THE EFFECT OF MANGROVE DEVELOPMENT ON CORAL REEF FISH IN BOCAS DEL TORO, PANAMA AND GLOBAL MANGROVE MANAGEMENT METHODS

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Mangroves provide a variety of ecosystem services to humans, such as timber for construction and a place for tourists to visit. They are also important nursery habitats for juvenile fish that migrate to nearby coral reefs, providing humans fish for food and recreation. In this study, 50-meter transects were conducted in Bocas del Toro, Panama, on coral reefs near coastlines under three categories: (1) with intact mangroves, (2) with mangroves interspersed with development, and (3) without mangroves. Transects were used to determine species richness, species diversity, and biomass of reef fish. The results showed a statistically significant difference in species richness, species diversity, and biomass of reef fish on coral reefs near intact and degraded mangroves when compared to coral reefs without mangroves. The results indicate that the development of mangroves in Bocas del Toro at these sites has minimized harm to reef fish because it has not removed many mangroves and has potentially provided an alternative habitat for juvenile fish. Studies need to be conducted on the relationship between the anthropogenic impact on mangroves and reef fish because mangroves face increasing disturbance due to rises in population and tourism. In addition to the sites in Bocas del Toro, this thesis also examines global mangrove management practices, including the role that ecotourism plays in mangrove conservation. It demonstrates that education about mangroves in local communities, combined with bottom-up management and research through multiple academic disciplines, is the most effective way to conserve mangrove habitats for both local and tourism opportunities.

TABLE OF CONTENTS

LIST OF TABLES

LIST OF FIGURES

PREFACE

I would like to thank Dr. Walter Carson for advising me on this thesis and many other projects throughout the course of my undergraduate career. I would also like to thank Dr. Crystal Fortwangler, Dr. Roger Rouse, and Dr. Molly Warsh for taking time out of their busy schedules to read my thesis and to provide valuable feedback. In addition, I am grateful for the help of Andrew Altieri, Janina Seemann, and the rest of the staff at the Smithsonian Tropical Research Institute in Bocas del Toro, Panama for helping me collect data for the Bocas del Toro case study portion of this thesis. I also would like to thank the Nationality Rooms for providing me with a Nationality Council Scholarship to conduct this research in Panama. Both the University Honors College and the Global Studies Center deserve my thanks, as well, for giving me the opportunity to pursue such an exciting project. Finally, I am grateful to both my family and friends for always supporting me in all that I do.

1.0 INTRODUCTION

1.1 WORLDWIDE MANGROVE LOSS

The combination of human activities and climate change synergistically alters both the structure and functioning of mangroves (Barreto 2008). As decisions are made about how to best develop the coastline and how to bring more money to nations through tourism, the importance of mangrove ecosystems cannot be ignored. Studies have shown that mangroves provide a crucial nursery habitat for many species of juvenile fish because of the shelter, protection, and food that is abundant within the mangrove roots (Nienhuis 2013; Nagelkerken 2006).

The density of most species of mangrove is declining throughout stands of mangroves across the world. When mangrove habitats are significantly damaged or lost, adjacent ecosystems can experience negative effects, specifically seagrass beds and coral reefs. In addition, the people who coexist with mangroves are forced to adapt to a new way of life that does not depend as much on mangroves. My objectives here are to examine how mangroves have been used and managed across the globe and to determine which forms of management have been the most successful. I will also examine the role that ecotourism has played in the preservation of mangrove ecosystems and the potential connections between ecotourism and conservation initiatives. Part of my thesis will focus on Panama, and will include scientific evidence needed to evaluate the degree that mangroves provide important habitats for numerous

species of juvenile fish. Mangroves in Panama (Fig. 1) are particularly important because of their ecological and social roles in both fisheries and tourism.

Many anthropogenic factors cause the degradation of mangrove forests all over the coast of Latin America, including poorly planned tourism, the overharvesting local fisheries, pollution from nutrient runoff and trash, and the exploitation of mangroves for wood (Ellison and Farnsworth 1996). Panama's mangrove forests are declining because the development of the coastal zone is increasing due to overpopulation and tourism. In the 1980s, Panama lost large expanses of mangroves. In just ten years, the amount of mangroves in Panama declined by 145 km^2 (Ellison and Farnsworth 1996). Although a substantial amount of hectares of mangroves are still lost each year, deforestation began to decline by the 1990s as more conservationists began to realize the importance of mangrove ecosystems. According to the Food and Agriculture Organization of the United Nations (2005), 3.6 million hectares of mangroves have been lost worldwide between 1980 and 2005, but there are still 15.2 million hectares of mangroves left.

Among all of the factors affecting mangroves, tourism is the main one that I am interested in studying because it is one of the fastest growing influences that can be mitigated by proper management. Because forty-eight percent of all tourism in Panama is on the coast, rapid development occurs in these areas (Guzman 2003). Panama has become an attractive and affordable destination for tourism and for people from other countries who want to retire in a tropical location (Jackiewicz 2010). The government of Panama has enacted policies to make the process of coming to Panama easy and cheap, causing a boom in both temporary and residential tourism (Jackiewicz 2010). Thus Panama can serve as a model to study the loss of mangroves and can be used to compare the losses there to other countries both in the same region of Latin America and elsewhere. Because mangroves are typically threatened worldwide, a

global effort emanating from both governments and local people will likely be necessary to combat the loss of these ecosystems. However global initiatives require knowledge from regional cases studies (e.g. Panama) and an overall melding of both global and regional approaches to environmental management and conservation. A management technique in one part of the world might be a novel and beneficial way to move forward in another part.

1.2 THE ECOLOGICAL LINK BETWEEN MANGROVES AND CORAL REEFS

Herbivorous fish, like many reef fish, are especially dependent on mangroves as juvenile nurseries (Mumby et. al. 2004). Studies on this connectivity between mangroves and coral reefs can provide useful information for conservation efforts. Another reason why I chose to conduct my scientific research in Panama is because of the need to focus conservation efforts on coral reef ecosystems in the Caribbean Sea. Coral reefs in the Caribbean exhibit less resilience than reefs in the Indo-Pacific due, in part, to the lower biomass and diversity of herbivores and the faster rates of macroalgal growth in the Caribbean (Roff and Mumby 2008). Mumby and Hastings also found that higher grazing pressure by parrotfish lead to greater coral recovery in the face of disturbances (Mumby and Hastings 2008). Parrotfish have been used in studies in the Caribbean in the past because they are less vulnerable to fishing than carnivorous fish (Vallès 2014). In addition, a study in American Samoa found that hard coral coverage increased with more biomass of large excavators (bioeroders). In this study, Heenan (2013) demonstrated that the biomass of herbivorous fish explained variation in benthic coral coverage. Therefore, it is critical to evaluate the status of herbivorous fish, like parrotfish, within coral reef ecosystems in Panama. Increasing coral cover and resilience is essential for coral reefs, and since herbivores

help do that, they are important to conserve. Because mangroves provide habitats for juvenile reef fish, mangroves need to be protected.

Coral reefs are also facing many pressures due to overfishing, development, and climate change. Studies need to be conducted to determine how these ecosystems can be more resilient in the face of these threats. One way to study these ecosystems is via indicator species like herbivores, such as parrotfish. To study these fish, researchers need to examine one of their primary habitats: mangroves. The connectivity between mangroves and coral reefs cannot be ignored. Rogers calls connectivity a prerequisite for resilience, and it is important to study how ecosystems are connected as they face anthropogenic impacts (Rogers 2013). In the future, mangroves will be necessary as protection from the stronger storms that are predicted to arrive with climate change. For example, in the tsunami that decimated thirteen Asian and African nations in 2006, it was shown that mangroves mitigated possible damage that the tsunami could have caused (Kathiresan 2005). Other countries are taking measures to protect mangrove forests, too, because of the protection that they have seen them provide to other nations. For example, after the 2004 tsunami in Sri Lanka, the Bombay High Court banned the destruction of mangrove forests in Mumbai, India (Everard 2014). There is no doubt that mangroves are an important habitat because, without mangroves, unpredictable damage to both land and ocean ecosystems could occur.

Development and human migration to coastal areas are putting an unbearable amount of stress on mangrove ecosystems. Here I define development as "development of a specific region achievable by exploiting the specific socio-economic, environmental and institutional potential of the area" (Bellù 2011). The construction of new homes and infrastructure to support the settlement of people in new places has removed and damaged mangroves. The wood of

mangroves is often used as building materials, and at times, entire mangrove swamps are paved over to provide more space for buildings (McMahon 2008). Below I describe the effect of development amongst mangroves on fish on coral reefs in Bocas del Toro, Panama as a case study to show how development is currently affecting coral reef fish.

To understand coastal development and its relation to tourism, I conducted a literature review of the management of mangrove ecosystems globally and how ecotourism can be used to foster better conservation efforts. Countries with well-managed mangrove habitats and ecotourism operations will have healthier coral reefs and less damaged mangroves than countries that place economic growth over environmental protection when making development plans. By looking at multiple case studies, it is possible to develop a better understanding of how the development of mangroves can best be managed. Hopefully, these findings will be able to provide information that can help mangrove habitats in the future. Here I take a multidisciplinary approach to examine ways to preserve mangrove ecosystems. Kelner (2013) accurately says that “no discipline is an island”, and I have done my best to approach the problem of mangrove conservation via an interdisciplinary lens.

2.0 A SHORT HISTORY OF BOCAS DEL TORO

History is an often overlooked and underutilized discipline when examining the management of a particular ecosystem. For many species, extinction risk, recovery targets, and fishery stock status can be better determined if historical data are consulted. This can lead to improved management decisions (McClenachan 2012). Another particularly important opportunity that historical data can provide is the stimulation of public support to protect an ecosystem. For example, ecological baselines in the Florida Keys National Marine Sanctuary have been used to show people just how drastically these environments have degraded over time (FKNMS 2011). When people begin to understand what an ecosystem looked like in the past and can compare it to its current state, conservation efforts can emerge with the new purpose of restoring an ecosystem. The scientific study that is a part of this thesis occurred in Bocas del Toro, Panama. Although this town is being used primarily as a tourist destination now, examining its past shows the relationship of this location with nature over time.

Bocas del Toro in Panama has been considered to be a paradise for hundreds of years. Many visitors to the area saw it as valuable for both its beauty and its resources. In a book describing the location of Bocas del Toro in 1911, it was said, “It will be remembered by students of President Lincoln’s administration that this was one of the locations considered by our Government for a naval station. In fact, it is almost certain that if Lincoln had not been assassinated we would have acquired the Lagoon” (Edwards 1911). As it has been with humans

and nature in many parts of the world throughout time, developers could not leave a place as practical and as beautiful as Bocas del Toro in its natural state. Edwards (1911) even predicted that by saying, "[Bocas del Toro] is remarkably salubrious, and on account of its ideal facilities for bathing and small boating and its marvelous scenery seems doomed to develop into a smart winter resort". A few contemporaries of Edwards also pointed out its beauty, one writing, "the province is famous for its beautiful Almirante Bay" (Villegas 1917).

People flock to beautiful destinations as tourists, and development has to occur to meet the needs of these visitors. Through hotels and restaurants for tourists to enjoy, or through new roads or homes for the people who find job opportunities in tourism, the same nature that people come to see is altered because of the arrival of those people. Development to sustain tourism operations in Bocas del Toro and in places similar to it has occurred rapidly in the past few decades but is currently at a crossroads. The town can now either choose the path of development that maximizes profit and does not prioritize the environment, or it can choose to develop the landscape in a way that is sustainable. The only reasons that Panama had not been more developed before the twentieth century, even though its natural resources were well known, was because there was uncertainty surrounding land titles, good roads were lacking, and a strong labor force did not exist (Villegas 1917). Since the exploration of Panama by early explorers, the bountiful resources of Panama's environment have been well known.

Although early Spanish explorers in the sixteenth century rarely mentioned mangroves, they did comment on the scenery during their interactions with people. In Mexico, Captain Bernal Diaz del Castillo only mentioned mangroves by saying that the sides of the river were covered with them and that the canoes of indigenous people were amongst them (Kerr 2004). The only mention of mangroves in the writings of Bartolomé de las Casas, the well-known

Spanish historian in the sixteenth century, was when European settlers found one of their companions hiding from an indigenous group amongst the mangroves. The way he phrased this anecdote is what is important. He called the mangrove area an "entangled and almost impervious grove" (Irving 1828). This suggests again that mangroves before any form of anthropogenic impact, apart from indigenous use for fisheries and timber, were dense and plentiful. Examples like this are often hidden in introductions about what the early explorers saw when they arrived in the Americas. In one such instance, an observer described how "mangroves choke the shallow inlets and the low salt-water marshes, standing on stilts in the water" (Howarth 1966). Today, in many areas where humans reside, this quote does not describe the landscape. This kind of historical, qualitative information is helpful to establish baselines. Even though these accounts are not quantitative measurements of the density of mangroves at the time, narratives suggest that mangroves abounded when early explorers arrived to Latin America in the early sixteenth century and again in the early part of the twentieth century.

Later writers have also provided accounts of the people and resources of Panama, but it was difficult to find a mention of nature in and of itself without an indication of its value to humans in the books about Panama in the early part of the twentieth especially. This was true even in books that were about the formation of the Panama Canal and the land where the canal was to go. In the time before the Panama Canal was built, when land value was analyzed and disputed, land with mangroves was not highly valued. The valuation on the property in Panama that the United States wanted to buy was a thousand dollars an acre, which is specified as land that was all mangroves or swamps or "lands that [the United States] did not think were worth over five dollars an acre" (Investigation of Panama Canal Matters, 1906). Even up to the 1980s and 1990s, lands with mangroves were considered unhealthy in South America, which led many

people to engage in purposefully harmful and negligent actions towards mangrove lands (FAO 2005).

However, in the past few decades, mangroves have been removed or damaged in Panama not because they were considered unhealthy, but because more space was needed to support the infrastructure that is required in any tourist destination. An increase in tourism often causes mangrove areas to be developed because visitors to the Panamanian coast want to stay right on the water. Tourism in Panama did not really develop until the creation of the Panama Canal. Villegas' 1917 book showcased the Republic of Panama, explaining how authorities of the Panama Canal coordinated "gasoline launch trips" for tourists to view the Panama Canal (Villegas 1917). One chapter, focused specifically on tourism, explained the best ways to see Panama City, by coach, automobile, or streetcar. However, the most popular activity for tourists was to go on a day trip from Panama City to islands that were good for "sea bathing", or swimming. Even in the early 1900s, the ocean was a crucial reason for tourists to visit Panama.

The town of Bocas del Toro now heavily relies on tourism to provide a source of income for its inhabitants, but it was not always this way. Before tourists flocked to the small town, it began as a port town to ship bananas to other locations. The United Fruit Company, an American company that had a monopoly on banana plantations throughout Central America, used Bocas del Toro as a base for many years. To create the town and nearby banana plantations, mangroves had to be cleared away. The United Fruit Company used Bocas del Toro until the founding of Almirante in the early 1900s, a town near Bocas del Toro but on the mainland, which caused Bocas del Toro to lose some of its commercial value (Villegas 1917). The countless banana plantations and 200,000 cocoa trees owned by the United Fruit Company

in the province of Bocas del Toro still brought money and people to both of these locations, which is why they still exist as towns today (Villegas 1917).

In addition to bananas and cocoa, this area has provided people with mangroves. A source from 1903 acknowledged how good mangroves were for building ships (Hale 1903). By 1917, mangroves became known in Panama to be suitable for many uses, especially for sailboats, firewood, and charcoal (Villegas 1917). At this time, mangroves were abundant, which meant the fish that used the roots as juvenile habitats were abundant. In describing Almirante Bay next to Bocas del Toro, Hale in 1903 states, "Good fish are plentiful in the bay" (Hale 1903). This one line is helpful to make a comparison with the current situation of fish in the same waters. Overfishing and the loss of habitats today have rendered a very different situation, for both the environment and the indigenous groups that have always lived off of it. For example, in the early twenty-first century, people of the Ngöbe-Buglé group say that they have two options when it comes to finding work. They can either do manually intensive labor with banana plantations or they can dive for fish. Due to fewer fish and lobster existing in the bay, local communities have to dive deeper and deeper to access the same resources. It is a dangerous line of work that can cause even the most experienced of divers to drown. The article says that the biggest challenge to resource management is education because people will not know that the ocean could be healthier than it currently is unless they are taught that (Kuntz 2010).

With the right education, sustainable development is possible in Bocas del Toro, Panama. In one article, Milford Peynado, a hotel owner in Bocas del Toro, is quoted as saying, "One of our main assets here is the environment. If that goes, your business goes. So if you can do anything to protect it, you know you'll still be in business." People in Bocas del Toro are realizing how important conservation efforts are to the economy. Milford Peynado attended the

conservation training sessions put on by the Rainforest Alliance, which sought to set criteria for sustainability. Conservation training sessions such as this kind help local people sustainably run their businesses. Different agencies set different standards for sustainability, but criteria often include emergency plans in case of a pollution accident and benchmark standards for energy consumption and chemical use (Goodstein 2006). By understanding what parts of the environment, like mangroves, are essential to preserve, the people of Bocas del Toro can minimize their impact on the environment there.

Education can also help shape perceptions of the wildlife that lives in Almirante Bay. For example, in Bocas del Toro, without proper education, people will think the island naturally has a small population of sea turtles. However, sea turtles are still seen as a delicacy in Panama, and although it is illegal to fish for them, they continue to be caught on purpose and through bycatch, or unintended catch. International non-profit agencies often try to educate younger generations on coastal conservation to solve issues such as this. In Bocas del Toro, the Sea Turtle Conservancy works to educate school children about sea turtles and other important conservation issues (personal experience 2015). Whether it is about sea turtles or mangroves, local people and tourists need to be educated on the natural resources around them and how they looked in the past.

Evidence suggests that mangroves have been abundant in Panama for hundreds of years and that they have been valued very little by people seeking to develop the land. Although the value that mangroves provide cannot be seen directly, mangroves have a high economic value through the resources that they provide for both humans and the environment. Since the creation of the Panama Canal, people have been visiting Panama to see the ocean. Without mangroves to

prevent coastal erosion and to provide juvenile habitats for coral reef fish, the ocean will not continue to be as appealing for tourists who come to snorkel or scuba dive on the reefs.

To guide conservation efforts, it is important to understand the conditions that currently exist in Almirante Bay, the area surrounding Bocas del Toro. Almirante Bay exhibits stress from particle run off and eutrophication, which can be seen through the analysis of environmental data (Seemann 2014). Previous studies have also shown a low abundance of larger predatory fish in the area due to overfishing, such as the fish families of Haemulida, Lutjanidae, and Serranidae. Seemann's 2014 study concludes by saying that coral mortality will result if the coral reefs of Almirante Bay do not become better protected. This would result in even fewer fish and less tourism. To protect coral reefs, mangroves must also be protected. Mangroves on the coastline help to prevent more runoff of sediment into the water and give commercially important predatory fish a juvenile habitat. Further study of this location is critically important to guide management decisions on how to best protect the environment there, for both the people who live there and the visitors who come to see the flora and fauna. Studying the past can only help to inform management decisions in the future so that this historically beautiful and resource-full location can continue to provide people with the same resources as it always has.

3.0 BOCAS DEL TORO CASE STUDY

3.1 INTRODUCTION

With fewer mangroves available to provide a haven for juvenile fish that will eventually inhabit the adjacent coral reefs, I hypothesize that fish species richness, species diversity, overall fish biomass, and the biomass of key indicator species will be highest on coral reefs near intact healthy mangroves (intact), lower in areas with damaged mangroves (degraded), and lowest in areas without mangroves (absent).

3.2 METHODS

I used habitats within the Almirante Bay of the Caribbean Sea in Bocas del Toro, Panama (Fig. 2) to evaluate how the quality mangroves habitats (intact versus degraded) and the absence of mangroves influence adjacent coral reef ecosystems. I selected nine coral reef sites throughout the Bocas del Toro archipelago: three with intact mangroves, three with degraded mangroves due to development, and three with mangroves absent. Degraded mangroves were defined by the presence of development (e.g. docks) interspersed throughout the mangroves. At each site, using scuba, I quantified fish species (greater than 2.5 centimeters) abundance along two to five 50-meter x 5-meter belt transects. Fish abundance was recorded throughout the entire water

column. Fish were quantified by swimming the length of the same transect line twice. Two additional passes were made to quantify cryptic species within 1 meter of the transect line (for details of this standard methodology see Edgar and Stuart-Smith 2014). Fish biomass was also calculated using allometric relationships (www.fishbase.org). I compared mean species richness, species diversity (using the Shannon-Wiener Index, see Ricklefs and Releya 2014), and mean total fish biomass among the three sites (intact vs. degraded vs. absent) using a one-way ANOVA.

Each site with mangroves and with damaged mangroves was also given a level of anthropogenic impact. On a scale of 0 to 5 for each category, with 0 being no impact and 5 being a strong impact, the number of cut mangroves, cut trails, and fringe degradation was assessed as one category. The same scaling was used to quantify the number of dead mangrove individuals seen along a 100-meter transect above the water. Using the same scale, I also quantified the amount of trash seen above and below the water, the amount of development within 100 meters, and using interviews I determined both whether the sites were popular tourism destinations, and whether the sites were important for local fisheries. These data were collected by visual census and interviews with retired fishermen and local tourism operators. Also, information was collected from boards that advertised sites that tourists could visit (Fig. 3). The numbers were averaged to give the sites a total anthropogenic impact number (Table 1; Fig. 4). While these metrics provide information on human impacts, there of course could be other processes impacting these mangroves (e.g., nutrient runoff).

3.3 RESULTS

Intact sites (STRI Point, Almirante, and Coral Cay) had similar species richness to degraded mangroves (Punta Caracol, Casa Blanca, and Juan Point) (Figures 5 and 8). And both had higher richness than sites with no mangroves (Popa, Salt Creek, and Hospital Point) (one-way ANOVA, $p = 0.017$). Intact mangroves had less average species diversity than degraded mangroves and both had higher species diversity than sites without mangroves (Figures 6 and 9, one-way ANOVA $p = 0.010$). Sites with intact mangroves have a significantly higher average total biomass than sites with developed mangroves or no mangroves. The sites without mangroves had the lowest total biomass overall (Figures 7 and 10, one-way ANOVA $p = 0.048$).

Indicator species were also chosen to see how their biomass differed amongst the different site categories. Their distribution amongst the sites was not statistically significant, but the presence or absence of these species at these sites is vital to note due to their importance, both ecologically and commercially (Table 2).

3.4 DISCUSSION

Counter to my hypothesis, degraded and intact sites had similar species richness, likely because degraded sites retained mangroves and always had docks interspersed throughout them. These docks could have provided another means of shade and protection for juvenile fish (personal observation 2015). This shelter and protection for juvenile fish is similar to the benefits that juvenile fish get from mangroves. Although a study using artificial mangroves found that the positive relationship between mangrove habitats and the degree of shade and structural

complexity is species specific, it showed that fish preferred mangroves for their level of shade and structural components (Cocheret 2004). Since docks provide shade and structure, more research needs to be done to evaluate the degree that shade and protection from docks might substitute for mangroves. Further research could focus on dock design to see if there were ways to promote viable refugia during development.

Species richness peaked at 20, yet the database of fish seen in Bocas del Toro by the Smithsonian Tropical Research Institute is 216 fish (STRI Fauna Database). Although some of these fish are found in other habitats (like the open ocean, seagrass beds, or mangroves), the number of different fish species I observed on the coral reefs was extremely low. This is potentially alarming, especially if this is caused by overfishing, habitat loss due to more extreme development, and pollution from nearby towns and rivers. However, this number could be lower than expected due to limitations of the sampling method.

Comparable to the results that I received for species richness, the site category in this study was correlated with the species diversity on the coral reefs. The results for the category of intact and degraded mangroves were almost similar. This indicates that there was either not enough development to be detrimental to the reef fish or that the docks became an artificial habitat for these juvenile fish.

In agreement with my hypothesis, sites with intact mangroves had a higher total biomass than degraded mangrove sites. However, this is contrary to the results of species richness and diversity. There are two possible reasons for this. One reason is that degraded sites had more juvenile fish migrating to the reef due to the disturbance. This would increase both species richness and species diversity, but juvenile fish would not add much to the total biomass. Another reason could be that the data from STRI Point, a site with intact mangroves, biased the

average total biomass count. STRI Point is the closest spot to the Smithsonian Tropical Research Institute and fishing pressures might be lower because fishermen might be reluctant to collect fish near the station.

Eight herbivorous fish from the Smithsonian Tropical Research Institute Fauna Database were chosen as indicator species, but only five of them were seen at all during the study. Mumby et. al. (2004) used only four indicator species, and all four were seen in the waters around Bocas del Toro, but two of the indicator species were never seen in the locations without mangroves). Of the seven commercially important species, two were not seen at all in these surveys and two of the remaining five were not seen in sites without mangroves. More research needs to be done on these indicator species, but without mangroves, the herbivorous fish that are important for coral health and the commercially important species of fish will likely decline in abundance.

All of these results highlight the importance of having mangroves next to coral reef ecosystems. The presence of lionfish, an invasive species, in this study is also concerning. The presence of lionfish at certain sites could have impacted the results. Green et. al. (2012) found that lionfish over a two-year time period were correlated with a loss of their prey by 65%. Although this could have depended on other factors, it is likely that lionfish play a large role in changing the composition of coral reefs. A lionfish were seen on one of the transect lines at Juan Point (one of the sites with degraded mangroves), and lionfish were seen outside of the transect line range on the reef at Punta Caracol (a degraded mangrove site) and on a mangrove transect at Popa (a site with no mangroves). It is also likely that lionfish were at many other sites due to their widespread distribution in the Caribbean.

Future studies need to be conducted at this location to assess the impact of mangroves and mangroves with development on coral reefs and other adjacent ecosystems. One such study could compare the species found in mangroves and under docks to see if the docks are really providing an alternative juvenile habitat for fish. Another interesting study would be to assess a reef before development is placed in a mangrove habitat and to continue to monitor this site for many years to see if species richness, diversity, or biomass stays the same or differs.

4.0 GLOBAL MANGROVE MANAGEMENT

By the 1990s, research on many ecosystems had been well established across the world. However, the research on mangroves, especially in regions of the world where external funding was not readily available, was lacking. A paper written in 1990 on mangrove research in Latin America and the Caribbean called for the development of a regional program that would support ecosystemic research, the development of management guidelines, and the provision of public environmental education (Schaeffer-Novelli 1990). Although advances have been made on these fronts, mangroves continue to be understudied and are shadowed by conservation efforts on more charismatic ecosystems, such as coral reefs. Mangrove forests and their connection to human populations remain significantly understudied, especially in places like South America and West Africa. Studies need to include the ecology of resource use in mangrove forests, as well as how the ecosystem functions, to best understand how to manage these habitats (Walters 2008).

In trying to understand how to manage mangroves, baseline data must first be measured. It is helpful to discover how mangroves looked in the past so that they can be returned to their natural state. A study done in Venezuela at the Cuare Wildlife Refuge compared aerial photos of the mangrove fringe and found that the total area of living mangroves had decreased 55% in 26 years in some areas (Barreto 2008). Natural climatic events, such as El Niño Southern Oscillation, have partially contributed to this decline of mangroves (Blanco et. al. 2006). However, human activities, both on a micro and macro scale, are the main factors driving

mangrove mortalities. By looking at case studies from around the world, it is possible to obtain a general idea of what the best mangrove management practices are. Although many of these mangrove management strategies are regionally and culturally specific, some overall themes can be seen throughout this section.

4.1 LEGISLATION TO PROTECT MANGROVES

Legislation to protect mangroves exists in many areas, but it is often not considerate of all of the people that depend on these ecosystems. A prime example of how mangrove ecosystems have been understudied and over utilized exists on the coast of Ecuador. In Ecuador, people have lived amongst the mangroves for hundreds of years. Once shrimp farming became popular on the Ecuadorian coast, the lives of these people changed. Shrimp extraction from the mangroves became an important part of the economy in Ecuador, but it damaged countless mangrove habitats and displaced many of the native population (Latorre 2013). When it was revealed that shrimp aquaculture and urbanization caused irreparable damage to the mangroves, the government of Ecuador passed Executive Degree 824 to highlight the importance of mangrove conservation. Although a commendable law to restore these ecosystems to their former health by limiting extraction, it prohibited even traditional resource extraction of the mangroves (Latorre 2013). Even though local people had sustainably used mangroves for generations, the destruction produced by large businesses caused the government to enact a law that would change local people's lives. Unfortunately, with no ability to actually implement these policies, mangrove usage and degradation by both native populations and the businesses involved in shrimp aquaculture continued.

The 1990s brought change to the world of mangrove conservation in Ecuador. The Coastal Resource Management Program began with the goal of using a participative form of management by local communities (Latorre 2013). However, these community efforts later collapsed through the determination of the shrimp industry to create shrimp farms in those areas, both legally and illegally. In addition, pollution from mining and wastewater, often from sites upriver and too far away to be controlled by local management systems, added another level of harm to these ecosystems that the native communities could not control (Latorre 2013). The struggle to conserve mangrove ecosystems still continues in Ecuador, as it does in many other countries.

In addition to the fish surveys that I conducted during my case study of Bocas del Toro, I would have liked to better understand what laws protected the mangroves that I looked at. In Panama, there is little legislation that is specific to the management and conservation of coastal ecosystems. Although there is legislation in place to protect the environment in general, more specific laws need to be made to conserve these valuable ecosystems ("Status and Uses of Mangroves"). At least 66 laws and other forms of legislation in Panama mention mangrove protection, but they fall under so many different departments that it is difficult to assign liability, and responsibility is often lacking (Cienfuegos and MacInnis 2015).

From just these few case studies, it can be seen that legislation is necessary to protect mangrove ecosystems, but it must take into account local, sustainable use of mangroves. That way, local groups will not have to change their way of life due to the environmental damage caused by other people, which is what inspired the legislation to be made. Also, laws need to be made not only for the area that is being protected, but also for areas whose poor management can negatively affect the protected area. Every law that is made to protect mangroves must be

enforceable and transparent so that someone can be held accountable if it is not followed. This way, more progress can eventually be made.

4.2 COMMUNITY MANAGEMENT OF MANGROVES

Global, larger-scale efforts to preserve mangrove ecosystems currently lack the ability to be implemented and enforced. In place of larger efforts, it can be beneficial to examine case examples to show the importance of community-level management. Case studies also suggest that community-level systems must be protected and supported by the government so that larger and more powerful stakeholders will not undermine them. The inclusion of stakeholders is important in managing an ecosystem that is used by multiple parties. Stakeholders in the management of mangroves might include local community members, government officials, fishermen, tourism operators, and more. In the above example of Ecuador, stakeholders included both local people and shrimp farmers. However, if commercial enterprises, both internal and external of a country, are considered stakeholders, it is possible to override the opinions on the less powerful villagers on management decisions (Walley 2004). This is indeed what happened with the shrimp farmers in Ecuador, and the battle between local people and those who want to profit from harvesting shrimp continues today. Ecuador is not the only country where people feel connected to mangroves, though. The following sections use case studies to give examples of both unsuccessful and successful mangrove management schemes in terms of the ecology of the mangroves and the culture of the people.

4.3 PRACTICAL IN THEORY, NOT IN APPLICATION

Many mangrove management methods are good in theory but not necessary good in application. This section highlights the failures of some management operations to show the problems that arise in trying to manage mangrove ecosystems. In many Asian countries where mangroves exist, mangroves have always been at the heart of people's lifestyles. The resources that mangroves provide are invaluable to the lifestyles of multiple communities there. For example, on Banacon Island in the Philippines, mangroves have always been heavily used as firewood. Since this was such a precious resource for people, the islanders knew that they had to do something if they wanted firewood in the future. As mangroves grew scarcer, residents began to plant new mangroves in 1957 (Walters 2003). By 1977, all of the natural trees within two to three kilometers of the village had been cut and replaced by a type of mangrove that was easiest to plant and worked best to build homes and fences or as firewood. Banacon became a wilderness area and a model of how communities could restore critically damaged habitats, but the harvesting and planting of a monoculture changed the way the ecosystem functioned because it was not natural (Walters 2003). That is why both the nature sciences and the social sciences must play a role in developing environmental management plans. Ideally, ecosystem-based management would be the way to combine multiple disciplines to better understand the environment. It recognizes that both nature and humans are interdependent, and it takes into account that social and economic systems are inseparable from ecosystems (UNEP 2006). In this example, people understood the value of mangroves to their society, but they did not understand the ecology of mangroves well enough to create a healthy ecosystem.

Mangrove restoration in the past has been tricky, but it seems to be possible when the community is not just involved but also educated. Before conducting a mangrove restoration

project in American Samoa on a mudflat that was previously a mangrove habitat, the local Nu'uuli village council and landowners next to the restoration site were asked by the project leaders to express support (Gilman and Ellison 2007). This restoration project was successful, however, it would have been even more successful if not for the human disturbance in the area. Debris, such as trash, was found in the water amongst damaged saplings, leading researchers to believe that the mangrove saplings would have survived if not for this physical damage. This means that the community involved in the restoration project and nearby communities need to become educated about what indirect effects their actions could have on projects such as this one.

Also, this restoration project required an initial cost because it takes labor to transport the saplings from a healthy area to the new site. 84 percent of the cost was due to human labor, which could cost less in less developed countries or could be negated through the use of volunteers. This study highlighted the importance of volunteer community participation in the restoration project, or else the new mangroves would have been cut down for firewood like the ones that were previously there (Gilman and Ellison 2007). In a place like this, collaboration needs to exist between scientists who might know what locations are best to remove saplings from and the people who will have to manage the new mangrove area after the scientists have left. An even better alternative, however, would be for communities to learn how to protect these ecosystems before they become so severely damaged that new plants have to be brought in to restore them back to their former status. In some areas, though, communities do not have the responsibility to manage these ecosystems.

In the Sundarbans, the world's largest single mangrove forest in Bangladesh, resources are managed through government-made wildlife parks. However, illegal timber harvesting and

unsustainable shrimp farming still takes place within the territory (Roy and Khorshed 2012). Under current control, local people, even though they are the main beneficiaries of the resources provided by the mangrove forest, have no control over the management of the ecosystem. In the future, to reduce degradation of the mangrove forest, the government may decentralize its authority over the protection of the ecosystem so that local communities can establish management systems (Roy and Khorshed 2012).

It can be seen here that often, seemingly suitable mangrove management strategies do not work. By looking at the case studies that have not been successful in the past, future management decision makers can know what not to do. For example, these case studies have shown that planting mangroves as a monoculture does not restore their natural state. Also, they have shown that to effectively manage an area with new mangrove seedlings, trash control must extend beyond the range of the protected area. In addition, it is less expensive and more successful to create a volunteer network of local people to manage mangrove environments, unlike in the previous examples. However, successful mangrove management examples do exist.

4.4 MORE SUCCESSFUL MANAGEMENT SCHEMES

With creative solutions and informed people, who have both scientific and local knowledge, mangrove ecosystems can be protected. Most current mangrove preservation actions are occurring in areas where a significant amount of mangroves have been removed, and it is therefore necessary to plant more mangroves. An interesting example of marine conservation in Latin America comes from Colombia. In the village of Pascaballos, even though the people there are extremely poor and lack the funding to engage in strong conservation efforts, a nursery

of mangrove seedlings to plant in the surrounding areas was established. The eventual goal of this project is to provide mangroves that can be legally taken to use as construction materials, but the presence of the nursery is generating conversation about mangroves and why they are important (Sánchez 1999). Although it is best to begin a project with the support of the community, the project itself can help educate and can keep people interested in the conservation effort.

When communities do not have the required funding to engage in conservation efforts, the government can declare a location as a protected area. An example of that occurred on the west coast of Panama. The Coiba National Park was designated a national park in 1991. A proposed law that was meant to strengthen the protection surrounding this national park, such as banning hotel development in the park itself, was vetoed by the president on the account that it restricted tourism development too much (Steinitz et. al. 2005). A study that assessed the possible alternatives for the future of this national park found that the vegetation in this region, especially the mangroves, requires the maximum amount of protection from development. In comparing alternative futures for the national park, what seemed to be the best for the nature of the park (the construction of only two guest houses at predetermined locations) was the worst for the economy. No regulation, which could result in significant environmental damage, was the best for the economy (Steinitz et. al. 2005). More studies need to be conducted to assess the current state of this location.

However, mangroves can help the economy by transforming coastal areas that are not very productive into areas that benefit both humans and the environment. In Colombia and Venezuela, a research team tested a proposal of a new kind of mangrove restoration technique to see how it worked out. Mangrove Productive Oases were formed to establish new mangrove

ecosystems by developing artificial wetlands in low-productivity coastal areas. Ancestral knowledge of the people that live in these coastal communities was used to develop this project, and local communities assisted with it. These cases showed that it is relatively easy to create artificial mangrove ecosystems and that they provide many goods and services to local communities. Traditional knowledge, if available, is important to use when creating these areas, but many professionals and sectors of society need to be consulted to best plan mangrove oases (Sánchez-Arias 2008).

One group of professionals that should be consulted is fishermen. Artisanal fishermen definitely need to be a part of the conversation when planning mangrove conservation because they can damage mangrove ecosystems through overharvesting. In Mexico, fishermen were interviewed to see what they thought were the worst disturbances facing mangroves. The two threats that they most talked about were the modification of water salinity (through the addition of an artificial canal) and hurricanes. Direct human impacts were not a concern for them (Kovacs 2000). In situations such as this one, it is often difficult for fishermen to know that by removing too many fish and invertebrates that live amongst the mangroves, the balance that exists in these ecosystems can be disturbed. Once fishermen are included in management decisions and are taught what kind of impact they can have, they can feel the agency to protect these valued ecosystems.

Fishermen can also lose the most when mangrove habitats are destroyed. Brazil's large coastline has many mangrove habitats, and it is important to conserve them there due to the fisheries that they help sustain. Road transportation is a huge priority in Brazil, which has damaged many mangrove areas, resulting in the termination of small-scale fisheries in those areas. Also, in Brazil, many mangrove areas have been cleared for real estate development

(Diegues 1999). However, mangroves are important to communities that have been described as "mangrove civilizations" in Brazil. The mangroves provide important sustenance and cultural services to these communities, but the migration of more people to the coast is causing these communities to become less sustainable (Digues 1995).

These studies show that it is valuable for community members to be given decision-making powers, but these responsibilities must go beyond the surface. A specific example of how this seemingly good idea can be overtaken by other factors can be seen in Tanzania. At the Mafia Island Marine Park in Tanzania, a law made the election of a village council required so that community members could participate in management decisions. However, the councils were not actually given decision-making powers. The warden, whose views were unpopular in the community and who was forced to represent the village council, always stood in the way of an actual dialogue between the village council and the board of trustees about managing the park (Walley 2004).

Not only do communities need to be involved in the management process, but also they need to understand the value that mangrove ecosystems provide that is not easily seen. To better protect mangroves in the future, mangroves also need to be valued for their ecosystem services that are not quantifiable. In Mumbai, India, mangroves serve as water filtration systems, a habitat for food sources, ornamental resources, and construction resources, among others. Disease and erosion were also highly reduced in areas with mangroves (Everard 2014). Economically, it is difficult to put a value on mangrove ecosystems based off of these factors. But these factors are almost necessary for humans to survive.

Unfortunately, some places do not even see the economic necessity of protecting mangroves. Across the world, people do not understand the importance of mangrove

ecosystems. For example, on the Pacific island of Wallis, interviews showed that few people feel concerned about the reduction of mangrove habitats because the main tourist attraction that they care about is the coral reef for scuba diving (d'Hauteserre 2016). However, without the mangroves, the coral reefs could be smothered by sediment runoff that the mangroves can help prevent, and there could be less fish on the reef because there would not be a juvenile habitat for the fish without the mangroves. Education is needed to show people that mangrove habitats are important in conserving the habitats that are more attractive to tourists.

These case studies show the numerous ways that people can manage mangrove ecosystems. Depending on the area and structure of the community, one of these methods or a combination of them might work. Some general themes that have been successful throughout the mangrove areas of the world include generating conversation about the importance of mangrove ecosystems, creating National Parks, establishing mangrove areas where they did not exist before using traditional knowledge, including all stakeholders in decisions, and allowing mangroves to be managed through small-scale, community efforts.

4.5 HOW TO PROTECT MANGROVE ECOSYSTEMS

Based on these diverse, global examples, we see that through a combined effort of governments, environmental NGOs, and local community members, laws can be made and enforced to protect mangroves. Even developers who want to be protected from storms or who want better water quality can start making changes (Everard 2014). Both the public and private sectors can make beneficial changes through careful planning and research.

Perhaps a new way to protect mangroves will be through "payment for ecosystem services" markets, or PES. These markets would internalize the value of the services that certain ecosystems provide, and landowners would receive compensation for protecting the ecosystems on their land due to the societal value that these ecosystems provide (OECD 2010). Although this could be helpful for large cities, in small, rural communities where mangroves are essential to the way of life, people will need to take responsibility without an incentive for the protection of the mangroves that exist there.

Protecting ecosystems without economic incentives might require a social movement, which would encourage more people to care about the environment. After an ecosystem is destroyed by external factors, such as development or aquaculture, the people who have lived amongst the environment for generations have to change their way of life or fight for it. In Ecuador, indigenous peoples set up an organization to protect mangroves. The "Ancestral Peoples of the Mangrove Ecosystem," or PAEM, defends mangroves from shrimp farmers. These indigenous groups claim rights to the land and are working to restore these ecosystems to their previous states, which is a novel strategy (Latorre 2014). However, a community does not have to be indigenous to share a connection to nature. In Latin America, five themes ideally govern the management of mangroves: fair participation, objective information and an ample knowledge base, local capacity, flexibility, and enabling context (García 2014). If all of these factors are present in a community, experts consider it possible to preserve mangrove environments.

Another important aspect of mangrove conservation is the integration of science in local communities. In Colombia, a staff member of the National Institute of Marine Research trained the local biologist and people who extract resources from the mangroves to monitor the health of

the mangroves. This led to a long-term monitoring project done by local people who had not received similar training before. For example, local people could be taught how to best intersperse development at the coastline while preserving mangroves. A study on mangroves recovering after coastal development showed that if some mangroves are preserved during construction, the area has the potential to rejuvenate (Benfield 2005). Some areas in the study, however, lost up to 100% of their mangrove area due to construction and the replacement of mangroves with other vegetation. Restoring a mangrove ecosystem naturally is complicated. If mangroves are allowed to rejuvenate naturally, they are more likely to be biologically similar to their original state (Field 1998). However, some species of mangrove are slower at natural rejuvenation and would require artificial restoration efforts (Toledo et. al. 2001). In cases like this, science is beneficial to aid in deciding what kinds of rejuvenation techniques are best, and this information can then be passed along to local management committees.

Success stories of mangrove restoration need to find a happy medium in between what is best for societies and what is best for the environment. In a study that asked mangrove planters in the Philippines their reasons for planting mangroves, most people said they did it for storm protection or for construction, but only two percent of people surveyed said they did it because it is good for ecology (Walters 2004). Because they are planting for reasons other than conservation and are not necessarily considering the environment in their planning, they are forming mangrove plantations with only one species of mangrove tree. When environmental resources are treated like a capital investment, the tie to the land that often helps people want to engage in conservation activities ceases to exist. Overall, this study showed that the relationship between people and mangroves will be different from location to location, and there is not one location that can be a model on which other places should strive to be like (Walters 2004).

In the formerly discussed island in the Philippines, Banacon, a new pro-conservation mayor brought forth an initiative to restore mangrove forests that had been lost to cutting and which would also initiate ecotourism in the area (Walters 2003). Today, the mangrove plantations of Banacon are managed by a combination of the local community and the Department of Environmental and Natural Resources (Camacho et. al. 2011). Later studies on this area recommend creating incentive-based conservation programs, such as payment for environmental services (PES) or Reducing Emissions from Deforestation and Forest Degradation projects (REDD) to continue the success of the mangrove plantations in this area.

Education is one of the most fundamental tools when it comes to managing the environment. At times, people might think that they are being stewards of the environment when they are replacing the resources that they are using, but in some cases, the efforts by the community to restore the mangrove habitat become more of a way to access a certain commodity, wood, rather than a way to preserve the environment. However, community participation is a key element when it comes to preserving mangroves. Allowing communities to find both economic value from mangroves and a connection to nature can help restore mangrove habitats. Both of these can be found through proper education.

Throughout this thesis, the importance of education has emerged as a theme regarding how communities can learn to protect nearby mangroves. It is possible that mangroves can be preserved, but education is definitely a critical step in this process. Education is so important in teaching the next generation about ocean conservation. At a young age, children can be introduced to mangrove habitats through children's literature. *The Mangrove Tree: Planting Trees to Feed Families* is an example of the kind of books that need to circulate at an early age. This book introduces mangroves by talking about what a mangrove is and how in Hargigo, the

sheep do not have enough to eat. It shows how women plant mangroves, giving them an opportunity to work close to home. By showing that every part of the mangrove tree can be used, by either humans or sheep, the book teaches about limiting waste. Also, the book introduces various fish and crustaceans that live amongst the mangroves and how they provide fish for the fishermen to catch. In case older children read this book, there is an afterward that shows Gordon Soto, the man who trained villagers to plant and care for mangrove trees, and where else projects like this one are taking place in Africa (Roth 2011).

In another book, *In The Sea, the Storm, and the Mangrove Tangle*, children are introduced to mangroves and the life the lives amongst the mangrove roots. From crabs to seahorses to manatees, beautiful drawings and words bring to life this important ecosystem. There is even a section where a fisherman suggests cutting down the mangroves to create a shrimp farm, but another fisherman says, "if we destroy the mangroves, we destroy the fish which gives us all life." In the end of the book, a storm comes, but the mangroves protect the fish from the elements. The author notes at the end of the book that the mangroves are in danger because they are being cut down for shrimp farms and hotels. It also importantly notes where one can see mangroves and what actions can be done to conserve them (Cherry 2004). These are just two examples of the kind of books that can help make children interested in mangroves at an early age. If communities become more engaged with ecosystem management, children can grow up to help the mangroves that they learned to love when they were young.

Education at an early age can stay with people as they become adults. In the Gambia, the Tanbi Wetland National Park is an area rich with mangroves. One study conducted interviews with local people to gage their knowledge of mangroves and how much they depended on resources that came from mangrove forests (Satyanarayana 2012). 98% of people living outside

of the urban areas mentioned the role that mangroves have as nursery grounds for fish and habitats for birds, as well as how useful mangroves were in controlling erosion. In the urban areas, 87% of people mentioned how useful mangroves were, but their reasons were more commercially orientated towards resources such as timber and fishery products. Both urban and nonurban populations viewed the mangroves as an important resource for timber, wood for ornamental purposes, fuelwood, and medicine for anemia. Because of education, a large proportion of the population knew about the importance of mangroves. However, a huge, damaging practice on the mangroves in this study was oyster collection, which involved cutting mangrove roots off. The study suggests further educating people on the consequences of this activity to reduce the impact of it (Satyanarayana 2012). An important thought to note about education is that education alone cannot make people interested in conservation. It can inspire people to become engaged in conservation, but people of all cultures will have to make the decision to internalize the environment as a personal value.

To best manage this ecosystem, the authors of this study suggest sharing rights and responsibilities amongst both local users and government organizations. Although the government manages natural resources, the users of the resources are the ones that have the most influence on them. Since local people can also have influence on government and non-government organizations, it was suggested that local people are given the most importance in management projects (Satyanarayana 2012).

A few common themes appear throughout this section. One of those is the value of education in conserving mangrove habitats. Scientific and local knowledge can be extremely helpful in figuring out how to best manage a specific habitat. Also, this knowledge can be taught to people from a young age in the hopes that they will then develop a connection to the land.

Another theme seen here is bottom-up management. By giving the people who use mangroves as a resource the power to decide what happens to them, increased interest in conserving these ecosystems can occur.

4.6 CONCLUSION

Without proper management in place, mangroves could fall prey to the Tragedy of the Commons (Hardin 1968). In the rush to develop as much land as possible before someone else does, the conservation of mangroves could be thrown aside for profit and growth. It is not hard to plant mangroves. A study by Walters showed that many mangrove planters did not give much thought to their mangrove planting, which shows that planting takes little technical knowledge (Vayda et. al 2004).

A general study on mangrove ecosystems in the Philippines suggested that every successful mangrove conservation project started with proper awareness. The authors of the study also suggested that the government implement mangrove planting guidelines to enhance the survival rate of the planted mangroves. These guidelines can come from the scientific community. The scientific community should also integrate their research with the training of community members in the conservation of mangroves (Garcia et. al. 2013).

In this section, various mangrove management strategies were discussed (Table 3). Overall, mangroves need to be managed from the bottom-up by local communities. This helps to ensure that people will not break laws that protect mangrove ecosystems if they feel like they have been a part of the regulation process. Governments also need to create laws to protect mangroves, but the laws need to be able to be enforced. Nature preservation must come before

other industries, even if the economic benefits cannot be as easily seen. Education from an early age can also help to preserve mangrove habitats in the future. Often, people do not understand why mangroves need to be protected or why certain "solutions" are actually not helpful. By looking at all areas of the world that engage in mangrove conservation, it is possible to develop strategies that can be adopted by other parts of the world to best protect mangrove ecosystems. Management strategies can be context dependent, but it is important to look at how mangroves are managed in other locations nonetheless. Although the ideas of education and community are very broadly articulated in this section, the successful overall themes of mangrove management shown here can hopefully influence mangrove management decisions in the future. However, more details about both the environment in that location and of the people that live there need to be included.

Thinking specifically about Bocas del Toro, social dynamics need to be examined to deeply understand the connections that the people there have with mangroves. This case study could have been improved if I had had the time and funding to conduct political ecology research. Through science, policy, and local environmental responsibility, this area can protect its mangroves from further damage. This area, like many other locations, has no choice but to protect mangroves if they want to continue to have healthy coral reefs for both fisheries and tourism. Although tourism can cause damaging development, it can also promote sustainable development in a way that causes minimal damage to the environment.

5.0 ECOTOURISM AND ITS EFFECT ON MANGROVES

The ecological problems caused by tourism are mostly created because of the massive amounts of people that come to visit a site. Often, sites become degraded due to tourism. Instead of changing the way in which tourism is handled, developers just transfer activities to "more attractive" areas that have not yet been degraded. If people have to choose between what activities are more environmentally sustainable vs. economically sustainable, the economy is most likely always chosen (Davenport 2006). Ecotourism, defined by the International Ecotourism Society as "responsible travel to natural areas that conserves the environment, sustains the well-being of the local people, and involves interpretation and education," is an alternative to regular tourism that has the potential to conserve marine ecosystems ("What is Ecotourism?" 2016).

Marine ecotourism includes many activities, such as diving, sailing, and surfing. By getting more people interested in these activities, conservation becomes a larger priority for people (Buckley 2008). The success of ecotourism depends on how it is implemented. Often, communities believe that it is a solution to the traditional goals of development. Places like the Mafia Island Marine Park in Tanzania are seeking to combine conservation and development into sustainable development that focuses on building infrastructure for tourists (Walley 2004). The Mafia Island Marine Park wanted to become a tourist destination so that it could develop sustainably, rather than be focused on more mainstream development goals.

To be successful and not environmentally destructive, ecotourism must strive to protect the environment over the enjoyment of tourists. For example, in India, ecotourism around mangrove habitats has proven to be detrimental to the organisms that live there. The organisms that live in the substrate that the mangroves take root in can be trampled by humans walking through the habitat, and birds can be easily scared away by human activity (Sandilyan 2008). Although people want to see mangroves, the activity of people walking through them is destroying the environment in this area. A solution to their problem can be seen from the Gambia. In the Gambia, people saw the mangroves as a way to bring in more tourists, but they knew that walking through the mangroves was destructive. To still allow tourists to interact with the mangroves, they built a boardwalk through the mangroves so that tourists could enjoy the scenery without damaging the environment and successfully engaged in ecotourism (Satyanarayana 2012).

There is often a lack of awareness of how tourists can damage the environment. In the case of mangroves, adjacent ecosystems, like coral reefs, attract the most tourists. However, the infrastructure that is built to accommodate the tourists damages mangrove areas if structures are built right on the water (Everard 2014). Unfortunately, the beautiful coral reefs and clear water that bring in tourists to these areas will cease to exist without the mangroves that keep runoff from smothering the coral. Mangroves themselves, however, can provide important tourism opportunities. For example, the Muthurajauela Marsh in Sri Lanka brings in 5.28 million SRRs per year in just recreation value, which comes out to about 36,000 USD per year. For one marsh in a developing nation, this is a good amount of money (Emerton and Kekulandala 2003).

Panama faces the fact that more and more tourists will come visit in the near future. The way that mangroves are managed in response to tourism could determine the fate of many

ecosystems in Panama in the future. On the island of Escudo de Veraguas off the coast of Panama, the pygmy three-toed sloth lives only in red mangrove trees and nowhere else in the entire world (Anderson and Handley 2001). Due to the possibility of this species being a draw for tourists, development projects are being proposed on the island of Escudo de Veraguas for an eco-lodge, casino, and marina (Ford and Jefferson 2013). Although, this species is considered Critically Endangered by the IUCN, tourists will still want to see them, and the habitat that they live in could be altered so that tourists will have places to stay and other activities to do (Voirin et. al. 2014).

Not only are mangroves removed so that resorts can be built right next to the water, but sometimes mangroves themselves are used as building materials. Traditional tourism operations use the easiest building materials to construct homes for visitors. In Colombia, low-cost holiday homes were constructed from mangrove wood, as well as electricity posts and firewood (Sánchez 1999). For ecotourism to actually work, countries need to be prepared for tourists so that they have time to sustainably build areas for the tourists to stay.

Otherwise, when ecotourists come to enjoy nature, the rapid infiltration of people may be too much for small populations to handle. For example, in the Bay Islands of Honduras, the construction of hotels, restaurants, marinas, and housing to accommodate tourists have all had significant damage on nearby mangroves and corals (Moreno 2005). Foreign investment in the islands, with the intention of capitalizing on an influx of tourists, has led to social conflict, such as a class divide due to the high cost of investing in a foreign company for local people. A counter example of sustainable ecotourism practices comes from the Toledo Institute for Development (TIDE), a non-governmental organization in Belize. It was created when the establishment of protected areas caused a decrease in fishing jobs, and it sought to create income

for local people through ecotourism. Not only does it certify tour guides, but it also conducts outreach education about conservation. The most important fact about TIDE is that it encourages local investment in future tourism operations. Both case studies from Honduras and Belize in this study show that encouraging local people to become invested in nature through ecotourism can bring about community conservation efforts (Moreno 2005).

Many tourists that come visit a country's coastal area are from other nations. Tourists that were interviewed in a study on mangroves in the Gambia were mostly from the Netherlands and the United Kingdom. Most local stakeholders saw ecotourism as a positive thing due to the foreign exchange and employment opportunities that they said it supplies (Satyanarayana 2012). The benefits of ecotourism in this study led local people to protect the mangroves from both natural and anthropogenic threats. However, the authors did make suggestions for ecotourism, such as educating visitors about the ecosystem services provided by the mangroves (Satyanarayana 2012).

Once again, education is key in the successful implementation of ecotourism. Foreign investment, through companies such as large cruise ships, need to make an effort to provide more educational, ecocentric tourist opportunities. Only an estimated 12% of cruise ship excursions in the Caribbean provide some kind of environmental advocacy. However, activities that not only try and minimize negative environmental impacts but also try to provide positive benefits to an ecosystem, such as using solar powered boats to explore mangroves in Bonaire, have the potential to provide benefits to these ecosystems (Johnson 2006).

Ecotourism also has the potential to bring in money for conservation efforts. A study done on ecotourism in China interviewed site-level managers and government officials and showed that most people considered ecotourism as a way to protect natural resources and to

provide benefits to local populations (Stone and Wall 2003). This study also discussed the feasibility of using ecotourism to raise funds to contribute to conservation, as long as high-quality tourist experiences are provided. In many developing nations, fees to enter protected areas are often nonexistent or lower than they could be (Stone and Wall 2003).

To best benefit from ecotourism, countries should charge a fee to view nature, as long as that fee goes back towards protecting it. Countries should also encourage the inclusion of all different groups in the tourism sector. Small efforts are taking place to get underrepresented groups in the tourist sector, such as indigenous groups and women, involved in tourist operations. For example, in Wallis, indigenous women are being taught how to sell their products as souvenirs. In both Wallis and Futuna, tourism is seen as a tool for positive development (d'Hauteserre 2016). However, ecotourism activities are predicted to still have an impact on both nature and culture if not properly managed. In the study that examined mangrove management practices across the Philippines, it was shown that ecotourism could be sustainable in mangrove areas as long as the area has management zonation so that ecotourism is limited to only certain areas. Also, all stakeholders must be involved in the management process, and any fees collected by visitors must go towards conservation efforts (Garcia et. al. 2013).

Mangroves can provide people with both sustenance and employment. In interviews with local residents in the Philippines, it was shown that mangroves are beneficial to residents because they provide a source of income through tourism and food. For these reasons, the government provides mangrove saplings and equipment to plant them to local residents, which makes it easier for residents to upkeep the ecosystem (Miranda et. al. 2013). Mangrove ecotourism has the potential to not only provide jobs for people, but also to give people a reason to focus conservation efforts on mangrove environments.

6.0 FUTURE RESEARCH NEEDS

Local ecological knowledge (LEK) has recently been informing management practices. LEK has the potential to significantly help inform conservation efforts, but researchers on LEK must be more detailed in reporting how they find LEK useful. A more systematic approach to LEK can provide a valuable asset to mangrove management (Davis 2003). This knowledge is especially useful in developing countries where the health of mangroves over the past decades may not have been documented. In Panama, near some of the sites used in the case study, indigenous groups lived on those islands. One study suggested combining scientific studies that have quantitative data with local knowledge to convince policymakers that environmental change is occurring (Kovacs 2000). Perhaps another study could use both my data and indigenous knowledge to create better management practices in Bocas del Toro.

In Puerto San Carlos, in the Baja California peninsula, the people are called “the people of the mangroves”. They depend on the mangroves for their livelihood and basic survival. Although the production of science has increased our understanding of natural resources, it has not necessarily led to more conservation. Scientists are often just studying resources as they decline. However, community-based conservation projects, based off of local knowledge, have the potential to make great strides in conservation (Küyük 2007). Successful conservation initiatives will most likely require researchers to integrate into communities so that they can build trust and partnerships to conserve ecosystems.

Science cannot function without this community-level partnership. The role of science in the Mafia Island Marine Park was seen as the only legitimate knowledge, whereas local knowledge was seen as significantly less important. This created a gap between popular knowledge and science (Walley 2004). Some would even call science a hindrance to conservation. Vandana Shiva, a famous environmental activist, considers science as something that "reduced the capacity of humans to know nature both by excluding other knowers and other ways of knowing…" (Shiva 2010). That is why combining science with local knowledge and education is so important. Relevant knowledge that could help preserve mangroves, whether it is scientific knowledge or LEK, is not shared in the general community in many cases. For example, in the Philippines, practical knowledge about planting mangroves was just not shared widely in society (Vayda et. al. 2004). However, local knowledge could help determine where community members decided to plant mangroves. For example, local people knew where people did most of their fishing and where boating activities most frequently took place, and mangroves were decidedly not planted in those locations (Vayda et. al. 2004).

There also lies a problem in the way that local people are still seen. Many development professionals will use words like "participation" but will still manage ecosystems from a top-down approach, while undervaluing local knowledge (Ellis and West 2004). LEK has the potential to inform conservation efforts, but local people must be consulted and must be a part of management decisions if this knowledge is to be of any use. Future education efforts must combine cultural and ecological knowledge. Also, to assess if education is helping not only inform, but also change the values of people, educational baselines should be obtained.

Other than more research that needs to be done on LEK, more research could be done on the quantitative data from Panama. For example, it might be beneficial to look at rare species or

if certain indicator species were found mostly in the mangroves, the seagrass beds, or on the coral reefs. Understanding what trophic levels inhabit these environments might also be helpful to see how the population dynamics of the coral reefs are changing. In addition, studies should be done on coastal practices such as aquaculture. Aquaculture, both of fish and of seaweed, is becoming more popular in Panama, and it has the potential to affect mangrove ecosystems. Before it is too late, more studies must be conducted on these important ecosystems, but the studies must also be used to inform management decisions so that real progress can be made to conserve them.

7.0 CONCLUSION

Governments are now starting to realize the importance of mangroves. Just last year, President Juan Carlos Varela of Panama signed a bill that would protect the mangrove wetlands outside of Panama City from construction, even though the previous president encouraged construction in that area and even lowered the fines that people had to pay for cutting down mangroves ("Panama Protects Wetlands" 2015). It is important to conserve mangroves for a variety of known reasons, such as that they are a habitat for juvenile fish or that they provide protection from storms, but there are also reasons that may not be known yet. Recent studies have shown that mangroves can provide important health benefits, such as having anti-inflammatory, antioxidant, antiseptic, and more properties. It is important to conserve these plants so that future research can be done on their possible contributions to medicine (Regalado et. al. 2016).

This thesis shows that species richness, species diversity, and biomass of fish is significantly higher on coral reefs near mangroves and mangroves with development than on coral reefs that are not near mangroves. It also highlights the importance of local involvement and education in conserving mangrove ecosystems, as well as how ecotourism, if implemented correctly, can also be used as a conservation tool. More site-specific research is needed to come up with the best management practices for mangroves, but it is important to look at how all places around the world manage these ecosystems so that they can continue to exist in the future.

APPENDIX

Figure 1: Example of Mangrove Swamp in Panama

Site	Anthropogenic Impact on Mangroves (0=no impact, 5=greatest impact (no mangroves))
STRI Point	2
Almirante	2
Coral Cay	1
Punta Caracol	3
Casa Blanca	4
Juan Point	2
Hospital Point	5
Salt Creek	5
Popa	5

Table 1: Anthropogenic impact on mangroves at all 9 sites in Bocas del Toro, Panama

Indicator Species	Why Indicator Species	Present in Mangrove sites? (0=none, 3=all)	Present in Developed Mangrove sites? (0=none, 3=all)	Present in NO Mangrove sites? (0=none, 3=all)
Caranx latus	Commercially important	0	0	0
Caranx crysos	Commercially important	0	0	0
Carangoides ruber	Commercially important	2	2	2
Ginglymostoma cirratum	High trophic level	0	1	0
Haemulon flavolineatum	Commercially important	3	3	2
Haemulon plumierii	Commercially important	3	3	0
Haemulon sciurus	Commerically important and Indicator species (Mumby et. al. 2004)	2	2	1
Lutjanus apodus	Indicator species (Mumby et. al. 2004)	0	1	0
Ocyurus chrysurus	Commercially important and Indicator species (Mumby et. al. 2004)	1	1	0
Pterois volitans	Invasive speices	0	1	0
Scarus coelestinus	Herbivore	0	0	0
Scarus coeruleus	Herbivore	0	0	0
Scarus guacamala	Herbivore	0	0	0
Scarus iseri	Herbivore and Indicator Species (Mumby et. al. 2004)	3	3	3

Scarus taeniopterus	Herbivore	0	0	0
Scarus vetula	Herbivore	0	0	0
Sparisoma aurofrenatum	Herbivore	2	2	1
Sparisoma viride	Herbivore	3	2	3

Table 2: Indicator species in study

Figure 2: The location of the case study in relation to the Americas

Figure 3: Example of how tourist sites were known

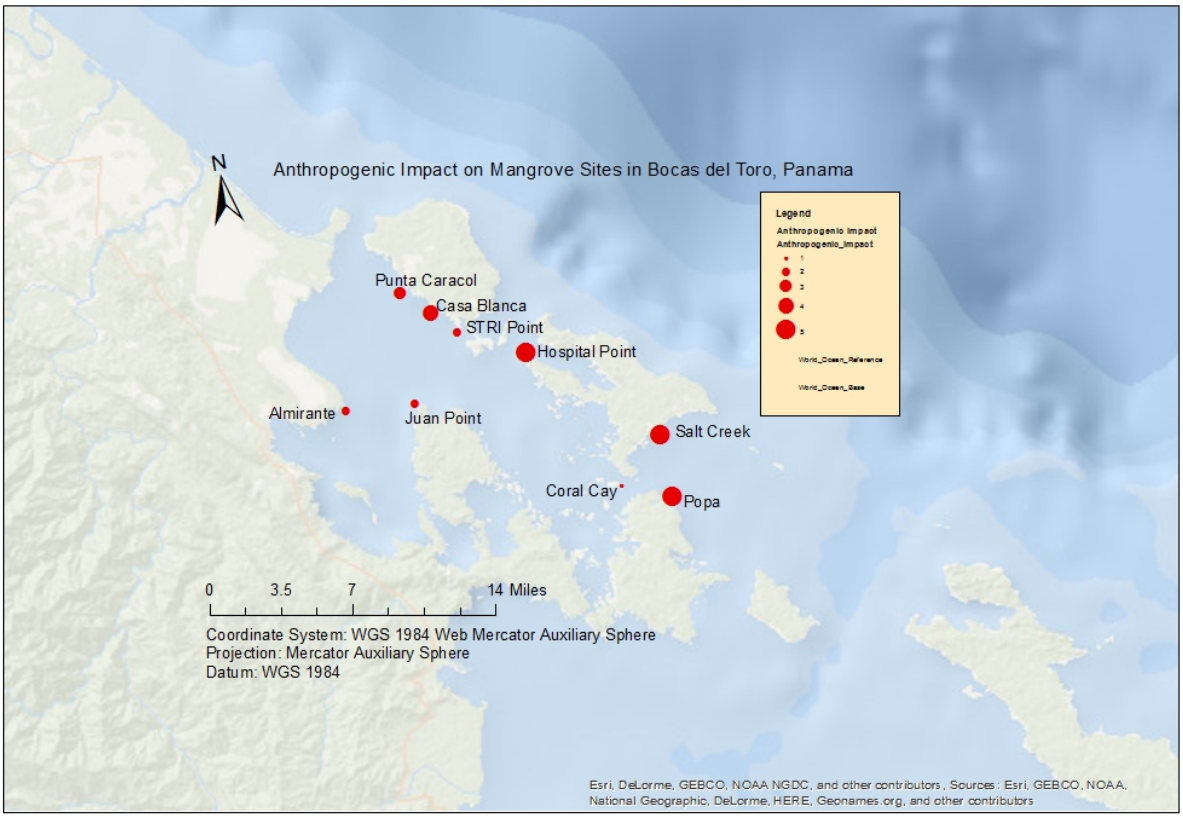

Figure 4: The anthropogenic impact on the mangrove sites. The larger the red dot, the stronger the impact.

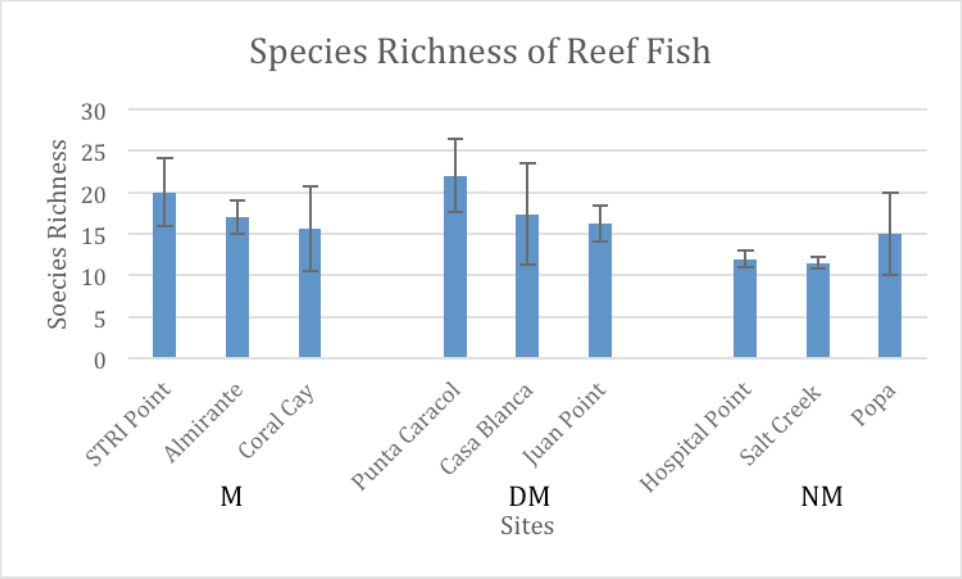

Figure 5: Species richness of reef fish

The three sites with intact mangroves (M) have less average species richness than the sites with degraded mangroves (DM). Both the sites with mangroves and the sites with degraded mangroves have greater average species richness than the sites that had an absence of mangroves (NM). The large standard error bars indicate small sample sizes.

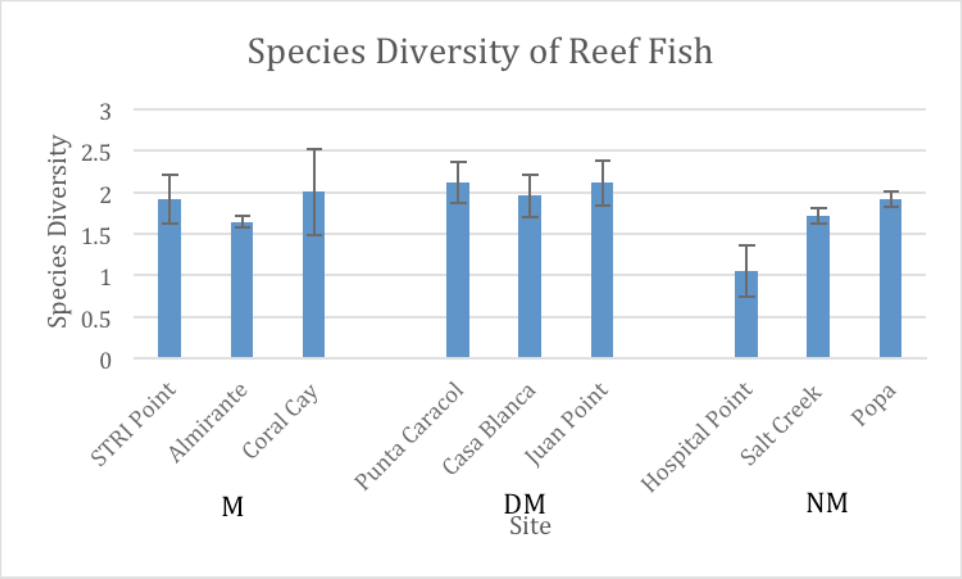

Figure 6: Species diversity of reef fish

The sites with intact mangroves (M) had slightly less average species diversity than the sites with degraded mangroves (DM), and the sites with an absence of mangroves (NM) had less average species diversity than both the sites with mangroves and the sites with developed mangroves.

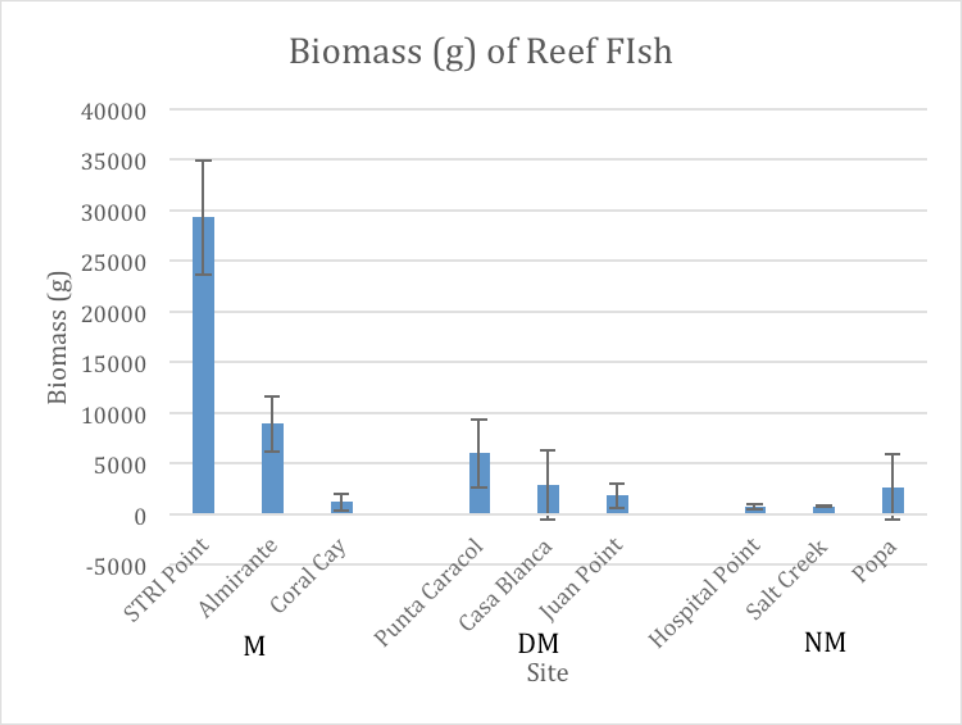

Figure 7: Average total biomass of reef fish

The sites with intact mangroves (M) had a higher average total biomass than the sites with degraded mangroves (DM) and the sites with an absence of mangroves (NM).

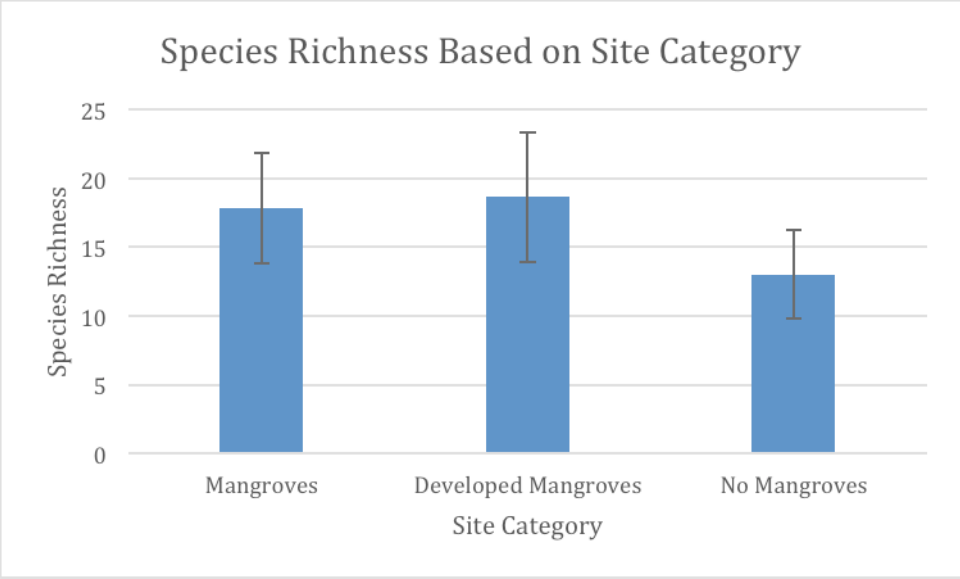

Figure 8: Species richness based on site category

Grouped as a category, the sites with developed (degraded) mangroves had slightly higher average species richness than the sites with intact mangroves. Both categories had higher average species richness than no mangroves.

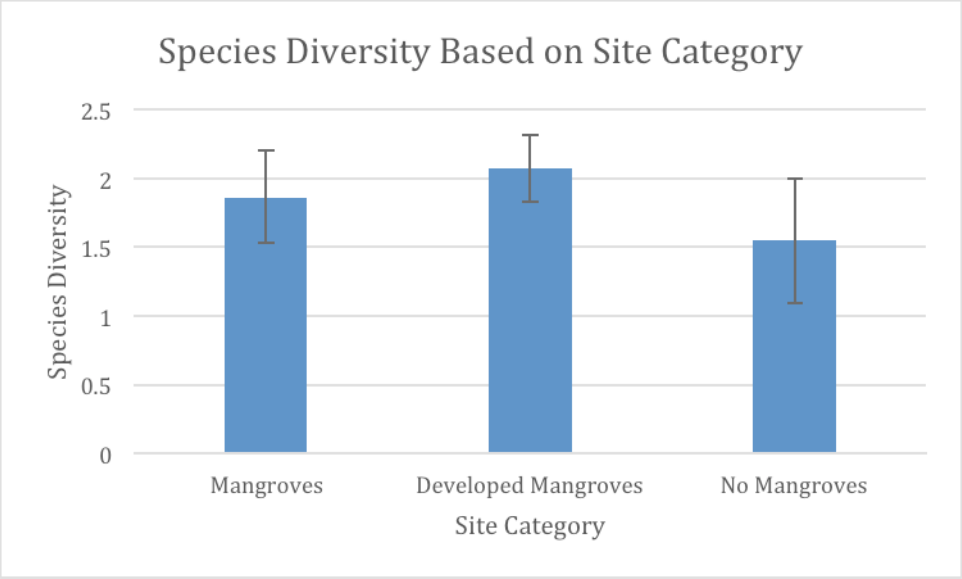

Figure 9: Species diversity based on site category

The sites with developed (degraded) mangroves had slightly higher average species diversity than the sites with intact mangroves. Both had higher average species diversity than the sites with no mangroves.

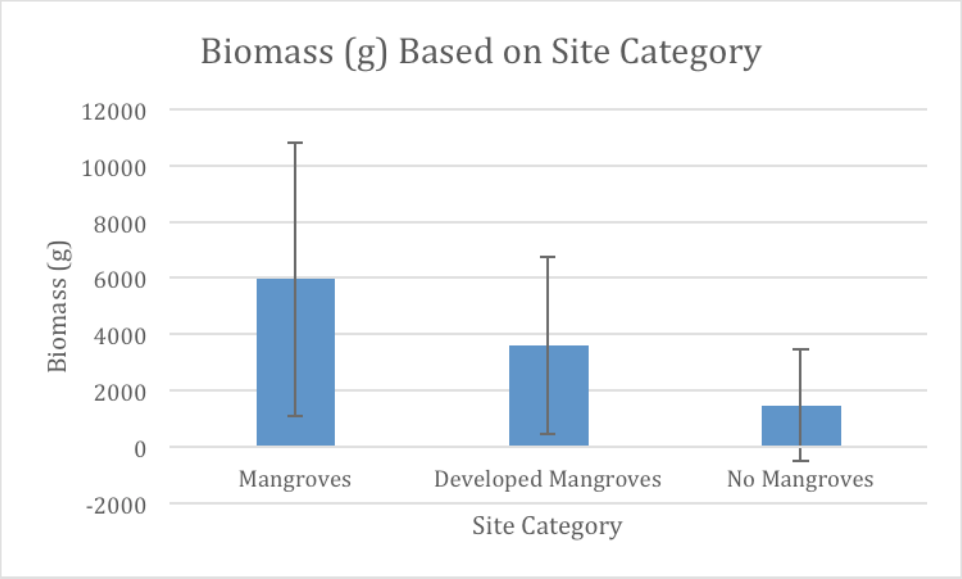

Figure 10: Average total biomass based on site category

The sites with intact mangroves had a higher average total biomass than the sites with developed (degraded) mangroves. Both had a higher average total biomass than the sites with no mangroves.

Mangrove Management Strategies
Take baseline measurements of mangrove ecosystems (Barreto 2008)
Take into account the use of a resource by local people when making laws to preserve their culture (Latorre 2013)
Create laws that can be enforced (Latorre 2013)
Create specific laws that departments can take responsibility for (Cienfuegos and MacInnis 2015)
Control Pollution from other sites, not just in the protected area (Latorre 2013); Gilman and Ellison (2007)
When replanting mangroves, do not create a monoculture (Walters 2003)
Include stakeholder engagement in management decisions but do not give too much power to large companies (Walley 2004)
Incorporate ecosystem-based management into a community (UNEP 2006)
Create a volunteer network to increase community engagement and save money (Gilman and Ellison 2007)
Decentralize authority over mangrove ecosystems and allow communities to take responsibility for their surrounding environment (Roy and Khorshed 2012)
Start somewhere. Even a single nursery can generate conservation in a community (Sánchez 1999)
Set up National Parks but do not allow tourism to jeopardize the conservation of them (Steinitz et. al. 2005)
Use ancestral knowledge to create protected areas (Sánchez-Arias 2008)
Include fishermen in management conversations (Kovacs 2000)
Encourage community members to feel a connection to the land (Digues 1995)
Actively include community members in the decision making process (Walley 2004)
Educate communities about how mangroves are connected to other economically important ecosystems (d'Hauteserre 2016)
Encourage developers to protect mangroves due to their storm protection and water quality values (Everard 2014)
Incentivize protection of ecosystems by landowners because of ecosystem services (OECD 2010)
Create a social movement to generate conversation and action about conservation (Latorre 2014)
Include fair participation, objective information and an ample knowledge base, local capacity, flexibility, and enabling context in the management of mangroves (García 2014)
Train local people to monitor mangroves (García 2014)
Find a management scheme that protects the environment but is good for society so people are willing to participate in the protection of an ecosystem (Walters 2004)
Educate children from a young age about ecosystems (Roth 2011); (Cherry 2004)
Share rights and responsibilities between the government and local communities (Satyanarayana 2012)

Table 3: A summary of the best global mangrove management stategies

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