) between Big Creek and Boca del Drago reef site.

The SWI is an ecological diversity index that quantitatively measures data and reflects how many different species there are in a dataset. The value of SWI increases both when the number of types of species increases and when evenness increases. Evenness refers to how close in abundance each species in an environment are. Boca del Drago had both a higher Evenness values and a higer SWI (Figure 6).

The Jaccard Index (J) was calculated to compare the similarity and diversity of the Big Creek beach and Boca del Drago sample sets. The Jaccard distance (d_j) was also calculated to measure the dissimilarity between the sample sets (Figure 7).

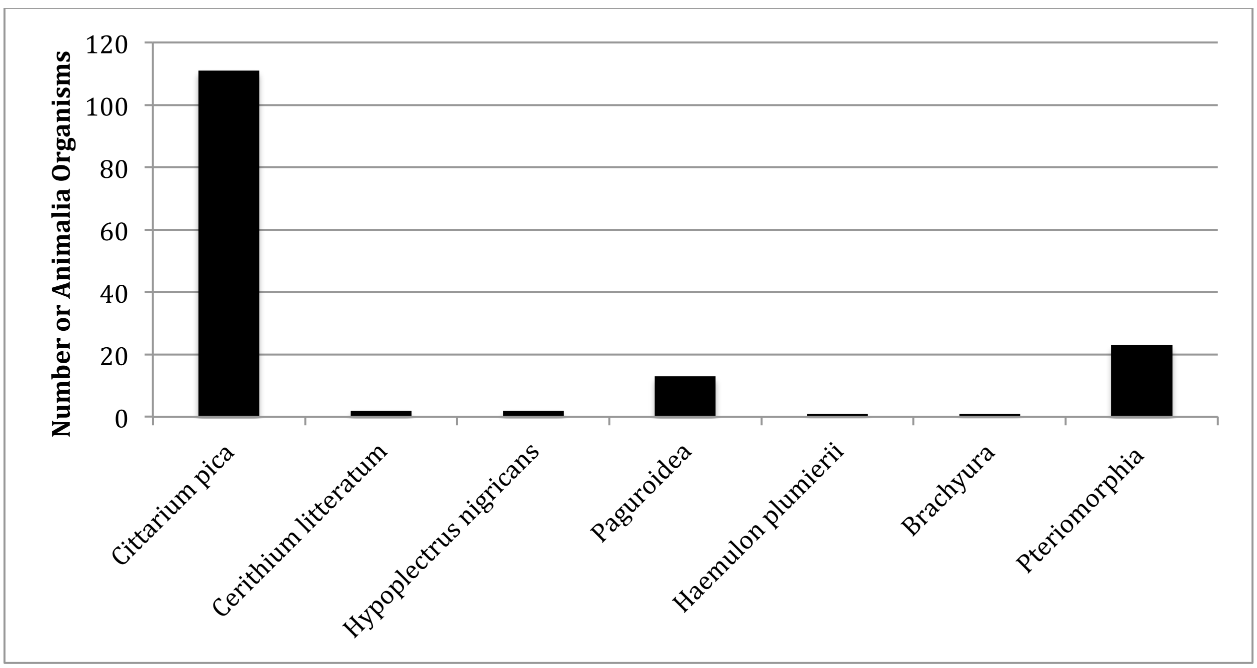

Figure 8: Number and type of Animalia organisms at Big Creek reef site

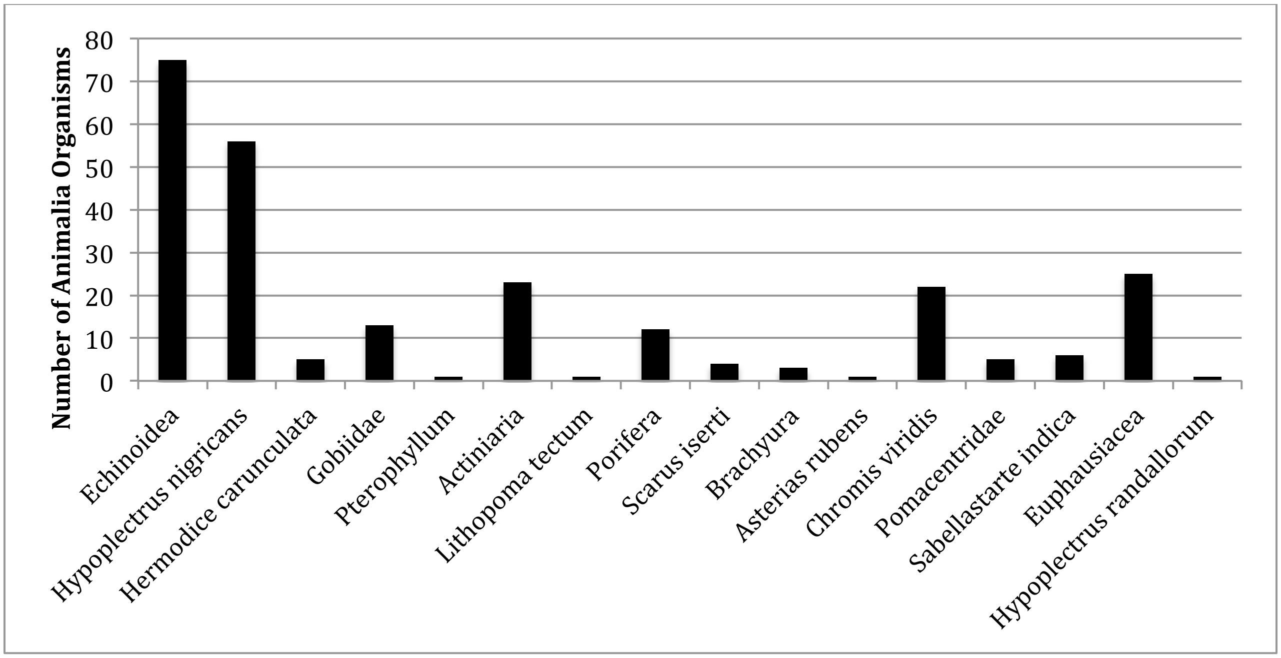

Figure 9: Number and type of Animalia organisms at Boca del Drago reef site

The category of Animalia organisms was broken down by species to further highlight the diversity that existed within each site. In the 125 1x1m^2 quadrat crosshair samples taken at Big Creek beach, 111 *Cittarium pica* (black snails), 2 *Cerithium litteratum* (white snails), 2 *Hypoplectrus nigricans* (Black Hamlet Fish), 13 Paguroidea (hermit crabs), 1 *Haemulon plumierii* (Grunt Fish), 1 Brachyura (common crab), and 23 Pteriomorphia (saltwater mussels) were counted and identified.

In the 125 samples taken at Boca del Drago, 75 Echinoidea (sea urchins), 56 *Hypoplectrus nigricans* (Black Hamlet Fish), 5 *Hermodice carunculata* (fireworms), 13 Gobiidae (Goby Fish), 1 *Pterophyllum* (Angelfish), 23 Actiniaria (sea anemones), 1 *Lithopoma tectum* (gray snail), 12 Porifera (sponges), 4 *Scarus iserti* (Striped Parrotfish), 3 Brachyura (common crabs), 1 *Asterias rubens* (common starfish), 22 *Chromis viridis* (Chromis Fish), 5 Pomacentridae (Damselfish), 6 *Sabellastarte indica* (Featherworms), 25 Euphausia (krill), and 1 *Hypoplectrus randallorum* (Tan Hamlet Fish) were counted and identified.

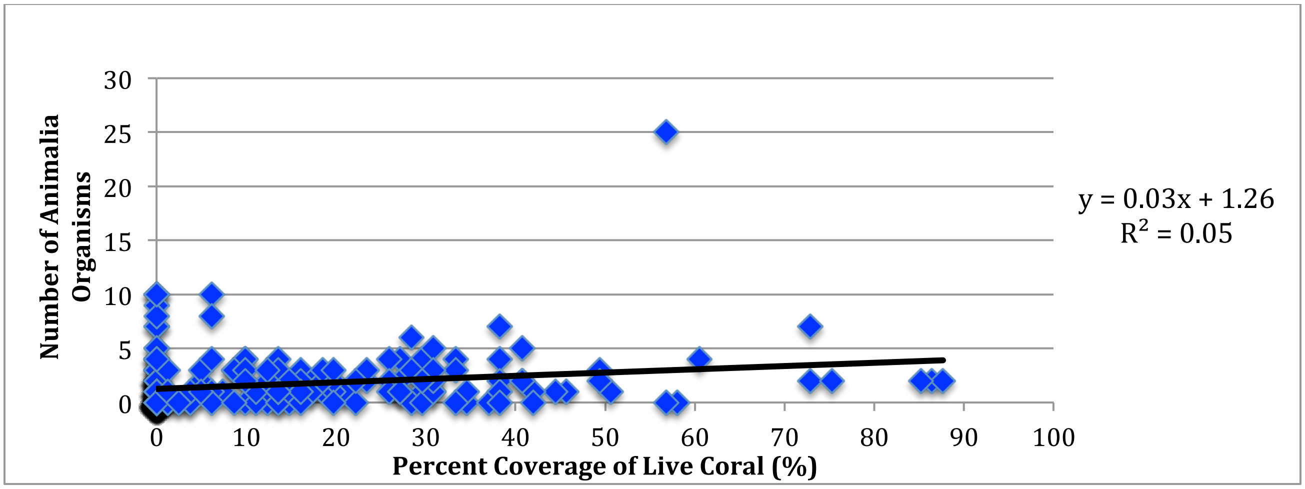

Figure 10: Percent coverage of live coral vs. number of Animalia organisms including both research sites.

A graph of percent coverage of live coral (%) vs. number of Animalia organisms was created using data from a total of two hundred and fifty 1x1m^2quadrat crosshair samples taken at both sites. Regression analysis revealed a non-significant R^2 value of 0.05.

Potential sources of error for this study include errors in counting organisms, rounding errors, and any errors that may have occurred while recording data in the field. Often it was difficult to get an accurate count of organisms while snorkeling due to a combination of strong waves and low tide. There also may have been errors in identifying Animalia marine organisms using the taxonomic guide as I am not an expert in coral reef species and may have misidentified some of the organisms observed.

Discussion

The average percent coverage of organisms at Big Creek reef site highlights the complete lack of any live coral at this site. Of all 125 quadrat samples taken, not a single sample contained live coral. Based on its physical appearance, I estimated that this reef was extremely old and had been dead for quite some time (See Appendix 1). I based this assumption on several factors. For one, when coral die as a result of bleaching, the symbiotic zooxanthellae algae inside the coral leave and the coral loses its color. As a result, the white of the limestone shell shines through the transparent coral bodies (Douglas, 2003). Coral can also be damaged in what is known as partial mortality. Partial mortality occurs when a coral surface is damaged, and the tissue surrounding this region does not regenerate to recover the wounds . This partial mortality appears as a bare patch of skeleton on the surface of the coral, and over time numerous lesions can develop (Paula 1997). In addition, corals can die as a result of disease. The black-band disease is one of the most common coral diseases that occurs as a result of excessive nutrients, and appears as a black ring around a bare white skeletal patch (Paula 1997). The coral reef that I observed in Big Creek beach was not white, but a dark gray or a brown-tan. There were no bare patches of skeleton evident, nor were there any black rings present around the coral bodies. The Big Creek beach reef was also not nearly as fragile as most living or recently living coral is, but was extremely compacted and was able to be walked on without any occurred damage. From these observations, I believe the reef is somewhat fossilized and has been dead for many years. However there are no records that indicate this, so I can only infer its age from my observations.

Even though it is apparent that this reef is in poor condition and likely has been in such a condition for quite some time, there is still a range of marine organisms that utilize this reef. Algae, a variety of Animalia organisms, and seagrass were all found on this reef (Figure 2). It is important to note that the dead coral reef is still a viable habitat for marine organisms, and provides its own unique ecosystem. In addition, it has been shown that coral reefs can come back from as much as a 2,500-year collapse (Toth et al. 2012). In a study on the coral reefs off the Pacific coast of Panama, a 17-foot-long sample of a coral reef was taken in 2012. After analyzing the sample, it was found that the 6,000-year-old reef had been shut down for 2,500 years—about 40% of its entire history. This 2,500-year period likely came as a result of a natural climate shift where the ocean water frequently cycled from high temperature El Niño conditions to the other extreme, La Niña (Toth et al. 2012). But then the climate shifted again at the end of this 2,500-year period, and the reefs came back to life (Toth et al. 2012). This implies that reefs are remarkably resilient, and may be able to withstand some of the effects of global warming (Toth et al. 2012). It is possible that the reef in Big Creek beach may also recover and regenerate—the area should be conserved and protected as the reef may still improve in condition and there are numerous organisms that currently utilize the Big Creek habitat.

The average percent coverage at the Boca del Drago reef site shows that a significant portion of the reef remains alive. There is also a significant percent coverage of other living organisms such as algae, seagrass, and Animalia organisms at the site (Figure 3). However, there is, on average, a 14.06% higher coverage of dead coral at Boca del Drago than live (38.12% and 24.06% coverage respectively). These percent coverage values indicate that, although there is a significant portion of dead coral coverage, the Boca del Drago reef site is in an overall better condition in comparison to the Big Creek beach site. While no singular, objective measure of coral health may exist (Holden and LeDrew 1998), researchers frequently use coral cover as an indicator of overall reef health and condition (McField and Kramer 2007).

A two-tailed t-Ttest with equal variance was calculated to compare the percent coverage of live and dead coral within each site to further analyze percent coverage as an indicator of reef health and prove statistical significance. Statistical analysis using this test ($p < 0.05$) led to the rejection of the null hypothesis that there is no significant difference in percent coverage of live and dead coral within each site. At each site, the mean percent cover of dead coral was greater than the mean percent cover of live coral. These results indicate that there is a statistically significant greater coverage of dead coral at both sites. More research of this area and conservation efforts are needed to protect this remaining reef and preserve its biodiversity.

The Shannon Wiener Biodiversity (H) and Evenness (E) Indices were calculated for each site to determine the diversity of marine Animalia organisms at Boca del Drago and Big Creek beach (Figures 5 and 6). The minimum value of H is 0, which is the value of H for a community with a single species, and increases as species richness and species evenness increases (Atlaf et el. 2014). Big Creek's value of 0.91 (H) can be converted to an effective number of species (ENS) value of 2.48 (Hill 1973). In the case of Big Creek, the H value of 0.91 means that the sample site has an equivalent diversity as a community with 2.48 equally common species. In the case of Boca del Drago, the H value of 2.10 means that the sample site has an equivalent diversity as a community with 8.17 equally common species. This ENS value better highlights the difference in diversity (and not just the index of diversity) between the two sites. For further analysis, species types and counts were graphed at each site (Figures 8 and 9). Through looking at the graph in combination with the ENS values, it becomes clear that the Boca del Drago site has both an overall higher diversity and higher count of marine Animalia organisms.

To further highlight the difference in sites, the Jaccard Index was calculated to compare the similarity and diversity of the Big Creek beach and Boca del Drago sample sets. The Jaccard distance was also calculated to measure the dissimilarity between the sample sets. Based on the results (Figure 7), the sites had very little similarity in their sample sets. The sites only had one species in common, and Boca del Drago had fifteen unique species whereas Big Creek beach only had six. This difference in marine diversity is important to note. For one, biodiversity allows the environment to adjust to shifting conditions. In addition, a diverse ocean is necessary for many of the communities that rely on fish as one of their main economic and protein resources (Cinner et al. 2009). If a certain level of diversity is not maintained in coastal ecosystems, entire ecosystem collapse is not unlikely.

This greater marine diversity observed at Boca del Drago is also interesting to note because there was effectively no live coral at Big Creek, and an overall percent coverage average of 24.06% of live coral at Boca del Drago. However, when the percent coverage of live coral was graphed against the number of Animalia organisms, regression analysis revealed an insignificant correlation of determination value (R^2) of 0.05 (Figure 10). This implies that only 5.0% of the total variation in the number of Animalia organisms can be explained by the linear relationship between percent coverage of live coral and number of Animalia organisms. The other 95.0% of the total variation in Animalia organisms remains unexplained. Even when data from Big Creek is removed and just percent coverage of live coral and number of Animalia organisms for the Boca del Drago reef site is compared, the regression analysis generated an insignificant R^2 value of 0.04. In this case, 96.0% of the total variation in Animalia organisms remains unexplained.

It is noteworthy that, in this study, the percent coverage of live coral does not have a strong relationship with the number of marine Animalia organisms. In other studies, the degradation of reef habitat and loss in live coral directly corresponded to reduced taxonomic distinctness and substantial reductions in species richness (Graham et al. 2006). It has also been shown that overall water quality decreases exponentially with declining diversity (Worm et al. 2006), which can negatively impact the health of the coral reefs and thus their overall cover. The lack of correlation between live coral cover and number of Animalia organisms seen at my study sites may be explained by several factors. For one, only one $1x1m^2$ quadrat sample exhibited more than ten Animalia organisms, while numerous $1x1m^2$ quadrat samples exhibited high counts of live coral. This resulted in a wide range of live coral percent cover, but a narrow range of number of Animalia organisms. This may have affected the linear relationship between the two variables. Furthermore, marine diversity can also be explained by average sea surface temperature (Roy et al. 1998), density of predators, nutrient availability, and anthropogenic activity—none of which I examined in my study. These are all important factors, and may clarify some of the unexplained total variation.

Conclusion

The Boca del Drago and Big Creek coral reefs are in need of conservation to ensure their long-term health and survival. In the Bocas del Toro, changes in coral and molluscan communities demonstrate that reefs near this area have experienced substantial ecological change (Cramer et al. 2005). Transformations observed in molluscan size and trophic structure signal an overall deterioration of reef environmental conditions (Cramer et al. 2005). This finding is supported in both the sites of Boca del Drago and Big Creek beach, as dead coral percent coverage was statistically proven to be significantly greater than live coral coverage ($p > .05$)—implying that the overall reef condition is poor. Big Creek beach was especially degraded as no live coral remained within the site, but it is still possible that this reef may regenerate with time and conservation efforts (Toth et al. 2012).

Big Creek beach should also be conserved due to the fact that, even in its present state, it remains a viable habitat for species such as crabs, seagrasses, snails, two species of reef fish, hermit crabs, and mussels. This reef site represents its own unique ecosystem, and supports life that, without such a habitat, may not exist in this area. Furthermore, Big Creek displayed a particularly high count of marine snails, which provide several useful services. Historically, humans have used many snail species as fish bait and for food. The shells of snails are often culturally significant, and are used in making decorative jewelry and other art. Throughout oceans, gastropods are an important part of the decomposer community, and have been shown to control the abundance and type of algae in some study sites (Lunchenco 1978). As coverage of algae was also high at Big Creek beach, it is likely that the snails found in this site were feeding on it. By feeding on the algae present at Big Creek, the snails may reduce overall coverage of algae and help the reef gain access to the light it needs to carry out the photosynthesis process required for survival. At Boca del Drago, marine snails were also present—in addition to sea urchins, seven species of reef fish, fireworms, sea anemones, sponges, crabs, starfish, featherworms, and krill. This site exhibited a greater diversity of Animalia organisms in comparison to the Big Creek reef—as evidenced by the SWI Index and ENS values.

Past studies have shown that the degradation of reef habitat and loss in live coral directly corresponds to reduced taxonomic distinctness and substantial reductions in species richness (Graham et al. 2006). However, as shown in my results, a regression analysis performed on the relationship between live coral coverage and number of Animalia organisms did not show a statistically significant correlation between the two ($R^2 = 0.05$). Further research is needed to determine why there is such a low correlation between live coral coverage and number of Animalia organisms at the Big Creek beach and Boca del Drago sites.

In addition to more research on the reasons behind this lack of correlation, future research should be performed on the Animalia organism diversity at these sites. As tourism continues to increase around the Big Creek beach and Boca del Drago site, it is likely that anthropogenic activities will impact and change the diversity seen in these areas. These sites should be continually monitored for changes in this diversity as well as in live and dead coral coverage, so that any significant changes in either of these two reef health indicators are considered. There is currently little scientific information available about the status of reefs in Big Creek beach and Boca del Drago, and more reports are needed if these specific coral reefs, and the reefs around the entirety of the Bocas del Toro archipelago, are to be protected and conserved for generations to come

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Appendix

Appendix 1: Dead coral reef at Big Creek Beach site.

Appendix 2: Coral reef at Boca del Drago site.