WATER QUALITY AND HEALTH OF CORAL REEFS

An Undergraduate Research Scholars Thesis

by

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ABSTRACT

Water Quality and Health of Coral Reefs

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This study estimates the impacts of degraded water quality parameters and a continued warmer climate on coral reef abundance in the Florida Keys National Marine Sanctuary (FKNMS). Degraded water quality effects can be directly observed in corals' reduced recruitment, decreased calcification, shallower depth distribution limits, altered composition (more heteroptrophic fauna), and loss of biodiversity (ISRS, 2004). The following species *Scleractinia*, stony coral, and *Octocorallia*, soft coral, are the primary focus of this study. Understanding the effects of increased turbidity, nitrates, silicates, and temperature on coral cover is crucial given the important ecosystem and economic roles coral reefs play. Analysis of the 10-year data on coral coverage and nutrient concentration in the FKNMS indicates that enhanced levels of nitrite and nitrate combined significantly reduce total coral coverage in the Keys. Initially elevated levels of silicate enhance the abundance of corals, however, excessive levels result in significant decline in coral ecosystem. The regression results also show that the increased turbidity is associated with low coral coverage and warmer climate negatively impacts coral abundance. Analyzing by types of corals, stony corals exhibit more sensitivity to nutrient pollution and enhanced turbidity levels relative to octocorals. Both types of corals remain sensitive to warmer climate.

The results of this research have significant policy implications. For policy making related to the Florida Keys Marine Sanctuary, this research suggests that management efforts geared towards efficient water pollution control can greatly enhance coral reef abundance in the Keys. Furthermore, coordinated efforts at local, regional, and national levels may deem vital for the achievement of these sustainability goals. General implication of the results are that corals remain highly sensitive to climatic and anthropogenic stressors even in marine sanctuaries, and these effects are likely severe and more alarming for reefs in unprotected areas.

DEDICATION

I would like to dedicate this thesis to my father, James Maithland Hinson. He has been my constant source of inspiration in pursuing a degree in conservation of our natural resources. He has given me the drive and discipline to tackle any task with enthusiasm and determination. His work for Texas Parks and Wildlife, U.S. Army Corp of Engineers, Parsons, and Tinker Air Force Base, has inspired me to further my studies in conservation of resources.

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CHAPTER I

INTRODUCTION

Coral reefs are the "rainforest of the sea" and are economically and ecologically valuable resources providing many vital ecosystem and economic services (Swart, 2013). Corals are primarily found in shallow, tropical environments, from the Middle East to Australia and America (Economist, 2016). Coral reefs provide coastal protection, habitat, medicine, human food source, and provide aesthetic value for millions of tourists (NOAA, 2015a). Marine and coastal tourism is one of the fastest growing areas of tourism in the 21st century (Hall, 2001). It is estimated that coral reef based tourism generates $9.6 billion globally, and that number is only climbing (Cesar, 2003). Corals around the world also support about a quarter of all marine species and provide nursery grounds for numerous others. Recently, these beautiful and biodiverse species have experienced significant decline worldwide, with impacts likely related to anthropogenic stressors and natural events (Santavy, 2011). Corals appear to be particularly sensitive to coastal and anthropogenic pollution, invasive species, climate change, hurricanes and other abnormal weather phenomena such as El Niño and La Niña (Hendee, 2001). Vegetation removal, soil erosion, fertilizer run-off, expanding coastal urbanization, and discharge of sewage are some of the main anthropogenic sources of pollution. These pollutants entering the sea are a concern for over 100 different nations dependent on coral reefs for survival (ISRS, 2004).

Poor water quality is linked to coral stress, which leads to coral bleaching, and eventually coral death (Hoegh-Guldberg, 1999). High concentrations of dissolved oxygen, high bacteria levels, salinity, and turbidity are just a few degraded water quality indicators that adversely impact coral reef distribution and overall ecosystem health (NOAA, 2015b). Degraded water quality also affects corals reduced recruitment, decreased calcification, shallower depth distribution limits, altered composition, more heterotopic fauna, and loss of biodiversity (ISRS, 2004).

Studies of hurricane impacts have shown coral loss and impaired recruitment from physical damage and increased mortality, with impacts appearing to increase with increasing storm intensity (Santavy, 2011). The lack of consistent data on changes in coral biodiversity distribution and water quality parameters has been detrimental in identifying the direct link between degraded water parameters and coral ecosystem. The purpose of this research is to fill in the gap in the literature and understand the impacts of deteriorating water quality and warmer climate on coral abundance in the FKNMS.

Florida Keys National Marine Sanctuary

The Florida Keys National Marine Sanctuary is one of the largest coral ecosystems in the US, and the third largest coral reef systems in the World (NOAA, 2015c). The U.S Congress established the FKNMS on November 16, 1990, and it represents one of 14 marine-protected areas (MPA) that make up the National Marine Sanctuary System. The FKNMS is located along the southeast side of Florida (see Figure 1.) The sanctuary protects 2,900 square nautical miles, and consists of a unique zoning plan enacted in 1997 as a consequence of a long term planning, design and public involvement (CREMP, 2011). The FKNMS provides enormous ecosystem and economic benefits. The average value generated from coral reef recreation solely is estimated at $184 per visit in the FKNMS (Brander, 2007).

The FKNMS is the first MPA that enacted comprehensive network of marine zones in the United States. The sanctuary consists of five different types of zones with varying degrees of protection. These include Ecological Reserves, Sanctuary Preservation Areas, Wildlife Management Area, Existing Management Areas, and Special-Use Areas (NOAA, 2016d). Ecological reserves protect an entire range of marine habitats and are the largest zone in the sanctuary. There are two areas designated as Ecological Reserves in the sanctuary and they are key to protecting natural spawning, nursery, and permanent residence areas for marine life (NOAA, 2016d). Discharging any matter into the water is prohibited, in addition to any and all types of fishing, touching, standing, or anchoring on coral (NOAA, 2016d). Vessels can only enter the Ecological Reserves if they are in constant transit with all gear stowed and no diving equipment aboard (NOAA, 2016d).

Preservation areas are relatively more abundant throughout the sanctuary, consisting of 18 locations, and are primarily designated to protect shallow reefs. Preservation areas have mooring buoys for boaters to anchor to, and allow diving, snorkeling, and boating (NOAA, 2016d). The only type of fishing allowed is bait fishing, which requires a special permit. Wildlife Management Areas are intended to minimize disturbances to endangered wildlife and their habitats, such as bird nesting, feeding areas, or turtle nesting beaches. Wildlife Management Areas outnumber other types of zones and currently are enforced in 27 areas (NOAA, 2016d). Of these 27 unique areas, 20 of these areas are co-managed with the U.S. Fish and Wildlife Service, and are idle seed only/no wake, or no motor, or no access zones (NOAA, 2016d). Restrictions in this area include idle speed, no motor zone, and limited closures.

There are 6 Existing Management Areas, (EMAs), which are jointly managed between the sanctuary, Crocodile Lake National Wildlife Refuge, Great White Heron National Wildlife Refuge, National Key Deer National Wildlife Refuge, and Key West National Wildlife Refuge. The U.S. Fish and Wildlife Service oversee these National Wildlife Refugees (NOAA, 2016d). EMAs have their own unique protections and restrictions. Lastly, the fifth type of zone is a Special-use Area, making up four areas in the sanctuary. These areas are set aside for scientific research, educational purposes, monitoring or restoration, and entering these areas requires a sanctuary permit (NOAA, 2016d).

As discussed, FKNMS represents a complex zoning system, which require continuous monitoring and enforcement of regulations. A management plan, based on integrated coastal management, was enacted between NOAA and the state of Florida, at the local and state level (Bohnsak, 1995). These federal and state agencies work together with the public to employ a “bottom-up, consensus-building approach” to address issues and ongoing management aspects surrounding coral ecosystems (Bohnsak, 1995). FKNMS is a unique area due to the extensive public involvement in sanctuary management. While “bottom-up” management has a few drawbacks and challenges, such as the required on-going cooperation between participating governments, agencies, and the public, if the consensus between parties is achieved, it enables enactment of significant legislation, which will likely be followed by most parties.

Figure 1: Florida Keys National Marine Sanctuary Boundary
Source: NOAA (2015e).

Species differences

The FKNMS is known for a variety of coral reef species, including 63 taxa of hard or stony corals (e.g. Scleractinia and Milleporina coral), [1] 42 reported species of octocorals, and two species of fire corals. Stony corals and octocorals dominate offshore patch reef habitat, while boulder corals are most prominent on the intermediate reef (Santavy, 2011). Deepwater octocorals are common on the deep and outlier reefs and in colder waters (Somerfield and Jaap, 2015).

A recent survey from 37 sites in the Keys suggests that the total cover of hard coral species declined between 1997 and 1999 followed by no recovery (Somerfield, 2008). These changes coincided with bleaching events in 1997 and 1998 and the passage of Hurricane George through the Lower Keys in 1998 (Somerfield, 2008). With the rise of sea surface temperatures, many

1 Hard corals are a type of corals that create skeletons out of calcium carbonate, a hard substance that eventually becomes rock.

corals are unable to adapt. Coral bleaching occurs when corals expel their zooxanthelle. Zooxanthelle play a key role in survival for coral species (Goulet, 2006). After photosynthesis is completed, the zooxanthellae supply glucose, amino acids, and glycerol throughout the coral (Barnes, 1987).

While octocorals and stony corals have numerous similarities, there are differences in the two species. Stony corals grow at a slow rate, and the recovery of this species may require several decades. Stony corals thrive in shallow tropical waters, where the species puts down great skeletal structures. Octocorals, on the other hand, grow at a faster rate and can potentially recover in 10-15 years (Jaap, 1999). Literature proves octocorals have been abundant in multiple habitats, including sand-flats, patch reefs, forereefs, and forereef ridges, and they appear to be more likely at recovering in a warmer climate (Howard, 1983). Another types of species including M. complanata and fire coral have also disappeared from Sand Key sites between 1998 and returned with low numbers in 2000 (Somerfield & Jaap, 2015). The lack of recovery among offshore reefs suggests that impacts may be irreversible and imply lack of general species resilience (Somerfield & Jaap, 2015).

Water quality

Degraded water quality effects can be directly observed in corals with the naked eye. Reduced recruitment, decreased calcification, shallower depth distribution limits, altered composition (more heteroptrophic fauna) and loss of biodiversity, are a few results of degraded water quality (ISRS, 2004). Increased temperature, turbidity, and inorganic nutrients (i.e. nitrates, nitrite and silicates) are commonly measured water quality parameters that directly affect coral ecosystem.

Literature states that in many coastal areas suspended particles create turbid environments, causing areas of low light levels and low photosynthesis rates (Anthony, 2000). Photosynthesis creates amino acids, and glucose, which are in turn used to create proteins, fats, and calcium carbonate, $CaCO_3$. Low photosynthesis rates lead to low $CaCO_3$ production and are detrimental to reef formation. Increased algal cover is a growing concern in the scientific community and is also being observed with the naked eye. The recent increase in algae cover in corals found around the world, has been credited to the loss of large herbivorous fishes, an increase in dissolved sea water nutrients, such as phosphorus, and loss of hard coral cover (McClanahan, 2002). Algae abundance is also affected by species *Diadema antillarum*, known as grazing sea urchins. Urchins will consume the majority of the algae cover on the reef. This can be beneficial to allow more sunlight, however corals are in decline in many areas therefore algae cover is increasing on reefs (McClanahan, 2002).

CHAPTER II

DATA

Primary data for this research are drawn from the Florida Keys National Marine Sanctuary Water Quality Protection and the Coral Reef Monitoring Programs. The data include numerous parameters of water quality and areas covered by various coral species throughout the Florida Keys for the period of 1996-2006. Coral data include percentages of areas covered at 136 unique coral sites for macroalgae, octocoral, porifera, stony coral, and substrate. Water quality data report surface and bottom temperatures at 138 sampling sites throughout the keys, along with the surface and bottom turbidity levels and various water quality indicators including but not limited to nitrogen oxide, nitrous oxide, total nitrogen and total phosphorous. For each sampling site, water quality measures were collected seasonally each year. From nutrient concentration, inorganic nutrients are the focus, specifically nitrate, nitrite, and silicate levels. Annual averages for these variables were calculated to match the single, annual observations of coral areas. Instead of averaging seasonal temperatures, the maximum-recorded temperatures in a year were chosen due to particular sensitivity of corals to extreme temperature.

Using the ArcGIS geospatial analysis tool, the coral site locations were spatially delineated relative to the 340 fixed water quality-sampling sites. In order to identify relevant water quality stations, a five-mile buffer around each coral site was established. Water quality measures from multiple sampling sites within a five-mile buffer zone were averaged correspondingly to create quality measures for each coral site. Figure 2 depicts spatial distribution of corals with the corresponding water quality stations identified within the five-mile buffer zones. The final sample consists of 1262 observations corresponding to 136 different coral stations over the 10-year period from 1996 to 2006.

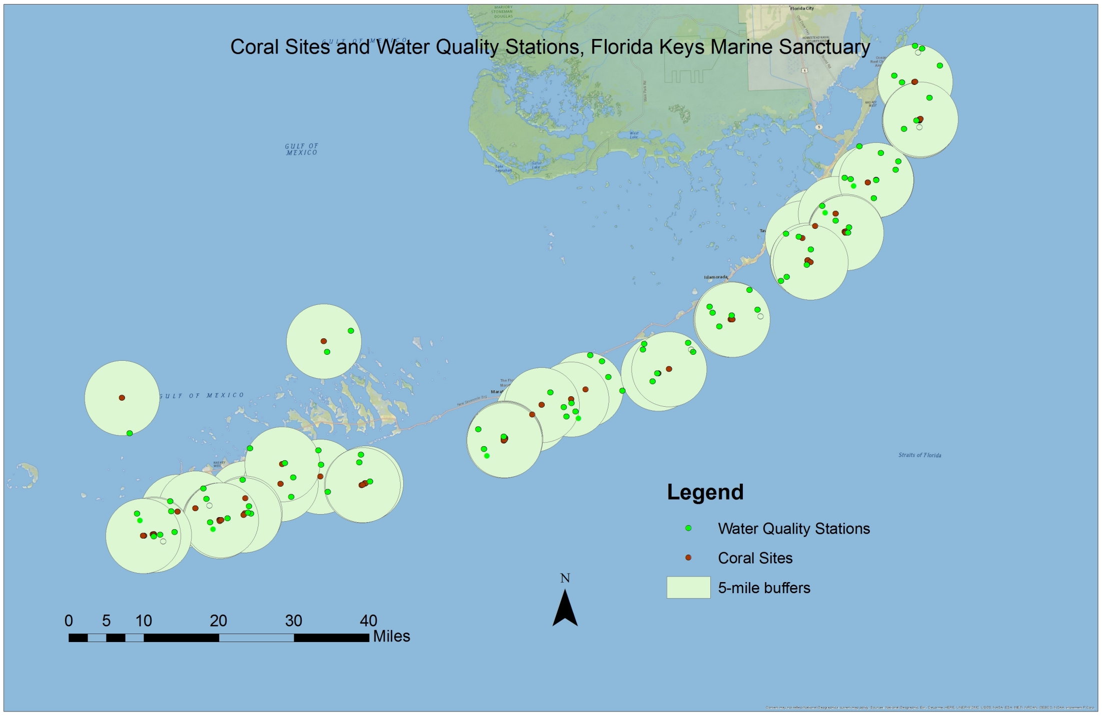

Figure 2: Coral Sites and Water Quality Stations 5 mile buffer
Notes: This figure depicts 136 coral sites and water quality sampling stations identified by a 5-mile buffer zones around each coral site.
Source: Authors; WQPP (2015); CREMP (2015)

Methods

The Least Squares Dummy Regression variable model presented in equation (1) below is utilized to identify the effects of water quality and warmer water on the abundance of coral reefs in the Florida Keys.

$$Area_{it} = \beta_0 + \beta_1 WQ_{it} + \beta_2 WQ_{it}^2 + \beta_3 TURB_{it} + \beta_4 TEMP_{it} + \lambda_i + \varepsilon_{it} \quad (1)$$

$Area_{it}$ is the percent of area covered by different species of corals at site i and at time t. WQ_{it} represents the vector of the water quality parameters and includes total bottom concentrations of nitrite and nitrate, as well as bottom silicate level. It is assumed nutrient loadings have non-linear effects on coral abundance - initially positively affecting corals by increasing their coverage. However, excessive loading may lead to their destruction (Muscatine 1989).

To account for this non-linear effect, the model defined in Equation (1) additionally includes squared terms of water quality variables. $TURB_{it}$ is the turbidity level, while $TEMP_{it}$is the maximum bottom water temperature. λ_i corresponds to site-specific dummy variables and capture time-invariant factors that vary across space, such as benthic conditions that are unique to each site. ε_{it} is the random variable and is assumed to be normally distributed.

CHAPTER III

RESULTS

Summary Statistics

Presented in Table 1 are the summary statistics of main model variables. The average percent area covered by Octocorals and Stonycorals combined was approximately 20% in the Florida Keys, the minimum corresponded to 0.1%, while the maximum was over 60% during the sample period. Of the 20% of coral areas, Octocorals comprised 11.6%, while the remaining 8.6% were represented by the Stony corals. The sample average turbidity measured in Nephelometric Turbidity Unit (NTU) was 0.56 and corresponded to the average of surface and bottom turbidities. The average concentration of nitrites and nitrates was 0.14 micromoles per liters (μM), the minimum was recorded at zero, and the maximum equaled to 0.96 μM. The average concentrations of silicates were on average 0.39 μM, with a minimum also at zero and a maximum at 3.37 μM. The average bottom temperature during the sample period was approximately 30 degree Celsius.

Table 1: Coral Summary Statistics

Variable	Mean	Std.Dev	Min	Max
corals	0.202	0.139	0.0012	0.608
Octocoral	0.116	0.102	0	0.489
Stony_cora	0.086	0.085	0.0005	0.456
TURB_B	0.299	0.441	0	4.914
NOX_B	0.141	0.189	0	0.958
SI_OH_4_B	0.392	0.568	0	3.369
TEMP_B	29.861	1.619	21.7	34.5

Table 1: Summary Statistics

Notes: Sample consists 1262 observations corresponding to 136 coral stations from 1996-2006.
Source: WQPP (2015); CREMP (2015); Author

Regression Analysis

Table 2 reports regression results from three different models, which differ from each other by the dependent variable. Column (1) corresponds the model in which the dependent variable is total area of Stony and Octocorals covered, while columns (2) and (3) correspond to regressions in which dependent variables are Octocoral and Stony coral separated by species. The variables containing three stars indicate that they are statistically significant at the 1% significance level, thus indicating highly significant effects of these variables on coral coverage. Two stars indicate significance at the 5% level and one star corresponds to 10% significance level. These results suggest that high turbidity levels and alleviated nitrite and nitrate concentration negatively affect total areas of corals; however when examined by species, turbidity exerts significant affect only on stony coral species.

The effect of nitrite and nitrate is found to be non-linear, as seen by insignificant coefficient associated with its squared term. Increased temperature drastically reduces coral cover and the effect remains significantly negative across the two species of corals examined. The results indicate that silicate concentration has a non-linear effects on coral coverage, initially promoting its abundance as indicated by significantly positive coefficient associated with this variable. However, excess loading results in coral coverage decrease, as indicated by the negatively significant coefficient associated with Silicate square term. This effect, similar to the effect of turbidity, appears to be driven primarily by Stony corals.

Table 2: Regression analysis results

	Corals	Octocoral	Stony Corals
TURB	-0.0124***	-0.0011	-0.0113***
	(0.0041)	(0.0019)	(0.0038)
NOX	-0.0695***	-0.0350**	-0.0345**
	(0.0229)	(0.0160)	(0.0172)
NOX sq.	0.0399	0.0080	0.0320
	(0.0259)	(0.0166)	(0.0201)
SI_OH_4	0.0234***	0.0066	0.0169***
	(0.0067)	(0.0050)	(0.0051)
SI sq.	-0.0069***	-0.0025	-0.0044**
	(0.0022)	(0.0017)	(0.0018)
TEMP	-0.0045***	-0.0020***	-0.0025***
	(0.0009)	(0.0006)	(0.0008)
Constant	0.3426***	0.1791***	0.1636***
	(0.0276)	(0.0192)	(0.0238)
R^2	0.91	0.91	0.87
N	1,260	1,260	1,260

Table 2: Final regression results generated in Stata

Notes: Regression results; Standard errors reported in parenthesis.

* p<0.1; ** p<0.05; *** p<0.01

Source: Author

Regression results prove that excess levels of nitrate and nitrite combined, either from natural or unnatural sources, significantly contribute to the decline in coral reefs in the FKNMS. Coral reefs initially react positively to the elevated levels of silicates, however over enrichment has an inverse effect, resulting in a great decline in coral cover. Our results also show that the increased turbidity are associated with low coral coverage and warmer climate negatively impact coral abundance. Analyzing by types of corals, Stony corals exhibit more sensitivity to nutrient pollution and enhanced turbidity levels relative to Octocorals. Both types of corals remain highly sensitive to warmer climate.

CHAPTER IV

DISCUSSION

The results of this research indicate that coral reefs remain highly sensitive to pollution and temperature even in marine protected areas. Sources of inorganic nutrient pollution in the Keys' waters originate from fertilizer and urban runoff, peat nitrogen, or pollution from oil and gas exploration occurring in the neighboring Gulf of Mexico waters, being transported by the Gulf Loop Currents. Previous studies conducted in the FKNMS emphasize coral reef sensitivity to inorganic nutrients as a result of sewage disposal systems into near shore and offshore waters (Lapointe, 2004). Nitrogen isotopes have been traced in order to determine if the source is natural or anthropogenic. Water samples taken in unpolluted coastal waters outside of the FKNMS typically had a mean ^{15}N of +0.5 ± 1.0 parts per hundred, indicating lower Nitrogen levels occurring through natural nitrogen fixation (Lapointe, 2004). Corals in the FKNMS appeared enriched in ^{15}N by ± 5 parts per hundred, at sewage polluted sites, much greater than unpolluted coastal waters (Lapointe, 2004). This specific urban run-off pollution is linked to phytoplankton blooms, hypoxia, and shallow groundwater contamination, not only affecting coral reefs but sea grasses, fisheries, and overall biological diversity (Lapointe, 2004). Natural events such as high winds, rains, and low tides also contribute to already elevated dissolved inorganic nutrient levels of nitrates, nitrites and silicates.

Results of this research indicate that cover of both species of corals will greatly be reduced as temperature rises. This trend can be seen throughout recent bleaching incidents of corals. There is a strong consensus among scientists that 1998 mass coral bleaching events were due to global climate change, and regionally specific El Nino and La Nina (Reaser, 2016). It is predicted that surface temperatures, SSTs, reaching even 1 ° C above normal summer maxima and lasting for 2-3 days will induce bleaching (Reaser, 2016). This is troubling due to the last three decades being warmest at the Earth's surface than any other preceding decade since the 1850's, with the Northern Hemisphere likely experiencing the warmest 30-year period during 1983-2012 (IPCC, 2014). The International Panel on Climate Change (IPCC) projects that surface temperature is likely to rise under all assessed CO_2 emission scenarios. An increased in intensity of heat waves, and extreme precipitation in many regions has also been predicted. The global oceans will continue to acidify, warm, and rise in sea level, with the strongest warming projected in the tropical and Northern Hemisphere subtropical regions, affecting the majority of the world's coral reef ecosystems (IPCC, 2014). Numerous marine species will be unable to adapt to live in a much warmer climate, and will be faced with lower oxygen levels in a more acidic environment. Coral reef ecosystems and polar ecosystems are listed among the most vulnerable ecosystems to climate change (IPCC, 2014).

Policy implications for coral ecosystem

Results of this thesis have implications for the policymaking concerning FKNMS as well as policymaking related to the biodiversity protection worldwide. While some of the sources of pollution and climate effects are beyond the efforts of the FKNMS, there are other areas in which stringency in regulation could enhance coral abundance. For example, human induced trash and pollution may also originate from fishing activities, tourism, and diving. While fishing with destructive gears are prohibited throughout the FKNMS, in Existing Management area, commercial lobster trapping within current regulations are allowed (Suman, 2000). Various ecological effects occur when bottom traps are utilized such as destroying benthic organisms and entangling the rest (Chiappone, 2005). In addition, fishing activity introduces significant amount of trash negatively impacting corals. In 2001, 63 sites were surveyed in the FKNMS and 87% of all debris encountered was from hook-and-line fishing gear, and responsible for 84% of the 321 impacts to sponges and benthic cnidarians (Chiappone, 2005). The direct effects of fishing on coral ecosystem while is beyond the scope of this thesis, it is still worth highlighting that overfishing affects the population structure of species by affecting the abundance, size, and growth and alters species interactions (Jennings, 1966). The FKNMS supports multimillion-dollar commercial and recreational fisheries. Approximately 2400 fishermen hold a Florida Saltwater Products License (SPL), and are classified as commercial fishers (Suman, 2000). Some of the most economically profitable fisheries include shellfish, finfish, lobster, shrimp and tropical fish (Suman, 2000). Maintaining a healthy fish stock of key species that consume algae off coral, such as parrotfish, is key for reef growth. Corals need the right amount of sunlight, and too much algae can suffocate corals. Overfishing of this species is one example that directly affects coral survival. Octocorals were the most frequently affected species, due to their branching physical appearance, and less than 0.2% of Stony coral were adversely affected (Suman, 2000).

Expanding "no take zones" throughout a sanctuary appears crucial to allow for coral species to repopulate and recover at some level of sustainability. Keeping novice divers and boaters away from threated coral species will also aid in maintaining ideal water quality. Securing success of these no takes zones requires cooperation of three key stakeholders: commercial fisheries, diver operators, and members of local environmental agencies. Each of these stakeholders' participation will determine the success and outcome of the sanctuary (Suman, 2000).

On a global-scale, concerns heighten as corals and other important biodiversity are threatened by pollution and climate change. The United Nations Environment Programme (UNEP) created the UN Convention on Biodiversity after the recognition that biological diversity is a global asset, therefore necessary to protect and preserve for future generations (Convention on Biological Diversity, 2016). The Convention was opened for signatures on June 5, 1992 at the United Nations Conference on Environment and Development. It received 168 signatures in approximately one year, and then was ratified and put into action on December 29, 1993.

The most recent Plan for Biodiversity 2011-2020 includes goals for the 2011-2020 to halve the rate of loss of natural habitats, and to restore at least 15% of degraded areas through restoration activities (Convention on Biological Diversity, 2016). Specifically regarding the oceans, the convention conservation targets expand to 17% of terrestrial and inland water areas, 10% of marine and coastal areas, and entail special efforts to reduce the pressure faced by coral reefs (Convention on Biological Diversity, 2016). The Strategic Plan is to be implemented through activities at the national level, with supporting action at the regional and global levels. Participation at all levels, and contributions of women, indigenous communities, civil communities, and the private sector are also deemed essential for this convention (Convention on Biological Diversity, 2016). The convention also makes financial support available to pooper, developing countries, and the most environmental vulnerable areas to promote their participation and successful implementation of the Strategic Plan (Convention on Biological Diversity, 2016).

While goals are set, implementation of the strategic plan faces many challenges as most of valuable coastal and ocean ecosystems are open access resources with poorly defined property rights and low level of enforcement. Currently, only 3% of the world's corals are in a MPA (Economist, 2016). In addition to managing current Marine Protected Areas, the implementation of the goals will require more reserves to be created across the globe.

CHAPTER V

CONCLUSION

The objective of this study is to understand the quantitative effects of the deteriorated water quality parameters and warmer climate on the distribution of corals in the FKNMS. Understanding the effects of increased turbidity, nitrates, silicates, and temperature on coral cover is crucial given the important ecosystem and economic roles coral reefs assume. Despite efforts to maintain the sanctuary in its pristine environment, scientific monitoring programs reveal declining trends in certain coral species with increased prevalence of disease and coral bleaching over the past 10 years. Identifying these causal relationships is important in order to inform sanctuary management policy as well as increase public awareness about their importance for the long-term functioning and sustainability of this ecosystem.

Many threatened dive sites across the world allow access to their site yearlong, through snorkeling, boating, diving, or fishing. Many of these sites will offer short certification courses, or even allow tourists into the water without proper diving certifications. Future management plans should only permit scientific in threatened areas, and better diving and snorkeling education needs to be enforced while students acquire S.C.U.B.A certifications. However no site can be managed the same way with many different pollutants coming into effect. Individual management efforts will be different from site to site around the world. International pressure on local government, especially from organizations like the UN Convention on Biological Diversity, needs to continue to establish and enhance marine protected areas around the world. Enforcing more MPA’s will help corals recover. However, this may not guarantee results.

Lawbreakers still exist and increasing coast guard patrol, diving and snorkeling education, satellites, or even drones can help fully enforce laws in MPA (The Economist, 2016). Ecosystem managers should ensure priority for research aimed at detecting ecological change in threatened species via continued water quality analysis and tighter policy enforcement (Munro, 1995).

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