2021

Managing Natural Resources Through Vulnerability Analysis: An Applied Case Study into Recreational Activities at Coral Reefs in Puerto Rico

Karin Jakubowski

Antioch University New England
Department of Environmental Studies
Doctoral Dissertation Committee Form

Student Name	Karin Jakubowski
Committee Chair Title/Affiliation	James Jordan, Ph.D. Core Faculty, Environmental Studies and Sustainability Antioch University New England Keene, New Hampshire
Committee Member Title/Affiliation	Thomas Webler, Ph.D. Associate Professor of Environmental Studies Keene State College Keene, New Hampshire
Committee Member Title/Affiliation	Alida Ortiz Sotomayor, Ph.D. Retired Professor Marine Biology Metropolitan University San Juan, Puerto Rico

MANAGING NATURAL RESOURCES THROUGH VULNERABILITY ANALYSIS: AN APPLIED CASE STUDY INTO RECREATIONAL ACTIVITIES AT CORAL REEFS IN PUERTO RICO

By

Karin Jakubowski

A Dissertation
Submitted in partial fulfillment
of the requirements for the degree of

Doctor of Philosophy
(Environmental Studies)

at

Antioch University New England
Keene, New Hampshire, United States
2021

For my sons,
Jakub and Noah

ACKNOWLEDGEMENTS

This dissertation would not have been possible without the support and encouragement from a number of people along this academic journey. I would like to express immense gratitude to my advisor Dr. James Jordan for his continued support and encouragement throughout the research and writing of this dissertation. I gratefully acknowledge Dr. Thomas Webler who was instrumental to the research conducted in Puerto Rico and has provided valuable input and guidance for my data collection, analysis, and dissertation writing. I express my warmest appreciation to Alida Ortiz Sotomayor for her thoughtful contributions and guidance for this research. I would also like to thank the National Oceanic and Atmospheric Administration (NOAA) Coral Reef Conservation Program for the opportunity to conduct this research.

I am thankful to the people working in the tourism industry in Fajardo, Puerto Rico. They extended their kindness, generosity, and hospitality to me throughout my entire time in Puerto Rico. It would have been impossible to complete this research without their assistance and expert local knowledge. It is very true that the places we love are often about the people. I will always be grateful to the captains and crews of the tourism vessels and the divers and snorkelers who completed my surveys and interviews.

I am thankful to my friends Adria, Jennifer, Maggie, and Sara for their encouragement, support, and wonderful adventures and my friend Tarsila for her professional support and guidance, especially with data analysis. I am also grateful for my Antioch friends – Ann, Brian, Dianne, Enid, Karen, Kate, and especially Meredith for the many writing days in Keene. I have enjoyed spending time with all of you during our classes and during our many dinner excursions. I have found it inspiring to hear about your work, lives, and passions outside of our academic environment.

Finally, I would like to thank my family for their unconditional love and support. Thank you to my husband Werner for being such a supportive, loving, and encouraging partner and helping with the research design, data collection, and analysis. My amazing sons Jake and Noah were incredibly patient and supportive while I worked on the many steps necessary to complete a dissertation. Being your mother is an honor and I hope this work will inspire you to spend your time working in a field you are passionate about. My brother Michael Jakubowski, for always being there for me and for some of the most memorable laughs. To my father Stanley Jakubowski, my favorite angler and role model for conservation. Thank you for providing many childhood experiences that fostered my love for the marine world. Last but certainly not least, my mother Edna Jakubowski for her unconditional love and support. My mom is my biggest fan and continues to inspire and support my passions and dreams wholeheartedly.

In 2017, the Island of Puerto Rico sustained massive damage during Hurricanes Irma and Maria. These storms affected the tourism industry and preliminary findings show the reefs experienced significant damage. I acknowledge this devastating loss and yet feel hopeful as I have since witnessed the resilience of Puerto Ricans and the Island of Puerto Rico as they bravely recover.

ABSTRACT

The purpose of this dissertation is to add knowledge to coral reef management by designing and testing a methodology to assess the vulnerability of select coral reefs to diving and snorkeling recreational activities within La Cordillera Nature Reserve, Puerto Rico. Vulnerability research consists of three main components. This includes measuring exposure to the stressor, characterizing the sensitivity of the exposure, and characterizing the capacity to act. In the context of this research, exposure refers to the number of potentially harmful actions that recreational snorkelers inflict on coral reef ecosystems when they contact the reef and includes the number of individuals over the reef, the duration of time spent over the reef, and the depth of the coral in relation to the location of individuals. Sensitivity includes the qualities that make some corals experience more impact when exposed to the same stressor (the snorkeler and diver behavior) and include the morphology of the coral and the topography of the reef. Finally, adaptive actions in this case refer to decisions and actions taken by a variety of individuals within the tourism industry. This includes crew decisions about dive and snorkel trips, interactions with divers and snorkelers during trips, and the attitudes, knowledge, and beliefs of divers and snorkelers about coral reefs.

Dive and snorkel data were collected between January 2011 and June 2014. My findings indicate that some reefs within La Cordillera Nature Reserve, Puerto Rico are vulnerable to snorkeling activities. Icacos Island reefs have a high exposure to contacts, most likely because of the depth of the coral in relationship to the snorkeler. Fin contacts were the most potentially damaging behavior. Topographic features of these reefs may

lead to more contacts. The number of potentially damaging contacts for snorkelers was high, (0.28 contacts per minute) at La Cordillera Nature Reserve when compared to the only other location where snorkeler contact rates were observed (St. Lucia). When this frequency is multiplied by the number of visitor-minutes spent at reefs on a yearly basis, the scale of the problem can appear to be a significant factor in increasing vulnerability.

Reefs within La Cordillera Nature Reserve are also vulnerable to scuba diving activities. Dive operator data analyzed found the average number of trips during both the peak and non-peak season was the same, 107 trips. The average number of divers per trip was nine. The dives lasted from 35 – 51 minutes with a mean of 45 minutes at an average depth of 50 feet. This averages to slightly more than 3,200 divers per year, which is below all of the other recommended carrying capacities in coral reef locations globally. While the average number of divers may be below carrying capacity, the contact rate for divers observed in La Cordillera Nature Reserve, was 0.5 contacts per diver per minute. This rate is five times higher than all but two other coral reef locations where research on number of contacts with reefs was conducted. Similar to other research, divers who use cameras while diving had significantly more contacts with the reef than non-camera users. The reefs at one of the main dive sites, Diablo Cay, had a high percentage of soft corals. The unpredictable movement of these corals can make it difficult for a diver to avoid a contact and may be a contributing factor to why the contact rate per minute is higher for divers in Puerto Rico.

Coral reef related tourism and recreational activities rank among one of the most important industries in Puerto Rico by providing jobs, supporting local economies, increasing visitor knowledge of coral reefs, promoting pro-environmental values, and helping to create a conservation ethic. Healthy and resilient coral reef ecosystems are essential to the tourism industry, specifically scuba diving and snorkeling operations. Given the current and expected growth in tourism and marine recreational activities, the problem of recreationally-based damage to coral ecosystems will continue to grow. This dissertation can inform management decisions designed to mitigate the impacts that dive and snorkel tourism have on coral reef systems in order to decrease the overall vulnerability of these systems. Recommended measures can be implemented to reduce the vulnerability of the system which then can continue to provide benefits to those who depend on this economy for their livelihood and well-being. Specifically, actions that decrease exposure is a tangible possibility. Reducing contacts is one such measure. Actions to encourage pro-environmental behaviors at the reef include revising briefings that reinforce etiquette at the reef and social norms that empower snorkelers, non-certified divers, and certified divers to make a greater effort to not contact the reef. Crew members should consider the skill and perceptions of their guests, mooring use, in water supervision, interventions, attending best practices workshops, and emphasis on the content and delivery of coral reef etiquette messages. Such measures are important for reducing the vulnerability of coral reefs to recreational activities, conserving these ecosystems, and sustaining the tourism economy of Puerto Rico and beyond.

TABLE OF CONTENTS

List of Tables

List of Figures

CHAPTER 1
Introduction

1.0 Coral Reef Biology

A well-developed coral reef ecosystem reflects thousands of years of history and is considered one of the most diverse and productive ecosystems on Earth (National Oceanic and Atmospheric Administration [NOAA], 2016). Scleractinians (stony corals) are the defining organisms of this ecosystem and consist of calcium carbonate deposits created by hundreds of thousands of small, invertebrate, colonial polyps. Reef building is a slow process that initially involves free swimming coral larvae attaching to submerged land edges. Polyps will grow to a certain size and then reproduce both asexually and sexually (Barnes & Hughes, 1999). When the coral polyps die, the calcium carbonate skeletons remain integrated as part of the coral reef ecosystem. This complex, three-dimensional structure supports high biodiversity and productivity.

Living coral polyps are inhabited by a symbiotic, unicellular, autotrophic, microalgae called zooxanthellae (Barnes, 1987; Lalli & Parsons, 1995). Zooxanthellae are essential for the survival of reef building corals, and are responsible for the bright colors associated with coral reefs. Through photosynthesis, zooxanthellae capture and fix carbon. Approximately 90% of this organic material is utilized by the polyps for energy and calcification (Sumich, 1996). In exchange, the polyps provide the zooxanthellae a place to live and carbon dioxide for autotrophic processes. On this dynamic, mutualistic, relationship rests the entire biological productivity of the coral reef ecosystem (Goreau et al., 1979). It is this complex symbiotic relationship that limits reef building corals to tropical and semi-tropical waters since their strict environmental requirements dictate their success. Certain species of scleractinians are particularly vulnerable and are at elevated risk of extinction as a combined effect of global climate change and local anthropogenic impacts. While some species of stony corals have resilience to natural disturbances caused by storms, most are sensitive to minor changes in temperature, salinity, turbidity, and the overall chemistry of the water they inhabit.

1.1 Coral Reef Resources

Coral reefs have been providing goods and services to humans for more than 35,000 years (Kirch, 2000). These services include natural wave barriers that protect coastal communities from hurricanes and storm surges, habitat for commercially valuable fish and shellfish populations, scientific research, medical compounds to treat serious diseases, aesthetic value, cultural benefits, and overall well-being. For instance, the Tahitians have more common names for coral reefs and the fauna and flora that occupy them than any other culture in the world (Salvat & Pailhe, 2002). Many Puerto Rican fishers describe fishing around coral reefs as a healthy activity that keeps their minds occupied on useful things and provides relief from stress (Griffith & Valdés-Pizzini, 2002). Indigenous communities are often solely dependent on reefs for their food and considering that a majority of reefs are located in economically disadvantaged regions, they serve as the only available and affordable source of protein for a majority of local people (Kirch, 2000).

Coral reefs also sustain the livelihoods of many coastal and island people. In particular, tourism and coral reef related recreational activities rank among the most important industries. While there are different monetary estimates that have been reported for the economic value of coral reefs, all are reported in the billions of dollars. One estimate places the total net benefit per year of the world's coral reef ecosystems at $29.8 billion dollars and the value of coral-reef based recreation and tourism at $9.6 billion dollars (Cesar et al., 2003; NOAA, 2016).

Coral reefs also provide biological and ecological services. They buffer adjacent ecosystems from waves and erosion, function as breeding and spawning grounds, provide nurseries and feeding environments for over one million species of marine life, and contain an estimated one to eight million still undiscovered marine species (Moberg & Folke, 1999; Reaka-Kudla, 1997). These ecosystems also house a great deal of genetic diversity for future generations of marine organisms. Coral reefs provide homes to apex predators, like sharks and endangered sea turtles. Also, the diversity of the reef structure provides specific niches for fish, crustaceans, algae, bacteria, and reptiles which makes it possible for the evolution of new species (Birkeland,1997; Paulay,1997). Finally, reefs sequester carbon, balance the Earth's calcium supply and fix nitrogen at a considerably higher rate than other marine ecosystems.

1.2 Threats to Coral Reefs

Despite these benefits coral reefs are threatened by a multitude of natural and anthropogenic stresses (Glynn, 1994; Hoegh-Guldberg et al., 2007). Approximately 20% of the world's reefs have been destroyed, 24% are under imminent risk of collapse, and another 26% are in grave danger of irreparable damage (Riegl et al., 2009). By 2050, reefs globally may no longer be dominated by hard corals (Hoegh-Guldberg et al., 2007). A combination of direct and indirect, local and global impacts is responsible for the severity of the coral reef crisis.

Examples of large-scale global threats to coral reefs include warmer ocean temperatures and changes in the chemistry of ocean water (Doney, 2006). There is a direct correlation between increased greenhouse gases, climate change, and regional-scale bleaching of corals (Hughes et al., 2003). This is due to the fact that corals respond to temperature, light, and nutrient stressors by expelling their symbiotic, unicellular zooxanthellae that live within the coral tissues and are responsible for providing corals with additional nutrients via photosynthesis (Polidoro &

Carpenter, 2013). The process is referred to as bleaching, since the loss of zooxanthellae leave the coral color lighter or even white. Moreover, changes in ocean chemistry due to increased concentrations of carbon dioxide in the atmosphere dissolving in ocean water, contribute to the weakening of coral skeletons and may cause death of coral species (Doney, 2006; Kleypas et al., 1999). Climatic changes can also result in an increase in the frequency and intensity of severe weather events such as storms and hurricanes, which can cause wave damage to corals and increase stress from terrestrial run-off (Heron et al., 2008). Coral bleaching and diseases associated with climate related stressors have already increased greatly in frequency and magnitude over the past 30 years (Baker et al., 2008; Baker, 2014; Glynn, 1993; Wilkinson & Souter, 2008). Warmer than normal sea temperatures have already caused long term damage to 16% of the world's coral reefs (Johnson & Marshall, 2007).

Localized anthropogenic threats include overfishing, which disrupts the ecological balance of the reef and can lead to algal infestations that slow the recovery of coral communities (Fenner, 2012) and pollution from sediments, chemicals, and sewage which decreases growth, reproduction, and survival rates (Koop et al., 2001; Negri et al., 2002; Nemeth & Nowlis, 2001). The main sources of these contaminants are agriculture, coastal construction, and wastewater outfalls (Hawkins & Roberts, 1994). Corals also suffer physical damage by vessels traveling over reefs and poor anchoring practices (Tilmant,1987).

Tourism activities in and around the marine environment, are another category of anthropogenic stressors. For example, snorkeling and scuba diving, both recreational activities offered to tourists, were once thought of as low-impact options for coral reef use. However, these recreational activities can significantly degrade coral reefs when visitors act inappropriately. Specific damaging behaviors include fins kicking coral, brushing up against the reef, holding on to coral, standing or kneeling on the reef, and walking on coral polyps (Barker, 2003; Medio et al.,1997; Prior et al.,1995; Rouphael & Inglis, 2001). Even minor human contacts can damage the protective layer of tissue that covers the corals leaving them susceptible to algae colonization, which then collects sediment and ultimately smothers the coral (Hall, 2001; Liddle & Kay, 1987; Walker & Ormond, 1982). Coral diseases caused by natural and anthropogenic physical tissue damage can kill corals and eventually lead to shifts in the type, diversity, and percentage of corals that occupy reef ecosystems (Hawkins & Roberts, 1997). The scleractinians (stony corals), in particular, are vulnerable to direct human contact since their slow growing calcium carbonate skeletons are relatively brittle and their conical and horn shaped polyps can be easily crushed (Tratalos & Austin, 2001).

Different stressors can act synergistically to cause even greater damage to reefs. For example, Connell and Slatyer (1977) found that recovery from storm damage was much slower for reefs with multiple stressors when compared to reefs not exposed to as much damage. Large areas of significant, intact, live corals, where ecosystems and food chains are stable and there is little human disturbances or climate change impacts, contain healthy coral that harbor the greatest genetic diversity (Smith & Marx, 2015; Wooldridge & Done, 2009). This diversity allows some species to cope in times of stress, the capacity to adapt, and the ability to undergo the process of speciation (Selkoe et al., 2016). When disturbance, for example a bleaching event, does occur coral recovery depends on the recruitment and arrival of larva from other reef locations. In the absence of anthropogenic stressors, recovery may happen more quickly. Gilmour et. al (2013) found that corals around isolated Scott Reef had a rapid recovery following a mass bleaching event possibly due to the fact that other anthropogenic disturbances were absent. While it is possible to develop strategies to effectively manage resource use on a local scale, such tasks become more difficult when compounded by multiple stressors, specifically the large-scale global threats. For all of these reasons, it is essential that we develop mechanisms to reduce the impacts of these threats.

1.3 The Problem

Coral reef related tourism and recreational activities rank among the most important industries by providing jobs, supporting local economies, increasing visitor knowledge of coral reefs, promoting pro-environmental values, and helping to create a conservation ethic (Coté & Reynolds, 2006). The industry markets these resources to attract tourists to tropical destinations like Puerto Rico, and provides a vacation experience based on the wants and perceptions of these visitors. Often the short-term economic gains from tourism come at the expense of the reef environment (Ragster & Geoghegan, 1992). Excessive and unmanaged use by the tourism industry, as well as irresponsible behaviors by individuals, can negatively impact the health of the reef ecosystem.

In Puerto Rico, recreational activities, such as diving and snorkeling are popular around the island's reefs yet there has been no research conducted about the behaviors of those participating in these activities at reefs. Without these findings, it is difficult to implement management techniques to effectively reduce or prevent reef degradation. This is especially so in regions where diving and snorkeling activities are chronic, concentrated, and popular. And while scuba diving and snorkeling tourism in particular may seem small compared to other stressors like warmer ocean temperatures and changes in the chemistry of ocean water, tourism activities do impact the health of coral reef ecosystems, and these impacts can be readily mitigated with appropriate actions (Webler & Jakubowski, 2011).

For these reasons, knowledge about the relative vulnerability of specific reefs to damage from recreational use within Puerto Rico is necessary for informing and prioritizing management and conservation decisions for the tourism industry and government officials responsible for managing coral reefs. Vulnerability can be defined as the state of susceptibility to harm from exposure to some specific stressor (Adger, 2006). Vulnerability research focuses on the shocks and stresses experienced by the social-ecological system, the response of the system, and the capacity for adaptive action. Human activities can affect the vulnerability of a system. Nonetheless, a majority of the impacts of tourism activities can almost always be prevented (Adger, 2006).

Not all reefs are equally affected by tourism impacts and the long-term effects of these impacts is unknown. It can be postulated that coral reef ecosystems are resilient to stresses below some threshold and above this threshold the reef rapidly degrades (Davis & Tisdell, 1995). Thus, it is difficult to estimate how many tourists a reef can support, if a threshold has not been defined. Reef management would be empowered with knowledge of the level of human impacts and the critical thresholds that must be avoided. The tourism industry wants the resources protected. However, without strong empirical data, precautionary management actions can be eclipsed by short-term economic gains (Ragster & Geoghegan, 1992).

1.4 Vulnerability Assessment

Designing a method to assess the vulnerability of select coral reefs to recreational activities includes measuring exposure of reefs to visitors, characterizing the sensitivity of reefs to potentially harmful visitor behaviors, and characterizing the adaptive capacity of the system by examining opportunities to influence management options. Adaptation refers to changing the sensitivity of the system to the exposure. Coping and adaptation together are frequently understood as resilience. Resilience is defined as the magnitude of the disturbance that can be absorbed before a system changes to a radically different state (Adger, 2006).

Effective environmental management must be based upon a sound understanding of natural and anthropogenic drivers and interactions (White et al.,1994). The challenge is that several different human activities are difficult to untangle and ecosystems are distinct in that they respond to stressors associated with each activity differently (Halpern et al., 2008). Environmental management of resources used by the tourism sector also involves maintaining the balance between the satisfaction of visitors and the preservation of the ecosystem qualities (Kenchington, 1993). In order to manage the various activities that take place within coral reef ecosystems, resource management and conservation efforts have moved toward interdisciplinary and multi-sector ecosystem-based approaches. Such integration involves both horizontal and vertical elements. Adaptive capacity enables management actions that can reduce vulnerability (Smit & Wandel, 2006). Ideally, adaptive actions should include horizontal integration that incorporates a variety of sectors such as fisheries, tourism, development, and transportation, as well as vertical integration which incorporates all levels of government and a variety of stakeholders that use, influence, affect, or manage marine resources from local through international scales (Brown et al., 2002).

Adaptive actions can assist coral reef managers and those in the tourism industry by assisting with informed choices for tourism activities around coral reefs. Tourism managers may be aware that damage to coral reefs affects their businesses thus making a need for adaptive measures even stronger. For instance, an adaptive management action that reduces exposure could include the installation of a mooring buoy at a popular dive and snorkel reef. Mooring buoys reduce the impacts to corals caused by vessel anchors. Buoys also allow dive and snorkel operators to have a set location to operate. However, buoys require government approval and funding to purchase, site, and install. Once installed full compliance may not be achieved and enforcement can be costly. Finally, a mooring buoy does not control for the number of vessels, divers or snorkelers visiting a specific area. Other examples of adaptive actions include tour company captains making decisions about which reefs to visit and crew providing education and instruction to tourists about coral reef etiquette.

While a few coastal governments and local communities have been active in implementing measures to reduce the negative impacts caused by humans, the results have varying degrees of success and the threats to reef ecosystems are still increasing (Sale, 2008). Gardner et al., (2003) state that if human behaviors could be managed correctly, corals would be capable of handling natural stresses more effectively. While Puerto Rico's Coral Reef Management Plan prioritizes the study of recreational use at reefs and includes strategies to reduce impacts, protect the health of coral reefs, and enhance coral reef resilience, most of the research on reefs that has taken place in Puerto Rico over the last decade has not focused on tourism. Community characterization, monitoring programs, coral diseases, and environmental impact assessments have been the priorities (Garcia-Sais et al., 2008).

1.5 Purpose

Two major problems are addressed by this research. First, there is a gap in knowledge about the type of stress recreationalists place on reefs. Limited study has been undertaken with regard to recreational misuse for divers and scarcely any data are available on snorkelers (Barker, 2003; Medio et al., 1997; Prior et al, 1995; Rouphael & Inglis, 2001). Some research has relied on self-reports of behavior, but it is not known how accurate these data are. These findings focus on reefs in other locations. No research has been undertaken with regard to recreational misuse in

Puerto Rico. Second, there is a gap in our understanding of what management actions are available or how effective they will be at mitigating impacts. The purpose of this dissertation is to contribute to both of these areas by addressing the following questions:

1. What threats does recreational scuba/snorkeling pose to coral reefs in general, and in Puerto Rico specifically?
2. What management actions will be most effective at mitigating the threats?

Given the growth in recreational activities all over the world, gaining a better understanding of how scuba divers and snorkelers behave around coral reefs and how their actions impact the reef is essential for coral conservation. The priority goal is to maintain the health of coral reefs while having them serve as attractive and educational destinations for tourists and local residents to visit and enjoy while generating income for the livelihoods of those working in the tourism sector as well as the local economies.

1.6 Overview of Dissertation

This introductory chapter provides background knowledge on this issue as well as justification for its study. Chapter two provides a review of the literature by examining the theories of vulnerability, behavior change, recreation specialization, and persuasion in order to design an approach to characterize the vulnerability of reefs in Puerto Rico to stressors associated with recreational visitation by divers and snorkelers. The literature in chapter two is presented in three sections: 1.) an overview of marine tourism and recreation with an emphasis on coral reefs, Puerto Rico, diving, and snorkeling 2.) a summary and review of the theory of vulnerability analysis and 3.) an examination of several behavior change theories, the theory of recreation specialization, and persuasion communication in order to better understand why divers and snorkelers behave the way they do and what can be done to modify their behavior as a course of action to reduce vulnerability. Chapter three discusses the development and application of the vulnerability assessment case study specific to snorkelers recreating in La Cordillera Nature Reserve, Puerto Rico and chapter four focuses on scuba divers. Chapter five discusses adaptive management options and evaluates their strengths and limitations based on the results for both divers and snorkelers in La Cordillera Nature Reserve. Chapter six summarizes the findings of this study, discussing its application and limitations, and recommendations for managing coral reefs vulnerable to dive and snorkel tourism and future research.

1.7 References

Adger, W. (2006). Vulnerability. *Global Environmental Change*, *16*(3), 268-281. https://doi.org/10.1016/j.gloenvcha.2006.02.006

Baker, A. (2014). Climate change: Many ways to beat the heat for reef corals. *Current Biology*, *24*(24), 166 – 168. https://doi.org/10.1016/j.cub.2014.11.014

Baker, A., Glynn, P., & Riegl, B. (2008). Climate change and coral bleaching: An ecological assessment of long-term impacts recovery trends and future outlook. *Estuarine, Coastal, and Shelf Science,80*(4), 435-471. https://doi.org/10.1016/j.ecss.2008.09.003

Barker, N. H. L. (2003). *Ecological and socio-economic impacts of dive and snorkel tourism in St. Lucia, West Indies* (Doctoral dissertation, University of York). ProQuest Dissertations and Theses Global.

Barnes, R.D. (1987). *Invertebrate zoolog*y (5th ed.) Harcourt Brace Jovanovich College.

Barnes, R.S.K. & Hughes, R.N. (1999). *An introduction to marine ecology* (3rd ed.). Blackwell Science Ltd.

Birkeland, C. (1997). *Life and death of coral reefs*. Chapman and Hall.

Brown, K., Tompkins, E., & Adger, W. (2002). *Making waves: Integrating coastal conservation and development*. Earthscan.

Cesar, H.J.S., Burke, L., & Pet-Soede, L. (2003). *The economics of worldwide coral reef degradation*. Cesar Environmental Economics Consulting, Arnhem, and WWF-Netherlands.

Connell, J. J. & Slatyer, R.O. (1977). Mechanisms of succession in natural communities and their role in community stability and organization. *American Naturalist,111* (982), 1119 – 1144.

Coté, I & Reynolds, J.D. (2006). *Coral reef conservation*. Cambridge University Press. https://doi.org/10.1017/CBO9780511804472.019

Davis, D. & Tisdell, C. (1995). Recreational scuba-diving and carrying capacity in marine protected areas. *Ocean and Coastal Management*, *26*(1), 19-40. https://doi.org/10.1016/0964-5691(95)00004-L

Doney, S. (2006). The dangers of ocean acidification, *Scientific American*, *294*(3), 58-65. https://doi.org/10.1038/scientificamerican0306-58

Fenner, D. (2012). Challenges for managing fisheries on diverse coral reefs. *Diversity, 4*(1), 105 – 160. https://doi.org/10.3390/d4010105

Garcia-Sais, J., Appeldoorn, R., Battista, T., Bauer, L., Bruckner, A., Caldow, C., Carrubba, L., Corredor, J., Diaz, E., Lilyestrom, C., Garcia-Moliner, G., Hernandez-Delgado, E., Menza, C., Morell, J., Pait, A., Sabater, J., Weil, E., Williams, E., & Williams, S. (2008). The state of coral reef ecosystems of Puerto Rico. In: J.E. Waddell and A.M. Clarke (Eds.), *The state of coral reef ecosystems of the United States and Pacific Freely Associated States: 2008.* NOAA Technical Memorandum NOS NCCOS 73. NOAA/NCCOS Center for Coastal Monitoring and Assessment's Biogeography Team (pages 75 – 116).

Gardner, T.A., Côté, I.M., Gill, J.A., Grant, A., & Watkinson, A. R. (2003). Long-term region-wide declines in Caribbean corals. *Science*, *301*(5635*)*, 958-960. https://doi.org/10.1126/science.1086050

Gilmour, J.P., Smith, L.D., Heyward, A.J., Baird, A.H., Pratchett, M.S. (2013) Recovery of an isolated coral reef system following severe disturbance. *Science 340*(69-71). https://doi.org/10.1126/science.1232310

Glynn, P.W. (1993). Coral reef bleaching: Ecological perspectives. *Coral Reefs 12,* 1–17. https://doi.org/10.1007/BF00303779

Glynn, P.W. (1994). State of coral reefs in the Galapagos Islands: Natural versus anthropogenic impacts. *Marine Pollution Bulletin*, *29*(1-3), 131-140. https://doi.org/10.1016/0025-326X(94)90437-5

Goreau, T.F., Goreau, N.I., & Goreau, T.J. (1979). Corals and coral reefs. *Scientific American, 241*, 124 - 136. https://www.globalcoral.org/_oldgcra/CORAL%20REEFS%20Scientific%20American%20ebook.pdf

Griffith, D. & Valdes-Pizzini, M. (2002). *Fishers at work, workers at sea: A Puerto Rican journey through labor and refuge*. Temple University Press.

Hall,V.R. (2001). The response of *Acropora hyacinthus* and *Montipora tuberculosa* to three different types of colony damage: Scraping injury, tissue mortality and breakage. *Journal of Experimental Marine Biology and Ecology, 264*, 209-223. https://doi.org/10.1016/S0022-0981(01)00318-5

Halpern, B., Walbridge, S., Selkoe, K., Kappel, C., Micheli, F., D'Agrosa, C., Bruno, J., Casey, K., Ebert, C., Fox, H., Fujita, R., Heinemann, D., Lenihan, H., Madin, E., Perry, M., Selig, E., Spalding, M., Steneck, R., & Watson, R. (2008). A global map of human impact on marine ecosystems. *Science*, *319*(5865), 948-952. https://doi.org/10.1126/science.1149345

Hawkins, J.P. & Roberts, C.M. (1994). The growth of coastal tourism in the Red Sea: Present and future effects on coral reefs. *Ambio*, 23(8), 503-508.

Hawkins, J.P. & Roberts, C.M. (1997). Estimating the carrying capacity of coral reefs for scuba diving. In H.A. Lessios, & I.G. Macintyre & M. McGee (Eds.), *Proceedings of the Eighth International Coral Reef Symposium* (2nd vol., pp.1923-1926). Smithsonian Tropical Research Institute.

Heron, S., Morgan, J., Eakin, M., & Skirving, W. (2008). Hurricanes and their effects on coral reefs. In C. Wilkinson & D. Souter (Eds.), *Status of Caribbean coral reefs after bleaching and hurricanes in 2005*. (pp. 31-36). Global Coral Reef Monitoring Network, and Reef and Rainforest Research Centre. https://coralreefwatch.noaa.gov/caribbean2005/docs/Status_of_Caribbean_Reefs_after_Bleaching_and_Hurricanes_2005.pdf

Hoegh-Guldberg, O., Mumby, P., Hooten, A., Steneck, R., Greenfield, P., Gomez, E., Harvell, C., Sale, P., Edwards, A., Caldiera, K., Knowlton, N., Eakin, C., Iglesias-Prieto, R., Muthiga, N., Bradbury, R., Dubi, A., & Hatziolos, M. (2007). Coral reefs under rapid climate change and ocean acidification. *Science*, *14*(318), 1737-1742. https://doi.org/10.1126/science.1152509

Hughes,T. P., Baird, A.H., Bellwood, D.R., Card, M., Connolly, S.R., Folke, C., Grosberg, R., Hoegh-Guldberg, O., Jackson, J.B.C., Kleypas, J., Lough, J.M., Marshall, P., Nystrom, M., Palumbi, S.R., Pandolfi, J.M., Rosen, B., & Roughgarden, J. (2003). Climate change, human impacts, and the resilience of coral reefs. *Science*, *301*(5635), 929-933. https://doi.org/10.1126/science.1085046

Johnson, J.E. & Marshall, P.A. (2007). *Climate Change and the Great Barrier Reef*. Great Barrier Reef Marine Park Authority and Australian Greenhouse Office. http://elibrary.gbrmpa.gov.au/jspui/bitstream/11017/584/1/Climate-change-and-the-Great-Barrier-Reef-2007-title-page.pdf

Kenchington, R. (1993). Tourism in coastal and marine environments - a recreational perspective. *Ocean & Coastal Management, 19*(1), 1–16. https://doi.org/10.1016/0964-5691(93)90073-8

Kirch, P.V. (2000). *On the road of the winds: an archeological history of the Pacific islands before European contact*. University of California Press. https://doi.org/10.1002/arco.5168

Kleypas, J. A., Buddemeier, R.W., Archer, D., Gattuso, J.P., Langdon, C., & Opdyke, B.N. (1999). Geochemical consequences of increased atmospheric carbon dioxide on coral reefs. *Science, 284*(5411), 118-120. https://doi.org/10.1126/science.284.5411.118

Koop, K., Booth, D., Broadbent, A., Brodie, J., Bucher, D., Capone, D., Coll, J., Dennison, W., Erdmann, M., Harrison, P., Hoegh-Guldberg, O., Hutchings, P., Jones, G.B., Larkum, A.W., O'Neil, J., Steven, A., Tentori, E., Ward, S., Williamson, J., & Yellowlees, D. (2001). ENCORE: The effect of nutrient enrichment on coral reefs. Synthesis of results and conclusions. *Marine Pollution Bulletin, 42*(2), 91 – 120. https//doi.org/10.1016/s0025-326x(00)00181-8.

Lalli, C. M. & Parsons, T.R.(1995). *Biological oceanography: An introduction*. Butterworth-Heinemann Ltd.

Liddle, M.J. & Kay, A.M. (1987). Resistance, survival and recovery of trampled corals on the Great Barrier Reef. *Biological Conservation*, *42*(1), 1-18. https://doi.org/10.1016/0006-3207(87)90049-8

Medio, D., Ormond, R. & Pearson, M. (1997). Effect of briefings on rates of damage to coral by SCUBA divers. *Biological Conservation*, *79*(1), 91-95. https://doi.org/10.1016/S0006-3207(96)00074-2

Moberg, F. & Folke, C. (1999). Ecological goods and services of coral reef ecosystems. *Ecological Economics, 29(2)*, 215 – 233. https://doi.org/10.1016/S0921-8009(99)00009-9

National Oceanic and Atmospheric Administration (NOAA). (2016). *U.S. Coral Reef Task Force Strategy FY 2016-2021.* https://data.nodc.noaa.gov/coris/library/NOAA/CRCP/other/USCRTF/uscrtf_strategy_2016_2021.pdf

Negri, A., Smith, L.D., Webster, N., & Heyward, A. (2002). Understanding ship-grounding impacts on a coral reef: Potential effects of anti-foulant paint contamination on coral recruitment. *Marine Pollution Bulletin, 44*(2), 111-117. https://doi.org/10.1016/S0025-326X(01)00128-X

Nemeth, R. S. & Nowlis, J.S. (2001). Monitoring the effects of land development on the near-shore reef environment of St. Thomas, USVI: Proceedings of the International Conference on Scientific Aspects of Coral Reef Assessment, Monitoring, and Restoration. *Bulletin of Marine Science*, *69*(2), 759-775.

Paulay, G. (1997). Diversity and distribution of reef organisms. In C. Birkeland, (Ed.), *Life and death of coral reefs* (pp.298-345). Chapman and Hall.

Polidoro, B. & Carpenter, K. (2013). Dynamics of coral reef recovery. *Science, 340*(6128), 34 – 35. https://doi.org/10.1126/science.1236833

Prior, M., Ormond, R., Hitchen, R., & Wormald, C. (1995). The impact of natural resources of activity tourism: A case study of diving in Egypt. *International Journal of Environmental Studies, 48*(3-4), 201-209. https://doi.org/10.1080/00207239508710990

Ragster, L. & Geoghegan T. (1992). Management training in the Caribbean, a necessity for sustainable development; The consortium approach. *Caribbean Perspectives,2*, 1-17.

Reaka-Kudla, M.L. (1997). The global biodiversity of coral reefs: A comparison with rain forests. In, M. L. Reaka-Kudla, D. E. Wilson, & E. O. Wilson, (Eds.), *Biodiversity II* (pp. 83 – 108). Joseph Henry Press. https://doi.org/10.1.1.466.2268&rep=rep1&type=pdf

Riegl, B., Bruckner, A., Coles, S.L., Renaud, P. & Dodge, R.E. (2009). Coral reefs: Threats and conservation in an era of global change. *Annals of the New York Academy of Sciences*, *1162*(1), 136-186. http://doi.org/10.1111/j.1749-6632.2009.04493.x.

Rouphael, A. & Inglis, G. (2001). "Take only photographs and leave only footprints"?: An experimental study of the impacts of underwater photographers on coral reef dive sites. *Biological Conservation*, *100*(3),281–287. https://doi/org/10.1016/S0006-3207(01)00032-5

Sale, P.F. (2008). Management of coral reefs: Where have we gone wrong and what can we do about it. *Marine Pollution Bulletin, 56*(5)*,* 805 – 809. https://doi.org/809.10.1016/j.marpolbul.2008.04.009

Salvat, B. & Pailhe, C. (2002). Islands and coral reefs, population and culture, economy and tourism world view and a case study of French Polynesia. In F.diCastri & V. Balaji (Eds.), *Tourism, biodiversity, and information*,(pp. 213 – 231). Backhuys.

Selkoe, K.A., Gaggiotti, O.E., Treml, E.A., Wren, J.L.K., & Donovan, M.K., Connectivity Consortium, H.R., & Toonen, R.J. (2016). The DNA of coral reef biodiversity: Predicting and protecting genetic diversity of reef assemblages. *Proceedings Royal Society, 283,*1 - 8. https://doi.org/10.1098/rspb.2016.0354

Smit, B. & Wandel, J. (2006). Adaptation, adaptive capacity and vulnerability. *Global Environmental Change,16*(3), 282-292. https://doi.org/10.1016/j.gloenvcha.2006.03.008

Smith, S.H. & Marx, D.E. (2015). De-facto marine protection from a navy bombing range: Farallon De Medinilla, Mariana Archipelao, 1997 – 2012. *Marine Pollution Bulletin, 102* (1),187-198. https://doi.org/10.1016/j.marpolbul.2015.07.023

Sumich, J.L. (1996). *An introduction to the biology of marine life* (6th ed.). Wm. C. Brown.

Tilmant, J.T. (1987). Impacts of recreational activities on coral reefs. In B. Salvat, (Ed.), *Human impacts on coral reefs: Facts and recommendation (pp. 195 – 214).* Antenne Museum E.P.H.E.

Tratalos, J. & Austin, T. (2001). Impacts of recreational SCUBA diving on coral communities of the Caribbean island of Grand Cayman. *Biological Conservation*, *102*(1), 67-75. https://doi.org/10.1016/S0006-3207(01)00085-4

Walker, D.I. & Ormond, R.F.G. (1982). Coral death from sewage and phosphate pollution at Aqaba, Red Sea. *Marine Pollution Bulletin,13*(1), 21-25. https://doi.org/10.1016/0025-326X(82)90492-1

Webler, T., & Jakubowski, K. (2011). *Characterizing harmful behaviors of snorkelers and SCUBA divers to coral reefs in Puerto Rico: Interim Project Report.* Social and Environmental Research Institute: Greenfield MA, 15pp.

White, A.T., Hale, L.Z., Renard, Y. & Cortesi, L. (1994). *Collaborative and community-based management of coral reefs: Lessons from experience.* Kumarian Press.

Wilkinson, C., & Souter, D. (2008). *Status of Caribbean coral reefs after bleaching and hurricanes in 2005*. Global Coral Reef Monitoring Network, and Reef and Rainforest Research Centre, Townsville, pp. 1 -152. https://repository.library.noaa.gov/view/noaa/486

Wooldridge, S. & Done, T. (2009). Improved water quality can ameliorate effects of climate change on corals. *Ecological Applications, 19*(6),1492-1499. https://doi.org/10.1890/08-0963.1

CHAPTER 2
Literature Review

2.0 Introduction

This chapter frames my research by examining vulnerability theory, behavior change, recreation specialization, and persuasion in order to design an approach to characterize the vulnerability of reefs in Puerto Rico to stressors associated with recreational visitation by divers and snorkelers. The literature review is presented in three sections: 1.) an overview of marine tourism and recreation with an emphasis on coral reefs, Puerto Rico, diving, and snorkeling 2.) a summary and review of the theory of vulnerability analysis and 3.) an examination of several behavior change theories, including the Knowledge Attitude Behavior Theory, Theory of Reasoned Action, Theory of Planned Behavior, Norm Activation Theory, Value Belief Norm Theory, Theory of Recreation Specialization, and Persuasion Communication in order to better understand why divers and snorkelers behave the way they do and what can be done to modify their behavior as a course of action to reduce vulnerability.

2.1 Marine Tourism

Tourism is considered one of the world's largest industries and plays a significant role in the economy of both developed and developing nations (Cater & Lowman, 1994). The fastest growth in tourism has been in coastal areas located in the tropical regions of the world where four ecologically vital marine ecosystems (saltmarshes, mangroves, estuaries, and coral reefs) are found (Miller,1993; Orams,1999). According to Orams (1999) marine tourism is defined as those recreational activities that involve travel away from one's place of residence and which have as their host or focus the marine environment, defined as those waters which are saline and tide-affected. This definition includes all activities that take place on, in, under, or near the marine environment. Marine tourism is separated out into its own category within tourism for several reasons. First it occurs in an environment where we do not live. Second, it is growing at a faster rate than the rest of the tourism industry. Third, activities that take place within this ecosystem can have significant impacts on the physical environment, the chemistry of the water, and the marine life. Finally, there are specific and unique management challenges associated with the ecosystems where marine tourism takes place (Orams, 1999).

Tourism in marine environments involves the sand and sea and attracts tourists who want to relax, play, or commune with nature. These tourists must be transported, accommodated, assisted, entertained, and satisfied. Those working in the tourism field are often under pressure since tourists express their disappointment when their expectations are not met. For tour operators, satisfied customers equate to economic gain. And while the benefits may be measured in economic terms, the costs often have environmental and social consequences. The United States National Oceanic and Atmospheric Administration (1998) remarked: “Of all the activities that take place in the coastal zones and the near-shore coastal ocean, none is increasing in both volume and diversity more than coastal tourism and recreation. Both the dynamic nature of this sector and its magnitude demand that it be actively taken into account in government plans, policies, and programs related to the coasts and ocean.”

2.2 Coral Reef Tourism

Coral reefs are popular recreation destinations for both local residents and tourists alike. The biological and geophysical diversity and visual beauty of coral reefs provide an attractive setting for recreational activities (Inglis et al.,1999). Approximately four million people visit the reefs in the Florida Keys National Marine Sanctuary annually and approximately two million people visit or travel through the Great Barrier Reef Marine Park each year (Barker, 2003; Harriott, 2002).

Coral reefs add value to existing tourism destinations by providing an outing opportunity and thereby supporting a local service industry for popular activities such as snorkeling, diving, swimming, recreational fishing, and boating. Stakeholders directly connected to coral reef tourism include boat operators, fishing charters, scuba diver instructors, and snorkel operators. Local lodging, retail, dining, boat mechanics, scuba tank refill shops, marinas, and artists also benefit indirectly. In addition, governments can receive tax revenues and foreign exchange, visitors enjoy the experience and may foster an awareness of nature and the importance of conservation, and local residents receive steady jobs and the potential for an increased income (Sherman & Dixon, 1991). The global annual value of these reef services has been estimated at 36 billion United States dollars (Spalding et al., 2017).

However, it has been documented that coral reef tourism can have harmful impacts on the physical and marine environment. In the Caribbean this includes damage from vessel anchors, groundings, walking on reef flats, pollution, and the actions of divers and snorkelers (Allison, 1996; Barker, 2003; Hawkins & Roberts,1992, 1994; Zakai & Chadwick-Furman, 2002). Damage from tourism related development includes erosion, pesticide run-off, sewage discharge, and overfishing (Allen, 1992). The costs of such damage include environmental degradation, economic inequity and instability, and negative socio-cultural impacts. For these reasons, the Organization for Economic Cooperation and Development has coined the phrase "tourism destroys tourism" (Boo, 1990). Often the short-term economic gains from tourism are at the expense of the environment and the local people (Ragster & Geoghegan, 1992).

Tourism research in other ecosystems has shown that even relatively few visitors can degrade the environment that was once appealing to them (Butynski & Kalina, 1998; Ceballos-Lascurain,1996; Jacobson & Robles, 1992). Unlike terrestrial ecosystems where recreationists and tourists are often constrained by the biological and physical topography of the land, divers and snorkelers are usually free to disperse throughout entire reef sites (Plathong et al., 2000). The effects of these unregulated activities can impact coral reef ecosystems and marine life at far fewer numbers of divers and snorkelers than are currently reported at popular dive locations.

For reef ecosystems, up to a certain level of activity, snorkel and diver-induced impacts appear to be minor, but beyond some “critical level” those impacts quickly become significant (Burgett, 1990; Davis & Tisdell,1995). For example, the daily use by thousands of visitors has left the near shore reefs in Hanauma Bay, Hawaii mostly dead (Wells & Hanna, 1992). Prior to the establishment of a beach road in the 1950s, the reef ecosystem was used for traditional food gathering. With a road in place, a number of private tour operators started to run tours to the Bay for snorkeling excursions and fish feeding. This use lead to an improved road, parking lots, restrooms, and picnic facilities. The rapid rise in the number of tourists due to these infrastructural changes resulted in the area exceeding 10,000 visitors per day (Burgett, 1990). Other reefs in other areas of the world have suffered this same fate.

Researchers have examined the relationship between diver and snorkeler activity and reef conditions at several locations, supporting the claim that snorkeling and scuba diving can be a serious threat to coral reefs (Allison,1996; Hawkins & Roberts,1992; Kay & Liddle,1989; Krieger & Chadwick, 2013; Liddle & Kay, 1987; Plathong et al., 2000; Prior et al., 1995; Riegl & Velimirov, 1991; Tratalos & Austin, 2001). The controversial and difficult challenge is to identify critical levels of impact and attempt to limit divers and snorkelers to a number below that threshold. Hanauma Bay’s carrying capacity was recommended to be set at 1,000 visitors per day but was never enforced (Burgett,1990). Sections of a reef can be managed as “sacrificial reefs” defined as a location where a high demand of reef visitors can be channeled as a concentration strategy to concentrate their negative effects (Orams, 1999). While local people realize the benefit from the income generated by tourism, they also understand that they need to protect the resource that is providing such an income. In coral reef tourism, that resource is a healthy and vibrant reef. However, often the immediate return from destructive activities outweighs the long-term benefits of reef protection.

The coral reefs in Similan National Marine Park, Phuket, Thailand serve as another example of how tourism can impact a reef system. The reefs in this marine park were considered to be in excellent condition pre-1990s and, therefore, an ideal location for scuba diving, receiving a small number of divers per year. However, in the mid-1990s, a popular magazine for divers rated the area's coral reefs in the park among the world's best locations to view marine biodiversity. Consequently, the tourism market and associated infrastructure exploded in the region. While in the early 1980s there were only two or three dive companies in the area, by the year 2000, there were more than 85 dive companies catering to over 100,000 divers a year (Dearden et al.,2006). Some of the damage to the reefs in Similan National Marine Park is a result of a rapid increase in recreational tourism.

2.2.1 Coral Reef Tourism in Puerto Rico

The island of Puerto Rico is considered a tourism-dependent country and has not been immune to the demands of the industry. The important role that tourism plays in Puerto Rico is reflected in the number of people who visit the island, the demand for services, and the number of people employed by the industry. The total number of visitors to the island has increased from 4.6 million in 1999 to approximately 4.9 million by 2009 (Puerto Rico Tourism Company [PRTC], 2009). Hotel development increased by 15% between 2000 and 2010 and tourism- related employment increased by 81% between 1985 and 2010 (Hernandez-Delgado et al., 2012).

Expansion of coastal tourism began in the early 20th century when the country began to move from an agricultural based economy to an industry-based one. Puerto Rico's recruitment tool was leniency with the enforcement of environmental laws, especially when compared to mainland United States (Hernandez-Delgado et al., 2012).

Fajardo, a small city located in the east region of the island, is a popular destination for boating, diving, and snorkeling. The development of the El Conquistador Hotel in the 1960's launched the tourism industry in a city which now claims five large marinas, including Marina Puerto del Ray, the largest in the Caribbean. A majority of the registered vessels in Puerto Rico (more than 65,000) are located in this area. While the tourism industry continues to grow rapidly, the effect of tourism and recreational misuse upon coral reef systems on the island of Puerto Rico is not well understood (Garcia-Sais et al., 2008). Tourism benefits are often measured as economic achievements and not ecological ones. In fact, concerns about ecological degradation are often seen as impeding tourism benefits. In Fajardo, sewage discharge, vessel groundings, anchoring, oil pollution, illegal dumping of garbage, recreational overfishing, and collecting of coral as souvenirs have all contributed to localized coral reef degradation and mortality at the reefs in the waters at Cayos de la Nature Reserve (La Cordillera Nature Reserve) (Hernandez-Delgado, 2005).

La Cordillera Nature Reserve, a string of ten small islands with reefs, is home to a variety of protected marine life. The islands are quiet and secluded. Opportunities for snorkeling, diving, and sailing are available because the waters are generally calm and clear. There are at minimum seven large snorkel excursion catamarans that leave from Fajardo daily during the high season, bringing hundreds of visitors to reefs like Icacos, Lobos, and Tortugas, and two scuba diving operators that run several boats to reefs like Diablos, Palominos Island, Sandslide, and Trench.

2.3 Scuba Diving

The development of scuba (self-contained underwater breathing apparatus) has expanded the abilities of humans to see and appreciate the underwater world, by providing a mechanism to breath underwater. On an international scale, scuba diving has been recognized as a form of marine-based leisure and tourism and is considered a multi-billion-dollar business (Dimmock, 2009; Garrod, 2009; Orams, 1999). The industry includes recreational vessels for day trips, live-aboard vessels, dive shops, dive operators, dive magazines, dive clubs, dive videos, dive-oriented resorts, and even floating hotels. Scuba diving is a fairly involved recreational activity that requires training, certification, and the rental or purchase of equipment. However, it is considered one of the world's fastest growing recreation sports. Reasons for this growth include safer equipment, ability for marine vessels to access remote marine sites ideal for diving, and a continued growing interest in the underwater world (Davis & Tisdell, 1995; Dimmock, 2009; Harriott et al., 1997; Parker, 2001). According to the Professional Association of Diving Instructors (PADI), as of 2017, approximately 25 million people worldwide received a scuba certification since 1967 (Professional Association of Diving Instructors [PADI], 2018). PADI reports that it averages over 900,000 additional diver certifications each year (PADI, 2017). Since scuba certifications do not expire, there really is no mechanism to track the activity level of every certified individual.

In addition, an important and growing component of the recreational scuba diving industry is "Discover Scuba." This course, offered at resorts and dive shops, is geared towards non-scuba certified vacationers interested in exploring the underwater world. The class provides a quick and easy, carefully supervised introduction to diving. Without needing certification, the concern with

“Discover Scuba” is the lack of a mechanism for tracking the number of inexperienced tourists participating in these excursions at coral reefs (Barker, 2003; Davis & Tisdell,1995).

A similar problem exists with cruise ship travelers who participate in dive excursions. Research has found that cruise ship divers are more likely to contact reefs and break coral when compared to non-cruise ship divers (Barker, 2003). Barker attributed these findings to the “non-specialist” level of cruise ship visitors. Cruise ship diving is usually only one of several off-ship activities and, therefore, attracts more unskilled participants or vacationers who may not take the activity seriously.

Finally, some island resorts offer unlimited, unsupervised day and night dives from shore. While these divers are certified, there is no way to track how often these individuals participate in such opportunities or how they behave while underwater.

2.4 Snorkeling

Snorkeling is an even more popular marine sport since it requires no certification. It can be done with a mask, snorkel, and a minimum amount of swimming skill. It has become an incredibly popular tourist activity, especially for beginners interested in seeing what lives under water. The increasing trend in activity based marine vacations serves as a good indication that more people are snorkeling each year at tropical destinations (Goodhead & Johnson, 1996). While it is hypothesized that the number of snorkelers far exceeds the number of divers visiting coral reef ecosystems, statistics to support this hypothesis are not available (Barker, 2003). And while some research has been done on the impact that divers have on coral reefs, even less is known on the impact that snorkelers have on these ecosystems.

2.5 Vulnerability

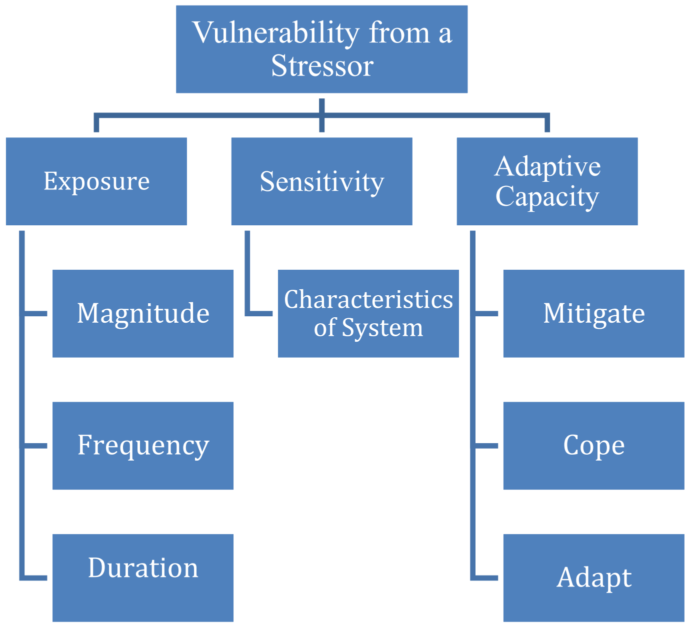
2.5.1 Components of Vulnerability

Vulnerability can be defined as the state of susceptibility to harm from exposure to some specific stressor (Adger, 2006). Vulnerability research is considered a powerful analytical tool and has been applied to geography, risk hazards, ecology, health, poverty, land use changes, food systems and more recently has been widely used in climate change science (Adger, 2006; Barnett, 2001; Kasperson et al., 2005; Kelly & Adger, 2000; Moser, 1998; Watts & Bohle, 1993). Vulnerability theory has been guided by various disciplines including geophysical sciences, human ecology, political economy, and political ecology (Eakin & Luers, 2006; McLaughlin & Dietz, 2008; Miller et al., 2010). Vulnerability research consists of three main components (Glick et al., 2011). This includes measuring exposure to the stressor, characterizing the sensitivity of the exposure, and characterizing the capacity to act (Figure 1.1). Exposure, is defined as the nature and degree to which a system experiences stress. Characteristics of the stressor to be measured include the magnitude, frequency, duration, and the spatial extent of the hazard (Burton, et al., 1993). Sensitivity refers to the degree to which the system is affected by the disturbance. Therefore, more species and systems that have increased vulnerability are likely to experience greater impacts from stressors than those that are less vulnerable (Glick, et al., 2011).

Adaptive capacity is the ability of the system to take actions to mitigate, cope, or adapt to the stressors and the harm. Mitigation refers to reducing the exposure in some manner. Coping refers to tolerating the exposure. Adaptation refers to changing the sensitivity of the system to the exposure. Coping and adaptation together are frequently understood as resilience. Resilience is defined as the magnitude of the disturbance that can be absorbed before a system changes to a radically different state (Adger, 2006).

Figure 2.1

Components of a vulnerability assessment



Note. The components of vulnerability from a stressor include the potential impacts which consist of exposure to the stressor, the sensitivity of the exposure as well as having the capacity to adapt by mitigating, coping, or adapting.

An important component of resilience research is the focus on social-ecological systems, defined as the concept that human action and social structure are an integral component of the natural world. Humans depend on natural resources and ecosystems and thus any explanation that classifies resilience as two systems is not genuine. Defining resilience, includes coupling both social and ecological systems instead of considering just one (Abesamis et al., 2006; Cutter et al., 2009; Pollnac et al., 2008). For example, Abesamis et al. (2006) define resilience as: "the capacity of a social system, involving multiple levels of government, communities and users, to embrace uncertainty and change in the advent of political, social or economic disturbances by building knowledge and understanding of resource and ecosystem dynamics." Cutter et al. (2009) define resilience as the: "capacity of the population, system, or place to buffer or adapt to changing hazard exposures." Pollnac et al. (2008) refer to resilience as community resilience and define it as the "capability of coping successfully in face of significant adversity or risk in place-based and activity-based communities, families, and households."

Adger (2000) also developed a specific definition for social resilience, "social resilience is the ability of groups or communities to cope with external stresses and disturbances as a result of social, political and environmental change." Adger agrees that there are differences in the behavior and structure of the social and ecological components but does identify links between both social and ecological resilience. An example of this coupling includes the dependency on natural resources for economic gain. The more a community depends on its natural resources for economic gain, the more the community's resilience will depend on the resilience of the ecosystem upon which it directly depends. Another example of this socio-ecological coupling includes the relationship between the institutions that create policies and manage the use of natural resources and the people dependent upon those resources and the natural system. Any regulations implemented by such agencies impact the resilience of ecosystems, which then can affect social resilience. Therefore, adaptive management must focus on the potential and unpredictable interactions that are evolving between social and natural systems (Berkes & Folke, 1998).

The resilience of reefs to stresses from human exposure is not well understood. Human management options are limited to managing the socio-ecological system in order to manage interactions between people and the coral reef ecosystem. These include reducing exposure of reefs to stressors and by implementing adaptive actions. Measures to reduce human contacts with the reef are an option for reducing exposure. These actions can be managerial, technological, or institutional. However, actions that are not feasible or practical will have low capacity, therefore, making them less likely to be implemented (Smit & Wandel, 2006).

Natural resource managers also apply ecosystem measures that lower sensitivity, promote recovery, and enhance adaptive capacity. For example, restoration projects have been designed and include the propagation and re-colonization of areas with damaged and dead coral as well as stocking areas with herbivorous fish and sea urchins to feed on algae. The objective for these restoration projects is to increase ecological resilience by focusing on recruitment, re-growth, and repair (Anthony et al., 2015). Considering that climate change and ocean acidification will continue to threaten the natural resilience of tropical coral reefs on a global scale, mitigating local and regional stressors, like tourism, with manageable actions is essential in order to enhance ecosystem resilience (Anthony et al., 2011; Cao et al., 2007; Kennedy et al., 2013).

2.5.2 Measuring Vulnerability

The vulnerability of a system can be described as a dynamic process with constant changes in the many variables that compose both the ecological and social conditions. For this reason, vulnerability is difficult to quantify or reduce to a single metric (Adger, 2006). In fact, some scientists believe that vulnerability cannot be measured, since measurement involves a systematic process of assigning a numerical value to something that can be observed. (Patt et al., 2008). Length, weight, and depth are examples of measurements that have conventional standards that most can agree on (Hinkel, 2011). While scientists can provide a number to measure the possible future harm of an event (mortality can be measured), the harmful event may or may not happen. In fact, the literature states that translating the parameters of vulnerability into a quantitative metric can lessen the impact and hide the complexity of the construct (Alwang et al., 2001).

The reason vulnerability cannot be measured is because it is a theoretical concept and not an observational one. For this reason, Hinkel (2011) states the theory of vulnerability should be made an operational concept. This involves providing a method for comparing it to observable concepts (Bernard, 2006; Copi & Cohen, 2005). One strategy for making theoretical concepts operational is through the use of indicators. Gallopin (1997) defines an indicator as "a function from observable variables." A scalar indicator can compare an observable variable to a theoretical variable. For example, the presence of a certain lichen in an ecosystem can serve as an indicator for the quality of the air (Hinkel, 2011).

Rygel et al. (2006) state "indicators are potentially useful tools for identifying and monitoring vulnerability over time and space, for developing an improved understanding of the processes underlying vulnerability, for developing and prioritizing strategies to reduce vulnerability, and for determining the effectiveness of those strategies." The process for developing indicators utilized by Hinkel (2011) for climate change research includes three steps. The first step is defining what is to be indicated, for example, the vulnerability of coral reefs to dive and snorkel tourism. The next is the selection of the indicating variables which can be either deductive, inductive, or normative. Deductive indicators are those based on available scientific knowledge, frameworks, theories, and models. Inductive indicators use data, patterns, and trends, as well as observed harm to develop the indicators. The third, normative indicators are developed using individual or collective value judgments. The choice of what type of indicators to use when analyzing exposure, sensitive, and adaptive capacity in a specific context depend on the vulnerability of whom to what (Alwang et al., 2001; Carpenter et al., 2001; Rygel et al., 2006).

The use of indicators can provide a framework for measuring vulnerability that can provide both quantitative and qualitative insights into the outcomes and perceptions of vulnerability based on this framework for guidance (Adger, 2006).

For assessing the vulnerability of select reefs to diver and snorkeler behaviors, inductive indicators will be utilized in this research for two reasons. First, the system can be described using several (but not many) variables. Second, sufficient data are available to indicate the variable and the potential harm. For example, one can induce that the variable "number of fin kicks to a coral" can indicate harm since it increases the incidence for breakage.

2.5.3 Vulnerability Assessment as Tools for Coral Reef Management

Throughout geological history, coral reefs have been exposed to a wide array of disturbances including several mass extinctions (Buddemier & Smith, 1999). While coral reefs have existed for more than 45 million years, the past few decades of human disturbances have resulted in significant degradation. Coral reefs are already considered one of the most vulnerable of marine ecosystems because of their low resistance to and slow recovery from threats. In relation to their ability to be resilient and recover, these disturbances can be classified as minor, frequent, pulsing (grazing, predation, storm activity) or large peaks (pollution, sedimentation, overfishing, ocean warming and acidification). While both pulses and peaks occur at different magnitudes, intensities, and durations, the location of the reef, its depth, geography, topography, morphology, life history, and behavior will affect the coral responses (Anthony, 2015). When several peaks and pulses occur at once around a reef, there is increased synergy which can increase vulnerability.

For example, the coral reefs of Jamaica have had a significant change in species composition over the past thirty years. Reefs once dominated by hard corals have overtime changed to fleshy algae. Possible causes include a combination of peaks and pulses. During the 1960s and 1970s the coral reef marine food webs in Jamaica had been heavily fished. Once most of the carnivorous fish had been removed from these food chains, fishers started fishing down the chain and harvesting herbivorous fish. This led to an increase in *Diadema antillarum*, sea urchins that feed on brown algae species. *Diadema antillarum* were able to keep the algae growing on the corals under control. However, in 1981, Hurricane Allen destroyed most of the branching coral species which resulted in the establishment of fast colonizing algae. *Diadema antillarum* were still able to keep the algae populations in check until a species-specific disease struck their population reducing the population of sea urchins by 99 percent in some areas. Without herbivorous fish and *Diadema antillarum*, macro-algae populations began to thrive affecting coral larval settlement as well as the health of large coral colonies (Nystrom et al., 2000). This example demonstrates the synergy between peaks and pulses and their effect on reducing coral reef resilience resulting in ecosystem shifts. Scientists are still uncertain if such transitions are reversible (Nystrom et al., 2000).

Effective environmental management should be based upon a sound understanding of natural and anthropogenic interactions (White et al.,1994). The challenge is that many different human activities and their cumulative, synergistic effects are difficult to dissect. While it is possible to develop strategies to effectively manage resource use on a local scale, such tasks become more difficult when compounded by multiple stressors. In addition, ecosystems are unique in that they respond to each of these stressors differently (Halpern et al., 2007). Coral reef managers can play an essential role in reducing the vulnerability of a coral reef system by implementing strategies that address one to all three vulnerability components (Chapin et al., 2009). These include reducing the exposure of the reef to the stressor, supporting ecosystem processes that reduce sensitivity, and increasing the system's resilience to the stress through recovery and adaptive capacity (Anthony et al., 2015; Marshall & Schuttenberg, 2006; McClanahan et al., 2012). This approach is referred to as adaptive resilience based ecosystem management (ARBM). Instead of trying to prevent or abate the change, the strategy recognizes that change is a part of natural and social systems and managers can respond by shaping the change so that it can either be alleviated or guided to benefit the ecosystem and society.

2.5.4 Vulnerability Assessment Methodologies

Vulnerability assessments can inform policy and decision making by 1.) identifying mitigation targets, 2.) identifying particularly vulnerable people, regions, or sectors, 3.) raising awareness, 4.) allocating adaptation funds to particularly vulnerable regions, sectors, or groups of people, 5.) monitoring the performance of adaptation policy, and/or 6.) producing scientific findings (Hinkel, 2011; Patt et al., 2008; Schroter et al., 2005). My research methodology identifies mitigation targets, identifies particularly vulnerable reefs, raises awareness, and produces scientific findings.

Moreno and Bechen (2009) developed a methodology to assess the vulnerability of specific coastal tourism activities to climate change in the Mamanuca Islands, Fiji where, like other islands, tourism is a vital income and job generator. Specifically, they identified and prioritized tourism activities that would be affected by climate change. One such relevant activity, snorkeling, included developing an assessment to determine the impacts that coral bleaching would have on this major tourist activity. Moreno and Bechen (2009) determined that the main components for measuring exposure to bleaching included reef location, ocean conditions, and storminess. Sensitivity would be measured by determining the number of species present and the diversity of species. Tourist preferences and knowledge about the reef would also be included as part of the sensitivity assessment since these factors can affect their behavior around the reef. The capacity to act includes the possibility for creating artificial reefs, managing visitors, and establishing marine protected areas to improve reef resilience. Next steps include applying the methodology at reefs around the Mamanuca Islands as well as several other tourist destinations including coastal areas in Spain, Australia, and New Zealand.

2.6 Modifying Human Behavior

This section of the literature review frames my research by examining theories of behavior change, persuasion, and recreation specialization, in order to design an approach to characterize the vulnerability of reefs in Puerto Rico to stressors associated with recreational visitation. Decreasing vulnerability and increasing adaptive capacity requires the active involvement of those most directly concerned. This includes policy makers, science practitioners and all other stakeholders connected to the assessment (Vogel et al., 2007). In this research, other stakeholders include divers, snorkelers, and individuals involved in the industry. A number of management strategies that can mitigate the impacts to coral reefs target tourist behaviors. These strategies also require support and compliance of staff working directly with the tourists. Therefore, a clear understanding of the habits, barriers, needs, laws, institutions, and social norms that constrain or facilitate certain behaviors is needed in order to modify behavior at the individual or group level (Moser & Dilling, 2007). For all these reasons, understanding behavior change theories is necessary for developing and implementing vulnerability assessments.

2.7 Factors Discussed in Behavior Change Theories

Human contacts with coral reefs are directly connected to how individuals behave while diving or snorkeling. Based on what is known about the effect of these impacts, there is a strong need to understand what factors influence a diver or snorkeler to perform or not perform a given behavior. For example, if a behavior is the result of a lack of skill or knowledge, effective interventions would need to provide appropriate information to address these factors. Effective interventions to influence diver and snorkeler actions around coral reefs are essential for the recovery, health and long-term viability of coral reefs (Dobrzynski & Nicholson, 2003).

Addressing human behaviors around coral reefs is not a new concept. In fact, indigenous communities have been incorporating behavior change concepts into their management plans for a long time (Birkeland, 2004). For example, the Yapese, Pacific Islanders who live on a small archipelago between Guam and Palau, recognized early on the need to address human behaviors in order to protect coral reefs. The president of the Palau Republic published messages in the local paper regarding the positive actions citizens could take to protect coral reefs and assist with the recovery efforts for lost or damaged corals. These messages advised people to avoid taking herbivorous reef fish for food since these primary consumers play an important role in controlling the algae that can suffocate the reef. Messages about how stepping on coral reefs can damage the polyps were also delivered through the media. These actions may not eliminate all the behaviors that harm coral reefs but they do provide rational knowledge and a sense of responsibility and stewardship. Research has shown that traditional community awareness of responsibility is most likely one of the most effective methods in conserving coral reef ecosystems (Birkeland, 2004).

On a larger scale, reports from the National Oceanic and Atmospheric Administration Coral Reef Conservation Program (2009), suggest that addressing the social-psychological factors that cause reef degradation should be an essential component of coral reef management plans. To address this issue, the United States Coral Reef Task Force (USCRTF) developed Local Action Strategies (LAS) in territories that possess coral reef resources. These strategies are defined as locally driven, short-term roadmaps for collaborative and cooperative efforts among federal, state, territorial, and nongovernmental partners. The goal of the Local Action Strategies is to identify and implement priority projects that reduce key threats to valuable coral reef ecosystems. Plans include elements designed to influence humans to adopt and practice environmentally responsible behaviors (United States Coral Reef Task Force, 2009).

Several of the Local Action Strategies have specifically developed action plans to address problems associated with recreational users including diver and snorkeler behaviors around coral reefs. For example, Puerto Rico's Local Action Strategies include educational pamphlets developed for local businesses and tourist information centers which provide recreational users with actions that should be taken to prevent the misuse and overuse of coral reefs. Other public service campaigns, including billboards and posters encouraging pro-environmental behavior around reefs can be found at airports along the east coast of the United States and in the Caribbean. Both Florida and Puerto Rico have also utilized English and Spanish public service announcements in print, audio, and video formats. In the Northern Mariana Islands, a recreational booklet for dive instructors was developed to provide guidance on how and what reef "friendly" information should be relayed to their students. In the United States Virgin Islands, Local Action Strategies include reef etiquette snorkeling clinics for youth. While these are important measures, the results of these initiatives have varying degrees of success. And the threats to coral reef ecosystems are still increasing. Effective behavior change strategies will require a clear understanding of what is known about changing human behaviors, specifically the unique behaviors exhibited by divers and snorkelers that are discussed in chapters three and four.

In order to change negative behaviors towards the environment, it is important to understand what factors promote “environmentally responsible behaviors.” Kollmuss and Agyeman (2002) define environmentally responsible behavior as “behavior that consciously seeks to minimize the negative impact of one’s actions on the natural and built world.” According to this definition, divers and snorkelers practicing environmentally responsible behaviors would consciously decide to make every effort to not come in contact with the coral. This would include not standing on, sitting on, touching, or kicking coral as well as not collecting it.

This section will now address the theoretical framework of several behavior change models in order to gain a clear understanding of why individuals decide to engage or not engage in a given behavior. In order to discuss these frameworks, it is necessary to first define and discuss several of the variables that are components of behavior change.

2.7.1 Knowledge

Knowledge about the environment is defined as being either environmental or behavioral (Schahn & Holzer, 1990). The former is considered abstract knowledge. A person with environmental knowledge has general knowledge about the state of the environment and environmental issues like recycling, waste issues, and pollution. Behavioral knowledge is defined as concrete knowledge required for action. For example, a person who knows how, when and where to dispose of hazardous waste has concrete behavioral knowledge about an environmental issue (Schahn & Holzer, 1990).

2.7.2 Norms

A norm is a rule or standard in regard to how an individual should act in a given social situation. Norms operate at two distinct levels. Personal norms represent an individual's expectations about her own actions while social norms are a set of standards or rules shared by a larger group of individuals, which all individuals in the group are expected to observe (Schwartz,1977; Vaske et al., 1986). A person is more likely to accept and follow a social norm if everyone else is doing it. For example, if all of my neighbors participate in household recycling and put out their bright blue curbside recycling containers weekly, I may be more likely to participate since I would feel obligated too. The expectations and obligations that are tied to social norms are directly connected to the social interactions we have with different groups of individuals as well as society (Schwartz, 1977, 1994). In contrast, personal norms are connected to one's evaluation of an act based on one's moral worth and personal expectations for self (Schwartz, 1994). Personal norms are the standards an individual has about his own actions.

Norms are characterized as either descriptive or injunctive (Cialdini et al.,1990). Descriptive norms describe one's perceptions of how other people are behaving. They apply to the typical or normal behaviors of people. Descriptive norms provide motivation since one can get a quick lesson on how one should behave in a situation by observing how everyone else is behaving in that situation. It is important to mention that a descriptive norm does not always have to be in reference to an appropriate behavior, it just describes a behavior that a larger group of individuals is partaking in and giving their approval too.

Injunctive norms are a type of personal norm and refer to the behaviors that one perceives as being morally approved conduct by others (Cialdini et al.,1990). Descriptive norms and injunctive norms are conceptually different and yet both have been shown to motivate human action. People tend to want to behave in a socially approved and popular way (Cialdini, 2003). Laws and regulations are excellent examples of how support for social norms can be established (Oskamp, 2000). If an individual violates a social norm there can be consequences that range from mild to severe.

2.7.3 Intention

An intention is defined as a choice with commitment (Cohen & Levesque, 1990). Intentions capture the motivational factors that influence a behavior. Intentions indicate how hard an individual is willing to try and how much effort they are willing to give in order to complete a behavior (Ajzen, 1991). The stronger one's intention is to perform a behavior, the more success one will have in carrying it out.

2.7.4 Values

Values are conceptualized important life goals or standards that serve as guiding principles in an individual's life (Rokeach, 1973). While the word "value" has many definitions, there are several distinct features that are common to a majority of these meanings. All define a value as a concept or belief about one's behavior or a desirable outcome that applies to more than just a specific situation. Other common definitions include values as being distinct, ordered by relative importance, and playing a major role in guiding one's selection or evaluation of behaviors or events. The total number of values that an individual possesses is actually relatively small (Rokeach, 1973).

Most of the research regarding values and the environment is based on Schwartz's value theory (1994) which proposes a general classification of fifty-six values. While the structure of these values is universal their importance can differ at the individual, cultural, societal and institutional level (Schwartz & Bilsky, 1987).

Values are classified into two dimensions (Schwartz, 1994). The first dimension is a comparison between openness to change and conservation. Openness to change reflects values that stress independence, self-direction, and stimulation while conservation stresses tradition and conformity. The second dimension compares a social, altruistic value orientation to an orientation that focuses on egoistic and personal interest values. Research shows that those who hold environmental values, defined as an underlying orientation held toward the physical environment, will be open to change, self-directed, and hold social and altruistic values (Schwartz,1994).

2.7.5 Attitudes

An attitude is defined as a psychological tendency that is expressed by evaluating a particular entity with some degree of favor or dislike (Eagly & Chaiken, 1993). Attitudes towards the environment are the result of an individual's general set of underlying values.

Three general environmental attitude types have been described. An egoistic environmental attitude is one in which a person tries to maximize outcomes that benefit the individual. For example, an egoistic person would be concerned with the effect that water pollution has on his health and well-being and not be focused on the effects that water pollution has on coral reefs. An altruistic environmental attitude is one that reflects concern for the welfare of other human beings. For example, an altruistic person would state that protecting the quality of water from pollutants and sedimentation is important for coral reefs because it benefits current and future generations. The third type is a biospheric environmental attitude. A person with a biospheric environmental attitude is concerned for the welfare of nonhuman species or the biosphere and would believe that people should not cause water pollution because of its effect on the coral reef ecosystems and all of its inhabitants (Stern, Deitz, & Kalof, 1993). Studies have shown that people who favor altruistic or biospheric attitudes are more likely to practice environmentally responsible behaviors (Steg et al., 2005).

In 1976 Dunlap and Van Liere developed a scale to measure environmental attitudes. This concept was in response to a shift in the way that people were thinking and responding to the environment. It was believed that the "Dominant Social Paradigm," which emphasized unregulated utilization of natural resources, rapid industrial growth, private property rights, and control over the environment, was no longer the dominant mind frame. Instead energy conservation, environmental protection, demands for clean air and water and limits to growth were becoming top priorities. This attitude shift was referred to as the New Environmental Paradigm and the scale utilized to measure environmental attitudes was considered a valid measurement (Dunlap & VanLiere,1978). Relevant attitudes to the field of recreation and tourism include attitudes towards oneself, authority figures, peers, wildlife, and the environment.

2.7.6 Worldviews

A worldview is defined as a general belief in the relationship between humans and the environment (Dunlap & Van Liere, 1978). An individual's worldview can affect one's behavior towards the environment. Since worldviews are less general and often deal with a specific domain of life (for example, the environment), they are considered to be unstable and, for this reason, their authenticity for influencing behavior has been challenged (Stern et al., 1995).

2.7.7 Beliefs

People have certain convictions about things that they perceive to be true. These perceived truths come with a high level of confidence even without having been rigorously tested and found to be true. Myers (2010) has stated that it does not take much effort for individuals to stand by and support their false beliefs. These beliefs can play a major role in influencing attitudes and thus behavior.

2.8 The Knowledge-Attitude-Behavior Model

One of the earliest behavior change models, the Knowledge-Attitude-Behavior model (KAB), asserts that education promotes behavior change. The KAB model hypothesizes that behavior change occurs linearly and is stimulated and directed by attitude change which in turn is directed by gaining new knowledge (Ramsey & Rickson, 1976).

Since the 1970's, this model had been instrumental in shaping environmental education programs and public service campaigns with some success. For example, one study found that students who took a college level environmental education course had increased their number of pro-environmental behaviors and continued to perform these behaviors two months after the course finished (Hsu, 2004). Rokicka (2002) found that citizens living in small towns and rural communities who had a higher level of ecological knowledge had also practiced more environmentally responsible behaviors. Researchers argue though that at some point in the learning process, concrete knowledge would have had to have been gained, since knowledge for action is necessary for behavior change (Schahn & Holzer, 1990).

Today, most environmental organizations still base their communication campaigns and strategies on the assumption that more knowledge will lead to changes in attitudes and ultimately improve behaviors towards the environment. Most coral reef management plans include strategies for addressing inappropriate behaviors around coral reefs. Several Local Action Strategies follow the Knowledge-Attitude-Behavior model. For example, Florida's Local Action Strategy includes providing coral reef education kits and teacher training workshops for science educators. These kits provide detailed knowledge about coral reef conservation for teachers to deliver to their students.

While I have provided a few examples that support the KAB model, overall the concept that knowledge alone automatically results in attitude changes which lead to an increase in pro-environmental behaviors has had limited value. This is not to imply that knowledge is not important. However, changes in behavior, even minor changes, are difficult to establish even when the new behavior is beneficial. Limitations of the KAB model center on the variable process by which people gain knowledge which is different from one individual to the next. First, an individual needs to have been exposed to the new knowledge. Second, the individual must consider the information presented. For example, if a person is handed a brochure or sees a billboard or poster, he has to be motivated to read and think about it. A third limitation to the model is reception, which refers to the ability of an individual to retain the information gained in one's long term memory (Roggenbuck, 1992).

Other gaps have been found in the link between attitude and behavior change. Rajecki (1982) explained that direct experiences have a stronger influence on people's behavior than knowledge about those experiences. In other words, learning about an environmental problem is not as effective as experiencing the issue in nature. Temporal discrepancies also exist. This results when knowledge is gained and attitude changes happen but the chance to perform the behavior occurs at a much later date. As previously mentioned, attitudes can change over time. Rajecki (1982) contributes this to the influence of social norms which has a major influence on attitude.

Leiserowitz et al. (2004) identified barriers that act to prevent the linear progression of knowledge gained leading to attitude change and behavior change. The first barrier, individual capabilities, refers to the reality that even when one provides individuals with knowledge, they are not always capable of changing their behavior. Barriers that can prevent an individual from taking action include lack of specific skills, low self-efficacy, lack of resources, habits, and routines. The other barrier to change includes larger external constraints that can be social, economic, or political in nature.

Since these limitations have been identified, researchers are moving away from the knowledge, attitude, behavior model and towards more complex models that include a multitude of factors that influence behavior.

2.9 The Theory of Reasoned Action

Developed in 1967, Ajzen and Fishbein's Theory of Reasoned Action is a general theory of human behavior that focuses on the relationship between beliefs, attitudes, intentions and behavior (Fishbein & Manfredo, 1992). The theory has been utilized to predict why people behave the way they do in several situations including smoking (Ajzen & Fishbein, 1980; Chassin et al., 1981) drinking (Budd & Spencer, 1985), exercising (Godin & Shephard, 1985) and breast feeding (Manstead et al., 1983). The theory makes the assumption that humans are able to reason and regularly process information available to them (Fishbein & Manfredo, 1992). The central factor in the Theory of Reasoned Action is the intention to perform a given behavior. Intention is influenced by a person's attitude toward the behavior and by subjective norms about the behavior. Therefore, if a person intends to behave a certain way, the behavior will be carried out.

Intentions have been utilized to explore a variety of natural resource-related behaviors (Jett et al., 2009). For example, Manfredo et al. (1990) conducted a nation-wide survey focused on understanding why people support or oppose controlled burn policy. According to the Theory of Reasoned Action, the stronger one's intention to support a controlled burn policy, the greater the likelihood that one will perform a supportive behavior. Supportive behaviors would include calling a congressman, writing a letter to an editor, or voting for a controlled burn proposition in an election. Intention was predicted from attitude toward supporting a controlled burn policy and subjective norms (people important to me think I should support controlled burn policy). Manfredo et al. (1990) found there was a strong relationship between intention and support for a controlled burn policy.

The theory has its limits though. First, it can only predict voluntary acts and, therefore, excludes many types of actions including those that are spontaneous, impulsive, habitual or mindless. These behaviors are considered excluded because they may not be voluntary or involve a conscious decision (Bentler & Speckart,1979). In addition, it was concluded that intention does not always correspond to the behavioral criterion in terms of action (Sheppard et al.,1988). For example, if one's aim is to exercise but one learns one has a medical condition that prevents one from participating in such activities, one's behavioral intention will be affected. Ajzen (1991) recognized such limitations and formulated the theory of planned behavior to provide a more complete and explanatory behavior change model.

2.10 Theory of Planned Behavior

Intention to perform a behavior is still at the central core of the Theory of Planned Behavior. However, Ajzen (1991) defined three independent antecedents necessary for intention to lead to a specific behavior. These are attitude towards the behavior, subjective norms (the perception that others think the individual should perform the behavior), or having the ability or perception to be in control of the behavior.

Perceived behavioral control refers to an individual's beliefs about the ease or difficulty of performing a behavior. It has been compared to self-efficacy or one's confidence or perception of his ability to accomplish an act. For example, two individuals can have similar skill levels and knowledge about scuba diving and attempt to get scuba certifications. If one individual believes her ability to pass the written test is slim, this individual has low perceived behavioral control. If the other individual feels confident about the test, she has high perceived behavioral control.

Perceived behavioral control also includes having the opportunities, resources, and skills necessary to perform a behavior. Behaviors that are not autonomous are referred to as non-motivational factors and include time, money, and the cooperation of others (Ajzen, 1991). Non-motivational factors also affect perceived behavioral control.

If behaviors have self-control, they can be predicted from intentions fairly accurately. However, the rule is that the more favorable the attitude and subjective norm in regards to behavior and the greater perceived behavioral control, the stronger an individual's intention to perform the considered behavior will be (Manstead, 2000). This rule does have its exceptions. First, it does not include the role that emotions and morals play in determining behavior. For example, if one's self interest and the interest of others are at odds with each other, these opposing interests could affect the outcome of the individual's behavior (Manstead, 2000).

In addition, one's perceptions of behavioral control must be realistic and reflect actual control in order for the behavior to occur. Just because an individual has high-perceived behavioral control, there is no guarantee that she will be capable of performing a given act (Davies et al., 2002). A scuba diving student may feel confident that she will get her scuba certification, but if she is not physically capable of completing all of the skills, she will not pass the test. Further, perceived behavioral control can change depending on the situation and the context especially since behaviors do not occur in isolation of other individuals, environmental surroundings, and events.

2.11 Norm Activation Theory

Schwartz's Norm Activation Theory (1977) focuses on the role that moral obligations or personal norms play in determining an individual's actions. The theory links the concern for the welfare of others to relevant action (including environmentally responsible actions) and states that an individual has a personal obligation to behave in a certain way. One's personal norms are activated by situational variables. First, an individual must be aware of the adverse consequences (AC) of not acting pro-socially towards other people or things that one values. Next the individual ascribes responsibility (AR) to himself in order to prevent these consequences (Stern & Oskamp, 1987). For example, a snorkeler would be aware that if she stands on a coral reef she can damage sensitive coral polyps (adverse consequences). Therefore, the snorkeler would feel an obligation (ascribe responsibility) to protect coral reefs and would take the necessary precautions in order to prevent making contact with the coral.

Norm Activation Theory has practical connections to gaining a better understanding of what can influence environmentally responsible behaviors. Research supports a relationship between AC and AR variables and the moral obligations of individuals. In fact, it has been determined that when major environmental events happen (Love Canal, Three Mile Island, Exxon Valdez and BP Deepwater Horizon oil spill) moral norms are aroused and action is taken (Walsh, 1981).

Personal norms have been proven to be effective if the outcome of one's behavior has a positive consequence for another individual or living thing. Other individuals can also trigger personal norms. Research indicates that people ascribe to many different norms, sometimes even conflicting ones. Observing the behaviors of other people can actually activate specific norms in an individual (Cialdini et al., 1990). For all of these reasons, activating snorkeler and diver personal norms could be an important intervention mechanism.

Guagnano et al. (1995) tested the Norm Activation Theory with a study on curbside recycling. When they started their research, curbside recycling was just being implemented in the community, so not every household had yet received a bin. Not having a bin could act as a barrier to acting altruistically. However, Guagnano et al. (1995) found that when the Norm Activation Model was applied to non-bin recyclers, it was a significant predictor of behavior. Non-bin individuals who recycled held AC and AR beliefs and had altruistic personal norms.

In another study, Nordlund and Garvill (2003) surveyed 2500 car owners in Sweden and found that values and problem awareness influenced personal norms. These moral norms in turn influenced a willingness to reduce personal car use. These findings again support the conclusion that personal norms are an important component of behaviors towards people and the environment.

While this theory appears to be effective for explaining low cost behaviors, it has been less effective at explaining behaviors that require greater effort, cost more money, or require a fair amount of time (Guagnano et al.,1995). Other concerns with the model include the effect that the dissemination of scientific information can have on an individual's behavior. If information downplays adverse consequences and lessens responsibility, moral norms will not be activated.

2.12 Value-Belief-Norm Theory

Stern, Dietz, Abel, Guagnano, and Kalof (1999) have proposed a theory for environmental behavior that builds on the other theories discussed. The Value-Belief-Norm Theory (VBN) of environmental behavior links the Norm Activation Theory, the Theory of Personal Values, and the New Environmental Paradigm (NEP) (Stern et al., 1999). Norms are still dependent on three beliefs - awareness of adverse consequences (AC), ascription of responsibility (AR), and one's ecological worldview. One's ecological worldview is evaluated by the New Environmental

Paradigm (NEP). Researchers believe that the VBN theory provides the best explanation of the factors that lead to environmentally responsible behaviors.

Like the Norm Activation model, personal norms are considered the ultimate predictor of conservation behavior in the Value-Belief-Norm theory. Stern et al. (1999) state that personal norms have a large influence on four types of behavior triggered by pro-environmental intent. These comprise environmental activism (demonstrations and protesting), non-activist community related actions (supporting public policies), personal actions that show one supports an environmental issue (disposing of hazard waste properly), and organizational actions (influencing the actions of organizations to which one may belong).

The VBN theory focuses on an individual's value orientation and attitudes through the New Environmental Paradigm. Both values and attitudes are included in the theory for several reasons. First, attitudes focus on an evaluation of an object, either positively or negatively, whereas one's value orientations are derived from one's basic beliefs. An individual may hold many attitudes and value orientations, which are limited to a specific core group of beliefs. Attitudes usually apply to a specific object, for example a sea turtle, whereas value orientations apply to a much larger subject, such as the entire coral reef ecosystem (Eagly & Chaiken, 1993; Vaske & Needham, 2007). For their differences, both value orientation and attitudes are utilized in the theory for determining behavioral intentions. (Fulton et al.,1996; Vaske & Donnelly, 1999).

The New Environmental Paradigm was researched and developed by Dunlap and Van Liere in the mid 1970's. Their argument was that environmentalism is inherently a challenge to our values, beliefs, and ideas about the relationship between humans and nature (Dunlap & Van Liere, 1978). They proposed that people subscribe to one of two dominant paradigms about the environment and that these paradigms can be aligned along a continuum. At one end is the anthropocentric paradigm, which refers to the idea that humans have complete control over the environment. At the other end, is the New Environmental Paradigm, which places value on all living things and emphasizes environmental protection, pollution prevention, limits to industrial growth, and population control (Dunlap & Van Liere, 1978; Dunlap et al., 1992).

Dunlap and Van Liere (1978) developed a quality of life, Likert scale survey that contained 12 questions about environmental issues. They found that a paradigm shift was occurring away from the anthropocentric views in favor of the NEP. The NEP scale has not been applied in the tourism and recreation fields.

VBN theory causally links personal values, norm activation theory, and the new environmental paradigm through five major variables; altruistic values, NEP, AC beliefs, AR beliefs, and personal norms through a casual chain. The theory posits that awareness of adverse consequences on what an individual values is what matters the most for activating personal norms (Stern, 2000). A person's awareness of consequences depends on one's ecological worldview, which is directly related to one's egoistic, altruistic, or biospheric values. If awareness of consequences favors environmentally responsible actions, the individual will have a self-ascribed, moral responsibility to act. For example, if a snorkeler values coral reefs and believes his actions could harm the reef, his personal norms will trigger environmentally responsible behaviors.

The VBN theory has been successfully applied to explain low-cost behaviors including waste recycling and political action to support political decisions in favor of the environment. Steg et. al., (2005), utilized the theory to determine what factors influence the acceptability of energy policies and found that the five variables that VBN connects in a causal chain are significantly related. They also found that biospheric values were correlated with a moral obligation to reduce household energy consumption.

Some researchers argue that the VBN theory has been less effective at determining high-cost behavior such as reducing vehicle usage and raise concern that the model is based at the individual level. For example, the culture in which one resides plays an important role in the creation of attitudes and beliefs that guide behavior (Oreg & Katz-Gerro, 2006).

Few studies have been conducted to examine the values, attitudes, intentions, and personal norms of divers and snorkelers towards coral reefs in recreation and tourism settings. Needham (2010) tested the value orientation of about three thousand recreationists at three specific coral reef sites in Hawaii. Recreationists included divers, snorkelers, surfers, sunbathers, and swimmers. He found that the largest number of users had strong protectionist orientations. No one surveyed had only an anthropocentric orientation towards the reef. There was no correlation between site selection, age, or residency and value orientation. However, Needham (2010) did find that females, snorkelers, swimmers, and sunbathers had stronger protectionist value orientations towards the reef. Male divers and anglers were more likely to have mixed protection use or moderate protection orientations.

Loomis et al. (2008) studied the behavioral norms of divers and snorkelers in the Florida Keys and found that most divers and snorkelers felt they had a strong obligation to never break off or take pieces of coral. Divers also felt that they had a strong obligation to maintain buoyancy, inform other divers not to touch coral, and to operate vessels at least 100 feet away from a dive flag. There is also a social norm among divers to look out for each other. Most snorkelers felt they had an obligation to pick up garbage from the sea floor. Loomis et al. (2008) stated that these findings suggest that divers and snorkelers recognize the value of coral reefs and feel a willingness to protect the coral even at the expense of having to correct someone else.

2.13 Theory of Recreation Specialization

While the Value-Belief-Norm Theory is a complete model for explaining environmental behavior, it has not been applied specifically to tourism or recreation behavior. For this reason, it is necessary to examine Bryan's (1977) Theory of Recreation Specialization to see if it can be combined with VBN to make a more powerful explanatory theory of tourism behavior (Thomas Webler, personal communication, March 19, 2011).

Recreation specialization is defined as a temporal linear progression in an activity performed by outdoor recreationists (campers, anglers, divers, and snorkelers) in which participants move from general interest and low involvement to specialized interest and high involvement. Each level of specialization involves distinctive behaviors and skills and includes other factors such as equipment preference, type of experiences sought, desired setting for the activity, attitudes toward resource management, preferred social context, and vacation patterns (Loomis et al., 2008).

Recreation specialization has been studied as a behavioral factor to better understand recreationists' attitudes and behaviors especially for conservation and management plans (Scott & Shafer, 2001). The theory posits that as a person moves from beginner to expert, behavioral, cognitive and affective changes occur. These three dimensions make up the construct of recreation specialization. Examples of behavioral change include increased experience and familiarity with the recreation setting. Cognitive change examples include an increase in knowledge, skill level, and an acceptance of social norms. Finally, affective change refers to an increased commitment and involvement in all matters related to the activity.

Van Liere and Noe (1981) found that, as individuals participate in a recreational activity over time, they are influenced by knowledge gained, social interactions, social norms, attitudes, organizational information and the skill acquisition. These influences may cause an individual to view his recreational experiences in a manner that creates a greater degree of awareness and concern about the environment. This in turn can manifest pro-environmental orientations (Jett et al., 2009). The catalyst responsible for this change is referred to as recreation specialization.

Bryan (1977) introduced the theory of recreation specialization, defining it as “a continuum of behavior from the general to the particular, reflected by equipment and skill used in a sport, and activity setting preferences.” Bryan observed within group variability among anglers and found that over time, those committed to the activity progressed from a lower to higher level of expertise and specialization. This progression led to specialized behaviors, changing attitudes, and different views about resource protection. The theory has been applied to numerous recreational activities including water rafting, hiking, mountain climbing, sailing, mountain biking, general forest recreation, camping, and scuba diving (Thapa, Graefe, & Meyer, 2006).

Empirical evidence supports Bryan’s hypothesis that a relationship exists between one’s specialization level in an activity and one’s tendency to shift away from consumptive practices towards appreciative and conservation-oriented attitudes. Chipman and Helfrich (1988) found that an increase in specialization among anglers resulted in more support for non-consumptive, catch and release fishing and stricter regulations for protecting aquatic species. Similarly, Katz (1981) found that experienced and specialized anglers had a greater commitment to specific conservation issues when compared with novice anglers.

Comparable results have been found in studies about other recreation activities and specialization. Dyck et al. (2003) studied mountaineers, recreationists who participated in a highly technical activity in environmentally sensitive landscapes. The study examined recreation specialization among this group of individuals and compared their level of skill to their attitudes towards the environment and then towards low-impact practices specifically. They found that attitudes toward low impact mountaineering were significantly associated with increasing levels of specialization, while general environmental attitudes among skilled mountaineers and less skilled mountaineers were not affected. In a different study, Kauffman (1984) researched canoeists and found that those with more experience had a higher level of concern for the environment when compared with novice canoeists.

McFarlane (2004) studied the relationship between site selection for camping and camper skill and found that campers who chose to camp at random sites, defined as unmanaged and having no facilities or services, had a higher level of bush skill and more familiarity with site selection. She concluded that specialized individuals seek settings that require a higher degree of self-reliance and have less of an impact on the environment.

There has been some research on the theory of recreation specialization related to the attitudes of divers. Todd (2000) found that commitment to the activity, skill, experience, participation, professional development and knowledge increased as a diver moved up the specialization scale. Interestingly, these factors decreased when divers stopped participating in the activity.

Thapa et al. (2006) collected data from 370 divers to see if there was a connection between recreation specialization and marine based environmental behaviors. They looked at factors related to three major categories of environmental behavior. The first category was contact behavior and included questions about frequency of participation in scuba diving and contact with marine life. The survey included questions about experience, participation, touching marine organisms, standing on coral, and collecting marine artifacts. The second category focused on general diving behaviors and included questions about wearing gloves, streamlining equipment, skill level, and buoyancy in the water column. The final category focused on education and knowledge and the centrality of scuba diving to one's lifestyle. Survey questions were designed to ask where specific knowledge about marine life was acquired and how often those surveyed participated in marine related activities (Thapa et al., 2006).

Thapa et al. (2006) found that the frequency of diving participation was high with 39% reporting having completed over 159 dives and 21% reporting they had completed over 100 dives in the area where the research was conducted. Almost 18% of those surveyed had been diving for more than 20 years. There was a strong correlation between increased levels of experience and ability and decreased participation in environmentally insensitive behaviors. They also found that as a diver increased his involvement in diving, centrality to lifestyle also increased as did one's knowledge about the marine environment. Efforts to practice environmentally responsible behaviors underwater were also reported as a priority. These findings suggest that there is a positive association with specialization and pro-environmental behavior. However, the researchers did state that they felt more research was needed to verify the specific dimensions of specialization and marine based environmental behaviors.

Loomis et al. (2008) also studied the role that recreation specialization has in fostering environmentally responsible behaviors of divers and snorkelers in the Florida Keys. In this study, the researchers utilized 8 testable propositions developed by Ditton et al. (1992) to further study Bryan's Theory of Recreation Specialization. Ditton et al. (1992) re-conceptualized the topic of recreation specialization in terms of social sub-worlds (Loomis et al., 2008). Social sub-worlds are defined as "internally recognizable constellations of actors, organizations, events, and practices which have coalesced into a perceived sphere of interest and involvement for participants" (Unruh, 1979).

In order to link Bryan's work with these social sub-worlds, Ditton et al. (1992) developed eight propositions. The first proposition states that people participating in a given recreation activity are likely to become more specialized in that activity over time. The second claims that as the level of specialization in a given recreation activity increases, financial and emotional investments will likely increase. Next, as the level of specialization in a given recreation activity increases, the importance of the activity will likely increase. The fourth states that as levels of specialization in a given recreation activity increase, compliance and support for the rules, norms, and procedures associated with the activity will likely increase. The fifth proposition posits that as the level of specialization in a given recreation activity increases, the importance attached to equipment and the skills required to use this equipment will likely increase. Proposition six claims that as the level of specialization in a given recreation activity increases, dependency on a specific resource (fish, lakes, forest, deer, coral), will likely increase. The seventh proposition states that as the level of specialization in a given recreation activity increases, the level of community interactions and relationship building relative to that activity will likely increase. The final proposition states that as the level of specialization in a given recreation activity increases, the importance of activity specific elements of the experience (catching fish) will decrease relative to non-activity specific elements of the experience (being close to the sea, relaxing, being outdoors).

Loomis et al. (2008), surveyed both resident and non-resident divers in the Florida Keys, and found that 98% of resident divers and 97% of non-resident divers were classified as having a moderate or high level of specialization. Their results supported several of these propositions.

For example, proposition number four (specialized divers have a greater acceptance and support for the rules, norms, and procedures associated with an activity), was found to be significant. This is an important finding for outreach and management strategies. Local Action Strategies can address different kinds of approaches for geographical regions based on where specialized divers and non-specialized divers recreate. Since specialized divers have a greater acceptance of the norms, rules, and procedures for protecting coral reefs, strategies can target low or moderately specialized divers to practice reef etiquette behaviors while participating in recreation activities. This also applies to "resort divers" who are not certified.

Loomis et al. (2008) also found that divers with higher levels of recreation specialization were more likely to seek out information compared to those at the lower end of the specialization scale, which supports proposition number six. They also found that specialized divers have a greater financial and emotional investment in the activity which correlates with proposition number two. In addition, they found that less specialized divers depend on other divers or dive operators for the necessary information needed about diving at specific locations. These divers did not depend on any other informational sources. This is an important finding for Local Action Strategies since it supports an important role for those in the dive industry. Dive operators, instructors, and masters can ultimately play an important role in the delivery of messages that promote environmentally responsible behaviors and coral reef etiquette. Local Action Strategies should include them in the process.

As for snorkelers, they were evenly distributed across the specialization scale from low to high. Loomis et al. (2008) found that snorkeler behavior supported Ditton's proposition two: specialized snorkelers have a greater financial and emotional investment in snorkeling as a recreational activity. They also found that snorkeler behavior supported proposition number three, that as level of specialization in a given activity increases, frequency of participation in the activity will also increase.

Unlike divers, snorkelers had very little variation in the types of sources they utilized to gain additional information including where to snorkel and how to improve one's skills. Loomis et al. (2008) found that information was not intentionally sought out regardless of specialization level. Snorkelers reported talking to other snorkelers as their only source of information sharing. Loomis et al. (2008) attribute this to the lack of training or certification needed to snorkel. This is a significant difference between divers and snorkelers and another important finding for Local Action Strategies to consider.

It must also be noted that specialized recreationists may make evaluations about appropriate behaviors on the basis of their own prior knowledge and values (Watson et al., 1991). For these reasons, a diver or snorkeler may be less likely to modify their own behavior if it means compromising their own goals set for the recreational activity, especially if they perceive the amount of damage an individual can cause as being minimal. Education messages, like briefings, should then focus on the cumulative impacts of many divers since such messages may be more valuable than those focusing on individual behavior.

2.14 Persuasion Communication Theory

The final section of this chapter focuses on persuasion theory, a psychology theory that explains how we make decisions to listen to a message. How we think about messages can influence and modify attitudes and behaviors. The previous theories discussed in this section have been descriptive in nature, explaining the factors responsible for producing specific behaviors. Persuasion theory is prescriptive in nature, and provides interventionist strategies for how to influence attitudes through messaging. Since VBN theory has not been used to design such strategies, it is useful to devote some time to discussing this applied theory since it provides the instructions for how to change attitudes by utilizing persuasion communication.

The Elaboration Likelihood Model of Persuasion (Petty & Cacioppo, 1986) posits that persuasion communication in the form of messages can work to influence beliefs, attitudes, and behavior. Persuasion communication can shape a recreationist's attitude and help an individual make more rewarding leisure decisions while not actually making the person feel like his behavior is being controlled and his freedom of choice is lost. This is an important point since freedom of choice in recreation activities is considered the most important factor of a leisure experience (Roggenbuck, 1992).

The model focuses on the process by which factors and conditions produce acceptance of the information contained in a message. Individuals working to manage the behaviors of tourists and recreationists visiting protected and natural areas have often applied persuasion communication to convince visitors to observe safety rules, minimize their impact on the natural world, and avoid conflicts with other visitors. For these reasons, persuasion communication can be considered a promising mechanism for managing the actions of divers and snorkelers in order to reduce exposure by contacting the reef.

The core of persuasion communication is the message, designed to sway the attitude of the receiver. When an individual receives a message, one makes the decision to pay attention to the content of the message or not. The model states that attitude change may occur through two different processing routes, the central route to persuasion or the peripheral route to persuasion (Petty and Wegener, 1999).

The central route to persuasion involves a great deal of effort by the receiver to process the information in a message in order to determine its merit. The recipient of the message pays a great deal of attention to the content of the message, pondering its meaning, thinking critically about its content, and integrating it into his existing belief system (Petty & Wegener, 1999). The elaboration goes beyond the message and involves additional relevant thoughts generated by the receiver. If the arguments within the message are perceived as strong, a greater persuasion should occur. If this occurs, the attitude change can be expected to last into the future since it will be internalized (Roggenbuck, 1992). For these reasons, the content of the message is extremely important. The success of this method also depends on other variables including the recipient's prior knowledge, skills, experience, interest, motivation and personal relevance to the situation.

It is fair to say that in order for the central route to persuasion to be effective, the recipient must have high motivation to pay attention to the message content, be capable of processing and understanding the message, accept the content of the message, and have the skills to carry out the behaviors. Attitudes formed through this process are considered strong since they are more resistant to counter persuasion. Therefore, they can be used to predict future behavior.

Attitude change through the second approach, referred to as the peripheral route to persuasion, occurs from less thoughtful processing of the communication (Petty & Cacioppo, 1986). The peripheral route differs both quantitatively and qualitatively when compared to the central route to persuasion. The peripheral is based on affect, not cognition. For example, if a message contains several arguments, a person processing the message through the peripheral route might only pay attention to one or two of the arguments. Important aspects that do not create strong feelings may not be factored into the decision. Qualitative differences include the lack of thoughtful evaluation to the arguments. For the peripheral route, attitude changes are often based on “rules of thumb” or issue relevant cues instead of a thorough evaluation of the message (Petty & Wegener, 1999). Recreationists processing through this route will pay little or no attention to the content of a persuasive message, and spend little to no time processing or integrating any part of the message into their value system (Roggenbuck,1992).

Individuals processing through the peripheral route cannot process all of the information they are receiving and may instead use a simple set of rules that are largely irrelevant to the message content. For example, the person who delivers the message may have a greater impact on producing a behavior change in the recipient following the peripheral route than does the actual message (Roggenbuck, 1992). The recipient of the message decides what ideas to accept or reject based on how credible he perceives the messenger to be. If the messenger is perceived as powerful, attractive, likable, and intelligent then the recipient will be more responsive. Attitudes are based on something other than a careful review of the message presented.

Other factors need to be taken into consideration with the peripheral route of persuasion. For instance, while this approach can trigger a prompt attitude change for a specific problem, it does not persuade the recipient to consider why the change is relevant and necessary. For this reason, behavior change will be less predictive and an environmental ethic or long-term attitude change will most likely not occur. However, if the message needs to be delivered in an environment that is distracting, loud, or chaotic this approach may be the best option for immediate results.

Roggenbuck (1992) discusses a third approach to persuasion which is often used by recreation managers and referred to as the applied behavioral analysis approach. This approach focuses on obvious behaviors rather than attitudes, beliefs, or values. The objective is to increase the frequency of desired behaviors or decrease the number of unskilled, careless, or uninformed behaviors. This methodology relies on behavioral prompts, manipulation of the environment, and rewards. Approaches include oral and written messages, demonstrations, modeling, pledges, competition, incentives, and disincentives.

The applied behavior analysis approach to persuasion is considered by social scientists to be simple, straightforward, and effective. This methodology does not teach new behaviors instead it serves as a quick fix to a specific problem. For these reasons, it is considered a deficient approach to attitude change since it does not teach a low-impact, environmental ethic effectively. Messages are usually short-lived (Roggenbuck, 1992).

2.14.1 Potential Effectiveness of Persuasion Theory

Most leisure scholars and recreation managers believe that problem behaviors in natural settings are not malicious and that persuasion theory is highly effective at reducing these negative behaviors. It is especially effective at reducing the number of uninformed, unintentional, unskilled, and careless behaviors (Roggenbuck, 1992). Research found that recreationists actually stated they valued the messages that they received. For example, Berrier (1980) and Oliver et al. (1985) provided persuasive messages about low impact camping to recreationists at both wilderness and developed campsites. Through surveys, they found that participants valued the information contained in the messages and supported continued programs. Irwin (1985) studied the effect of messages about low impact hiking and camping given by rangers at trailheads. His results found that recreationists found these contacts appropriate and enjoyed the opportunity to talk with a ranger who could answer questions, provide guidance and then the hikers and campers would presumably follow advice given.

Other factors found to be important indicators of the success of persuasion theory include the channel used to communicate the message. While the important role of the messenger was discussed when explaining the peripheral route to persuasion, research does suggest that personalized contacts are not always the most effective medium (Roggenbuck, 1992). If a messenger is a poor communicator, unfriendly, or just having an off day, the delivery of the message may not be successful. For this reason, written or visual messages are considered more effective since the recipient can process the information at his own pace. Messages delivered via a computer or video format have shown great promise as an effective tool to promote increased learning and behavior change. Video messages can target specific audiences by providing direct, clear-cut, and consistent information in a specific order (Roggenbuck, 1992).

The timing of the video message is also an important part of the persuasion process. If the message is given too late in the recipient's decision-making process, it will not have an effect. The recipient must have time to associate the intervention with the need for action. However, if designed properly, placed in an ideal location, and delivered at an appropriate time, video messages are effective forms of persuasion media (Roggenbuck 1992).

As previously stated, freedom of choice has been identified as a defining characteristic of outdoor recreationists. Some question whether persuasion may also result in decreasing the quality of the leisure experience. However, the benefit of raising a recreationist's environmental sensitivity and increasing environmental responsibility may outweigh freedom of choice if it leads to resource degradation (Roggenbuck, 1992). Ultimately a majority of leisure and recreation scientists have considered persuasion communication as a technique that can shape attitudes without controlling behavior

(Lucas, 1982). Most forms of persuasion communication still allow the recipient the freedom to accept or reject the message. For these reasons it is considered a subtle management strategy.

2.15 Studies into Modifying Snorkelers' and Divers' Behaviors

There is only one published study to modify snorkeler behavior, and six published studies on modifying the behavior of divers. Webler and Jakubowski (2016) developed a coral reef etiquette message for snorkelers to view before boarding a vessel. Puerto Rico's Coral Reef Conservation Local Action Strategies emphasize messaging to discourage negative behaviors (Ortiz Sotomayor, 2015). However, previously developed messages, when evaluated, were found to be inconsistent with social science theories of behavior and behavior change. For example, none of the messages referred to self-efficacy - the ability of snorkelers or divers to avoid doing harm. They also contradicted descriptive social norms by showing images associated with improper behavior (e.g. garbage on the reef, motor boats scarring the reef). New coral reef etiquette video messages were developed based on the Value-Belief-Norms (VBN) Theory (Stern et al, 1999; Stern, 2000) and the Theory of Planned Behavior (Ajzen, 1991) (Table 2.1). As many variables from both theories were included.

Table 2.1

Snorkeler coral reef etiquette messages

Message	Value-Belief-Norm Component
Snorkelers come to Puerto Rico to experience its remarkable coral reefs.	*Asserts positive environment
Of course, we would never deliberately do anything to hurt marine life.	* Attitude towards reefs * Reinforcement of benevolence
However, even experienced snorkelers can accidentally impact the reef. Here are a few things you need to know about how snorkelers can affect coral reefs and suggestions for practicing good reef etiquette.	* Awareness of consequences

Table 2.1 (continued).

Corals build a strong skeleton but their "skin" is fragile. Even the lightest touch with your hands or fins can damage sensitive coral.	*Awareness of self-consequences
Keeping a little distance from coral reefs and sea life helps ensure your safety and protects the reef!	* Self-efficacy
Some corals can burn. Keep your distance.	* Awareness of consequences
Some animals that live in the reef can bite or sting.	* Awareness of consequences
Waves and currents can push you into reefs resulting in scrapes, bruises, and cuts.	* Awareness of consequences
For all these reasons, it's a good idea to keep a little space between you and the reef.	* Prescriptive norm to protect oneself
Coral is not like grass; it will die if you stand on it.	* Awareness of consequences
Any silt your fins kick up can land on coral, smothering it over time.	* Awareness of consequences
Photographers can get clear and colorful pictures without holding on to the reef. Calm and slow movements are less likely to startle fish and result in great pictures.	* Self-efficacy
Leave sand, empty shells or bits of deal coral. Coral reefs need these non-living resources to remain vibrant.	* Prescriptive norm

Note. Developed by T. Webler and K. Jakubowski based on the VBN (value, belief, norm) theory of environmental change.

After watching the video, Webler and Jakubowski (2016) asked people to read and sign the pledge stating commitment to specific behaviors. Commitment techniques have been shown to be effective in promoting a diverse variety of behaviors (McKenzie-Mohr & Smith, 1999). Specifically, written commitments have been found to be more effective then verbal commitments (Pardini & Katzev, 1983).

79 unique individuals were a part of the treatment group who observed the video and signed a pledge. Only 19 potentially damaging behaviors were observed. No one in the treatment group had more than four contacts. 89% of people in the treatment group had no reef contacts.

Table 2.2

Coral reef pledge stating commitment to specific behaviors around coral reefs

Most visitors to coral reefs never touch, kick, or stand on the coral. They are careful not to stir up the sand near the coral with their fins. Coral are fragile and, if injured, are slow to recover. Keeping a safe distance from the reef is the best way to ensure these beautiful reefs are here for future generations. If you need to fix your mask or snorkel, it is best to swim away from the reef first. **I pledge to be a responsible visitor** to the reef by:

- Being aware of where my fins are at so I don't kick the coral
- Treading water instead of standing on the reef
- Not stirring up silt near the reef
- Keeping a safe distance from all marine organisms.

Signature Date

Frequency of potentially damaging contacts for snorkelers in the treatment group was 0.052 contacts per minute, a five-fold reduction from the baseline of 0.26 contacts per minute (Webler & Jakubowski, 2016).

Giglio et al. (2018) developed and tested a video for scuba divers recreating in Brazil. The video provided environmental education and knowledge for low-impact diving techniques. Like Webler and Jakubowski (2016), they found that divers who watched the video-briefing exhibited significantly lower rates of contact and damage to the coral reefs than divers who did not watch the video. Giglio et al. (2018) also conclude that such measures are easily implemented educational approaches that support sustainable use of coral reef resources.

Krieger and Chadwick (2013) compared divers affiliated with Blue Star dive shops to divers not affiliated with a Blue Star shop. The Blue Star program was established in the Florida Keys National Marine Sanctuary to recognize charter boat dive operators who promote responsible and sustainable diving in the Florida Keys. Blue Star operators promote reef conservation awareness and diving and snorkeling etiquette through various strategies including on-line information, coral identification cards, and informative pamphlets. Blue Star dive shops administered short dive briefings prior to each dive explaining that divers were in a protected area and should not touch or take any corals since they are living organisms and vital to the health of the reef. They found dive contacts from Blue Star operations were significantly lower (0.23/min) than non-Blue Star operations (0.37/min; $p<0.001$). Coral tissue abrasion and sediment deposition was also significantly lower for Blue Star divers than non-Blue Star divers ($p <0.001$).

Medio et al. (1997) examined the effects of a verbal intervention on divers at Ras Mohammed National Park in Egypt. This study evaluated tourists who purchased a 5-day or 10-dive package. Mean rates of contact with coral for the first 3 dives were 0.2/min. Before the 4^{th} dive, tourists received a 45-minute presentation explaining coral reef biology, diving behaviors that damaged reefs, and the justification for creating marine protected areas. This was followed by an in-water demonstration of how to identify live reef cover and non-living substrate. Mean rates of contact significantly reduced to 0.05/min for subsequent dives.

Barker (2003) tested the effect of a one-sentence inclusion in a regular pre-dive briefing given by tour operators at St. Lucia. The additional message which asked divers to avoid touching the reef, was surprisingly weak and had no effect on diver behavior. She also tested whether in-water policing by dive leaders would alter behavior. Policing did have a significant effect on behavior, reducing average per minute contacts rates from 0.29 to 0.06.

Roche et al. (2016) examined the role of dive supervision by recording dive guide interventions underwater and observed a total of 81 interventions. 80% of these interventions were a buoyancy correction or a correction to prevent a contact with the reef before it occurred.

In two subtropical rocky reef marine protected areas, Hammerton and Bucher (2015) tested two levels of interventions to determine if these strategies reduced the number of diver contacts with the coral reefs. The first was a targeted briefing with specific references to minimizing benthic contact and the second included the targeted briefing as well as a direct underwater reinforcement at the time of the contact (an underwater slate was shown to a diver contacting the reef with the message "please keep off the reef." They found that the targeted briefing had a significant effect over the usual briefing, but in-water reinforcements had a significantly greater effect than just the targeted briefing alone. Photographers made more contacts with the reef than non-photographers, even when receiving the targeted briefing. These findings suggest that direct underwater reinforcement at the time of the first contact may be required in more sensitive areas or for divers who are prone to making more direct contacts with the reef.

2.16 Conclusion

If human behaviors could be managed correctly, coral reefs may be more capable of handling natural stressors (Gardner et al., 2003). Understanding how to change diver and snorkeler behaviors in particular, is one such measure to reduce vulnerability on the reef ecosystem by reducing exposure via adaptive actions. From the theoretical background provided in this literature review, gaining a stronger understanding of how vulnerable a coral reef system is to diving and snorkeling is the first step in this process. Application of the assessment and recommendations for mitigation and adaptive action will require a clear understanding of advanced behavior change theories to develop interventions that target specific, depreciative behaviors. The VBN theory provides the most comprehensive explanation of environmental behavior by explaining that awareness of adverse consequences, contrary to an individual's values, is what matters the most for activating personal norms (Stern, 2000). However, divers and snorkelers are heterogeneous in their skills, knowledge, and experiences (Needham et al., 2007). These factors are not considered in the VBN theory. Based on this heterogeneity, it is important to combine the VBN theory of behavior with recreation specialization theory. Recreation specialization theory states that, as individuals participate in a recreational activity over time, they are influenced by knowledge gained, social interactions, social norms, attitudes, organizational information, and the skills they acquire. These influences may cause an individual to view his recreational experiences in a manner that creates a greater degree of awareness and concern about the environment. A combination of both of these theories would provide a solid theoretical foundation for recommending tangible adaptive actions that address specific types of divers and snorkelers utilizing coral reefs. Adaptive actions can also incorporate persuasion theory, a communication mechanism in the form of messages designed to influence the beliefs, attitudes, and behaviors of recreationists. Mechanisms to implement such changes are essential for coral reef conservation. Without the ability to implement these actions, coral reef degradation from recreation and tourism stressors will continue to escalate.

2.17 References

Abesamis, N.P., Corrigan, C., Drew, M., Campbell, S., & Samonte, G. (2006). *Social resilience: A literature review on building resilience into human marine communities in and around MPA networks.* Conservation International. https://www.reefresilience.org/pdf/Social_Resilience_Literature_Review.pdf

Adger, N.W. (2000). Social and ecological resilience: Are they related? *Progress in Human Geography*, *24*(3), 347-364. https://doi.org/10.1191/030913200701540465

Adger, N.W. (2006). Vulnerability. *Global Environmental Change*, *16*(3), 268-281. https://doi.org/10.1016/j.gloenvcha.2006.02.006

Ajzen, I. (1991). The theory of planned behavior. *Organizational Behavior and Human Decision Processes, 50*(2), 179-211. https://doi.org/10.1016/0749-5978(91)90020-T

Ajzen, I. & Fishbein, M. (1980). *Understanding attitudes and predicting social behavior.* Prentice Hall.

Allen, W.H. (1992). Increased dangers to Caribbean marine ecosystems. *Bioscience, 42*(5), 330-335.

Allison, W.R. (1996). Snorkeler damage to reef corals in the Maldive Islands. *Coral Reefs*, *15*(4), 215-218. https://doi.org/10.1007/BF01787454

Alwang, J., Siegel, P.B., & Jørgensen, S.L. (2001). *Vulnerability: a view from different disciplines*. Social Protection Discussion Paper Series No. 0115. Social Protection Unit, Human Development Network. The World Bank. https://documents.worldbank.org/curated/en/636921468765021121/Vulnerability-a-view-from-different-disciplines

Anthony, K.R.N., Marshall, P.A., Abdulla, A., Beeden, R., Bergh, C., Black, R., Eakin, C.M., Game, E.T., Gooch, M., Graham, N.A.J., Green, A., Heron, S.F., van Hooidonk, R., Knowland, C., Mangubhai, S., Marshall, N., Maynard, J.A., McGinnity, P., McLeod, E., Mumby, P.J., . . .Wear, S. (2015). Operationalizing resilience for adaptive coral reef management under global environmental change. *Global Change Biology*, *21*(1), 48-61. https://doi.org/10.1111/gcb.12700

Anthony K.R.N., Maynard, J.A., Diaz-Pulido, G., Mumby, P.J., Marshall, P.A., Cao, L. & Hoegh-Guldberg, O. (2011). Ocean acidification and warming will lower coral reef resilience. *Global Change Biology, 17*(5), 1798–1808. https://doi.org/10.1111/j.1365-2486.2010.02364.x

Barker, N.H.L.(2003). *Ecological and socio-economic impacts of dive and snorkel tourism in St. Lucia, West Indies* (Doctoral dissertation, University of York). ProQuest Dissertations and Theses Global.

Barnett, J. (2001). Adapting to climate change in Pacific island countries:The problem of uncertainty. *World Development*, *29*(6), 977-993. https://doi.org/10.1016/S0305-750X(01)00022-5

Bentler, P. M., & Speckart, G. (1979). Models of attitude–behavior relations. *Psychological Review*, *86*(5), 452-464. https://doi.org/10.1037/0033-295X.86.5.452

Berkes, F., & Folke, C. (1998). *Linking social and ecological systems: Management practices and social mechanisms for building resilience.* Cambridge University Press. https://doi.org/10.5751/ES-00202-040205

Bernard, H.R. (2006). *Research methods in anthropology: Qualitative and quantitative approaches* (4th ed.). Altamira Press.

Berrier, D.L.(1980). *The effectiveness of information on dispersing wilderness campers* (Master's thesis, Virginia Polytechnic Institute and State University). ProQuest Dissertations and Theses Global.

Birkeland, C. (2004). Ratcheting down the coral reefs. *BioScience,54* (11), 1021-1027. https://doi.org/10.1641/0006-3568(2004)054[1021:RDTCR]2.0.CO;2

Boo, E. (1990). *Ecotourism: The potential and the pitfalls*. World Wildlife Fund (U.S.).

Bryan, H. (1977). Leisure value systems and recreational specialization: The case of the trout fishermen. *Journal of Leisure Research,9*(3*),*174-187. https://doi.org/10.1080/00222216.1977.11970328

Budd, R.J., & Spencer, C.P. (1985). Exploring the role of personal normative beliefs in the theory of reasoned action: The problem of discriminating between alternative path models. *European Journal* of *Social Psychology,15*(3), 299-313. https://doi.org/10.1002/ejsp.2420150305

Buddemeier, R.W., & Smith, S.V. (1999). Coral adaptation and acclimatization: A most ingenious paradox. *American Zoologist*, *39*(1), 1-9.

Burgett, J. (1990). Diving deeper into Hanauma: Identifying conceptual barriers to effective management. In M. Miller and J. Auyong (Eds.), *Proceedings of the 1990 Congress on Coastal and Marine Tourism*. (Vol 1., pp. 100-105). National Coastal Resources Research Institute.

Burton, I., Kates, R.W., & White, G.F. (1993). *The environment as hazard* (2nd ed.). Guilford Press.

Butynski,T.M. & Kalina, J. (1998). Gorilla tourism: A critical look. In E.J. Milner-Gulland & R. Mace (Eds.), *Conservation of Biological Resources* (pp. 294-313). Blackwell Science.

Cao, L., Caldeira, K., & Jain, A. (2007). Effects of carbon dioxide and climate change on ocean acidification and carbonate mineral saturation. *Geophysical Research Letters, 34*(5), 1-5. https://doi.org/10.1029/2006GL028605

Carpenter, S., Walker, B., Anderies, J.M., & Abel, N. (2001). From metaphor to measurement: Resilience of what to what? *Ecosystems, 4*(8), 765-781. https://doi.org/10.1007/s10021-001-0045-9

Cater, E. & Lowman, G. (1994) *Ecotourism: A sustainable option*. John Wiley and Sons.

Ceballos-Lascurain, H. (1996). *Tourism, ecotourism, and protected areas*: *The state of nature-based tourism around the world and guidelines for its developmen*t. IUCN.

Chapin III, F.S., Kofinas, G.P., & Folke, C. (2009). *Principles of ecosystem Stewardship: Resilience-based natural resource management in a changing world*. Springer Science & Business Media.

Chassin, L., Corty, E., Presson, C. C., Olshavsky, R. W., Bensenberg, M., & Sherman, S. J. (1981). Predicting adolescents' intentions to smoke cigarettes. *Journal of Health and Social Behavior*, *22*(4), 445-455. https://doi.org/10.2307/2136684

Chipman, B.D. & Helfirch, L.A. (1988). Recreational specialization and motivations of Virginia river anglers. *North American Journal of Fisheries Management, 8*(4), 390-398. https://doi.org/10.1577/15488675(1988)008<0390:RSAMOV>2.3.CO;2

Cialdini, R.B. (2003). Crafting normative messages to protect the environment. *Current Directions in Psychological Science,12*(4),105-109. https://doi.org/10.1111/1467-8721.01242

Cialdini, R.B., Reno, R.R., & Kallgren, C.A. (1990). A focus on theory of normative conduct: Recycling the concept of norms to reduce littering in public places. *Journal of Personality and Social Psychology,58*(6),1015-1026. https://doi.org/10.1037/0022-3514.58.6.1015

Cohen, P. & Levesque, H. (1990). Intention is choice with commitment. *Artificial Intelligence*, *42*(2-3), 213-261. https://doi.org/10.1016/0004-3702(90)90055-5

Copi, I. & Cohen, C. (2005). *Introduction to Logic* (12th ed.). Pearson Education.

Cutter, S.L., Emrich, C.T., Webb, J.J., & Morath, D. (2009). Social vulnerability to climate variability hazards: A review of the literature. *Oxfam America,*1- 44. https://citeseerx.ist.psu.edu/viewdoc/download?doi=10.1.1.458.7614&rep=rep1&type=pdf

Davies, J., Foxhall, G.R., & Pallister, J. (2002). Beyond the intention-behavior mythology: An integrated model of recycling. *Marketing Theory,2*(1),29-113. https://doi.org/10.1177/1470593102002001645

Davis, D. & Tisdell, C. (1995). Recreational scuba-diving and carrying capacity in marine protected areas. *Ocean and Coastal Management*, *26*(1),19-40. https://doi.org/10.1016/0964-5691(95)00004-L

Dearden, P., Bennett, M., & Rollins, R. (2006). Implications for coral reef conservation of diver specialization. *Environmental Conservation,33*(4), 353-363. https://doi/10.1017/S0376892906003419

Dimmock, K. (2009). Finding comfort in adventure: experiences of recreational SCUBA divers. *Leisure Studies, 28*(3), 279-295. https://doi.org/10.1080/02614360902951674

Ditton, R.B., Loomis, D.K., & Choi, S. (1992). Recreation specialization: Re-conceptualization from a social world's perspective. *Journal of Leisure Research,24*(1), 33-51.

Dobrzynski, T.J. & Nicholson, E.E. (2003). User group perceptions of the short-term impacts of marine reserves in Key West. In M.K. Kasim Moosa, S. Soemodihardjo, A. Nontji, A. Soegiarto, K. Romimohtarto, Sukarno, & Suharsono, (Eds.) *Proceedings of the Ninth International Coral Reef Symposium* (759-764). Indonesian Institute of Sciences and State Ministry for Environment, Republic of Indonesia.

Dunlap, R.E. & Van Liere, K.D.(1978). The new environmental paradigm – A proposed measuring instrument and preliminary results. *Journal of Environmental Education, 9*(4), 10-19. https://doi.org/10.1080/00958964.1978.10801875

Dunlap, R., Van Liere, K., Mertig, A., & Howell, R. (1992). *Measuring endorsement of an ecological worldview: A revised NEP scale*. Paper presented in the Annual Meeting of the Rural Sociology Society, PA.

Dyck, C., Schneider, I., Thompson, M., & Virden, R. (2003). Specialization among mountaineers and its relationship to environmental attitudes. *The Journal of Park and Recreation Administration, 21*(2), 44-62.

Eagly, A.H. & Chaiken, S. (1993). *The psychology of attitudes*. Harcourt, Brace, & Janovich College Publishers. https://doi.org/10.1002/mar.4220120509

Eakin, H. & Luers, A.L. (2006). Assessing the vulnerability of social-environmental systems. *Annual Review of Environment and Resources, 31*, 365-394. https://doi.org/10.1146/annurev.energy.30.050504.144352

Fishbein, M. & Manfredo, M. (1992). Theory of Behavior Change.In M. Manfredo (Ed.), *Influencing Human Behavior* (29-50). Sagamore Publishing.

Fulton, D.C., Manfredo, M.J., Lipsomb, J.(1996). Wildlife value orientations: A conceptual and measurement approach. *Human Dimensions of Wildlife,1*(2), 24-47. https://doi.org/10.1080/10871209609359060

Gallopin, G.C.(1997). Indicators and their use: information for decision-making. SCOPE—Scientific Committee on Problems of the Environment. *International Council of Scientific Unions 58*, 13–27.

Garcia-Sais, J., Appeldoorn, R., Battista, T., Bauer, L., Bruckner, A., Caldow, C., Carrubba, L., Corredor, J., Diaz, E., Lilyestrom, C., Garcia-Moliner, G., Hernandez-Delgado, E., Menza, C., Morell, J., Pait, A., Sabater, J., Weil, E., Williams, E., & Williams, S. (2008). The State of Coral Reef Ecosystems of Puerto Rico. In: J.E. Waddell and A.M. Clarke (Eds.), *The State of Coral Reef Ecosystems of the United States and Pacific Freely Associated States: 2008*. NOAA Technical Memorandum NOS NCCOS 73. NOAA/NCCOS Center for Coastal Monitoring and Assessment's Biogeography Team (pages 75 – 116).

Gardner,T.A., Côté, I.M., Gill, J.A., Grant, A., & Watkinson, A. R. (2003). Long-term region-wide declines in Caribbean corals. *Science*, *301*(5635*)*, 958-960. https://doi.org/10.1126/science.1086050

Garrod, B. (2009). Market segments and tourism typologies for diving tourism. In B. Garrod, B. & S. Grossling (Eds.), *New frontiers in marine tourism: Diving experiences, sustainability, management* (pp. 31- 39). Elsevier. https://doi.org/10.1016/b978-0-08-045357-6.50005-x

Giglio, V., Luiz, O., Chadwick, N., & Ferreira, C. (2018). Using an educational video-briefing to mitigate the ecological impacts of scuba diving. *Journal of Sustainable Tourism, 26*(5), 782- 797. https://doi.org/10.1080/09669582.2017.1408636

Glick, P., Stein, B. A., & Edelson, N. A. (2011). *Scanning the conservation horizon: A guide to climate change vulnerability assessment*. National Wildlife Federation. https://www.nwf.org/~/media/pdfs/global-warming/climate-smart-conservation/nwfscanningtheconservationhorizonfinal92311.ashx

Godin, G. & Shephard,R.J. (1985). A simple method to assess exercise behavior in the community. *Canadian Journal of Applied Sports Science,10*(3), 141-146.

Goodhead, T. & Johnson, D. (1996). *Coastal Recreation Management, The Sustainable Development of Maritime Leisure*. Taylor and Francis. https://doi.org/10.4324/9781315024851

Guagnano, G.A., Stern, P.C., & Dietz, T. (1995). Influences on attitude-behavior relationships: a natural experiment with curbside recycling. *Environment and Behavior,27*, 699-718. https://doi.org/10.1177/0013916595275005

Halpern, B. S., Selkoe, K.A., Micheli, F., & Kappel., C.V. (2007). Evaluating and ranking the vulnerability of global marine ecosystems to anthropogenic threats. *Conservation Biology, 21*(5), 1301-1315. https://doi.org/ 10.1111/j.1523-1739.2007.00752.x.

Hammerton, Z. & Bucher, D. (2015). Levels of intervention – Reducing SCUBA-diver impact within subtropical marine protected areas. *Journal of Ecotourism, 14*(1), 3-20. https://doi.org/ 10.1080/14724049.2015.1073738

Harriott, V.J., Davis, D., & Banks, S.A. (1997). Recreational diving and its impact in marine protected areas in eastern Australia, *Ambio,26*(3), 173-179.

Harriott, V.J. (2002). *Marine tourism impacts and their management on the Great Barrier Reef*. CRC Reef Research Centre Technical Report No 46. CRC Reef Research Centre. https://www.rrrc.org.au/wp-content/uploads/2014/04/Technical-Report-46.pdf

Hawkins, J.P. & Roberts, C.M. (1992). Effects of recreational SCUBA diving on fore-reef slope communities of coral reefs. *Biological Conservation*, *62*(3), 171-178. https://doi.org/10.1016/0006-3207(92)91045-T

Hawkins, J. P. & Roberts, C.M. (1994). The growth of coastal tourism in the Red Sea: Present and future effects on coral reefs. *Ambio, 23*(8), 503-508.

Hernández-Delgado, E.A. (2005). *Natural history, characterization, distribution and current status of Puerto Rico coral reefs. Puerto Rico biodiversity: Terrestrial vertebrates and ecosystems.* Natural History Series. San Juan, Puerto Rico: Editorial Instituto de Cultura Puertorriqueña, 281-356.

Hernández-Delgado, E.A., Ramos-Scharrón, C.E., Guerrero, C., Lucking, M.A., Laureano, R., Méndez-Lázaro, P.A., & Meléndez-Díaz, J.O. (2012). Long-term impacts of tourism and urban development in tropical coastal habitats in a changing climate: Lessons learned from Puerto Rico. In: M. Kasimoglu (Ed.)., *Visions from global tourism industry-creating and sustaining competitive strategies* (357-398). InTech Publications.

Hinkel, J. (2011). Indicators of vulnerability and adaptive capacity: Towards a clarification of the science-policy interface. *Global Environmental Change, 21*, 198-208. https://doi.org/10.1016/j.gloenvcha.2010.08.002

Hsu, S. (2004). The effects of an environmental education program on responsible environmental behavior and associated environmental literacy variables in Taiwanese college students. *The Journal of Environmental Education, 35*(2), 37-46. https://doi.org/10.3200/JOEE.35.2.37-48

Inglis, G.J., Martin, V.Y. & Ponte, F. (1999). Crowding norms in marine settings: A case study of snorkeling on the Great Barrier Reef. *Environmental Management, 24*(3), 369-381. https://doi.org/10.1007/s002679900240

Irwin, K.M. (1985). *Wilderness visitor response to ranger educational contacts at trailheads*, (master's thesis). Virginia Polytechnic Institute and State University, Blacksburg, VA.

Jacobson, S.K. & Robles, R. (1992). Ecotourism, sustainable development, and conservation education: development of a tour guide training program in Tortuguero, Costa Rica. *Environmental Management,16*(6), 701-713. https://doi.org/10.1007/BF02645660

Jett, J., Thapa, B., & Ko, Y.J. (2009). Recreation specialization and boater speed compliance in manatee zones. *Human Dimensions of Wildlife,14*(4), 278-292. https://doi.org/10.1080/10871200902905984

Kasperson, R.E., Dow, K., Archer, E., Caceres, D., Downing, T., Elmqvist, T., Eriksen, S., Folke, C., Han, G., Iyengar, K., Vogel, C., Wilson, K., Ziervogel, G. (2005). Vulnerable people and places. In: Hassan, R., Scholes, R., Ash, N. (Eds.), *Ecosystems and human wellbeing: Current state and trends*, vol. 1 (pp. 143-164). Island Press.

Katz, M. (1981). *An assessment of intra-group differences in conservation attitudes and environmentalism as a function of activity involvement among fly fishermen.* (Unpublished doctoral dissertation). Pennsylvania State University, State College, Pennsylvania.

Kauffman, R. (1984). *The relationship between activity specialization and resource related attitudes and expected rewards for canoeists*. (Unpublished doctoral dissertation, University of Maryland).

Kay, A.M., & Liddle, M.J. (1989). Impact of human trampling in different zones of a coral reef flat. *Environmental Management*, *13*(4), 509-520. https://doi.org/10.1007/BF01867685

Kelly, P. M. & Adger, W.N. (2000). Theory and practice in assessing vulnerability to climate change and facilitating adaptation. *Climatic Change, 47*(4), 325-352. https://doi.org/10.1023/A:1005627828199

Kennedy, E.V., Perry, C.T., Halloran, P.R., Iglesias-Prieto, R., Schonberg, C.H., Wisshak, M., Forum, A.U., Carricart-Ganivet, J.P., Fine, M., Eakin, C.M., & Mumby, P.J. (2013). Avoiding coral reef functional collapse requires local and global action. *Current Biology, 23*, 912–918. https://doi.org/10.1016/j.cub.2013.04.020

Kollmuss, A. & Agyeman, J. (2002). Mind the gap: Why do people act environmentally and what are the barriers to pro-environmental behavior? *Environmental Education Research, 8*(3), 239-260. https://doi.org/ 10.1080/13504620220145401

Krieger, J & Chadwick, N. (2013). Recreational diving impacts and the use of pre-dive briefings as a management strategy on Florida coral reefs. *Journal of Coast Conservation*, *17*(1), 179-189. https://doi/org/ 10.1007/s11852-012-0229-9

Leiserowitz, A. A., Kates, R. W., & Parris, T. M. (2004). *Sustainability values, attitudes, and behaviors: A review of multi-national and global trends.* CID Working Paper No.113. Science, Environment, and Development Group, Center for International Development, Harvard University.

Liddle, M.J. & Kay, A.M. (1987). Resistance, survival and recovery of trampled corals on the Great Barrier Reef. *Biological Conservation*, *42*(1), 1-18. https://doi.org/10.1016/0006-3207(87)90049-8

Loomis, D., Anderson, L., Hawkins, C., Paterson, S. (2008). *Understanding coral reef use: Scuba diving in the Florida Keys by residents and non-residents.* The Florida Reef Resilience Program. The Nature Conservancy Florida Keys Program, 1-141.

Lucas, R.C. (1982). Recreation regulations – When are they needed? *Journal of Foresty,80*(3), 148-151.

Manfredo, M. J., Fishbein, M., Watson, A., & Haas, G. (1990). A national survey of public attitudes toward prescribed fire policy. *Journal of Forestry*, *88*(7), 19-23.

Manstead, A.S.R. (2000). The role of moral norm in the attitude-behavior relationship. In D. J. Terry & M. A. Hogg (Eds.), *Attitudes, behavior and social context: The role of norms and group membership* (11-30). Lawrence Erlbaum.

Manstead, A.S.R., Proffitt, C. & Smart, J.L. (1983). Predicting and understanding mothers'infant-feeding intentions and behavior: Testing the theory of reasoned action. *Journal of Personality and Social Psychology,44*(4), 657-671. https://doi.org/10.1037/0022-3514.44.4.657

Marshall, P.A., & Schuttenberg, H.Z. (2006). *A reef manager's guide to coral bleaching*. Great Barrier Reef Marine Park Authority. https://www.coris.noaa.gov/activities/reef_managers_guide/

McClanahan, T.R., Donner, S.D., Maynard, J.A., MacNeil, M.A., Graham, N.A.J., Maina, J., Baker, A.C., Alemu, J.B., Beger, M., Campbell, S.J., Darling, E.S., Eakin, C.M., Heron, S.F., Jupiter, S.D., Lundquist, C.J., McLeod, E., Mumby, P.J., Paddock, M.J., Selig, E.R., & van Woesik, R. (2012). Prioritizing key resilience indicators to support coral reef management in a changing climate. *Plos One*,*7*(8). http://doi.org/10.1371/journal.pone.0042884

McFarlane, B. (2004). Recreation specialization and site choice among vehicle-based campers. *Leisure Sciences, 26*(3), 309-322. https//doi.org/10.1080/01490400490461981

McKenzie-Mohr, D., & Smith, W. (1999). *Fostering sustainable behavior: An introduction to community-based social marketing* (2nd ed.). New Society Publishers.

McLaughlin, P. & Dietz, T. (2008). Structure, agency and environment: Toward an integrated perspective on vulnerability. *Global Environmental Change,39* (1), 99-111. https://doi.org/ 10.1016/j.gloenvcha.2007.05.003

Medio, D., Ormond, R. & Pearson, M. (1997). Effect of briefings on rates of damage to coral by SCUBA divers. *Biological Conservation*, *79*(1)*,* 91-95. https://doi.org/10.1016/S0006-3207(96)00074-2

Miller, F., Osbahr, H., Boyd, E., Thomalla, F., Bharwani, S., Ziervogel, G., Walker,B. Birkmann, J., van der Leeuw, S., Rockstrom, J., Hinkel, J., Downing, T., Folke, C., & Nelson, D. (2010). Resilience and vulnerability: Complementary or conflicting concepts? *Ecology and Society,15(*3), 1-25.

Miller, M.L. (1993). The rise of coastal and marine tourism. *Ocean and Coastal Management*, *20*(3), 181-199. https://doi.org/10.1016/0964-5691(93)90066-8

Moreno, A. & Becken, S. (2009). A climate change vulnerability assessment methodology for coastal tourism. *Journal of Sustainable Tourism,17*(4), 478-488. https://doi.org/10.1080/09669580802651681

Moser, C.O.N. (1998). The asset vulnerability framework: Reassessing urban poverty reduction strategies. *World Development,26* (1),1-19. https://doi.org/10.1016/S0305-750X(97)10015-8

Moser, S.C., & Dilling, L. (2007). *Creating a climate for change: Communicating climate change and facilitating social change*. Cambridge University Press.

Myers, D. (2010). *Social Psychology* (10^{th} Ed.). The McGraw-Hill Companies, Inc.

National Oceanic and Atmospheric Administration. (1998). *1998 year of the ocean-coastal tourism and recreation*. Discussion paper, National Oceanic and Atmospheric Administration, Washington, DC.

National Oceanic and Atmospheric Administration Coral Reef Conservation Program. (2009). *NOAA coral reef conservation program international strategy 2010-2015*. https://permanent.access.gpo.gov/lps124467/3threats_go.pdf

Needham, M.D. (2010). Value orientation toward coral reefs in recreation and tourism settings: A conceptual and measurement approach. *Journal of Sustainable Tourism,18*(6),757-772. https://doi.org/10.1080/09669581003690486

Needham, M.D., Vaske, J.J., Donnelly, M.P., & Manfredo, M.J., (2007). Hunting specialization and its relationship to participation in response to chronic wasting disease. *Journal of Leisure Research, 39* (3), 413-437. https://doi.org/10.1080/00222216.2007.11950115

Nordlund, A. M., & Garvill, J. (2003). Effects of values, problem awareness, and personal norm on willingness to reduce personal car use. *Journal of Environmental Psychology, 23*(4), 339–347. https://doi.org/10.1016/S0272-4944(03)00037-9

Nystrom, M., Folke, C., Moberg. F. (2000). Coral reef disturbance and resilience in human-dominated environment. *Trends in Ecological Evolution,15*(10), 413-417. https://doi.org/10.1016/S0169-5347(00)01948-0

Oliver, S.S., Roggenbuck, J.W., & Watson, A.E. (1985). Education to reduce impacts in forest campgrounds. *Journal of Forestry, 83*(4), 234 -236.

Orams, M. (1999). *Marine tourism: Development, impacts, and management*. Routledge.

Oreg, S. & Katz-Gerro, T. (2006). Predicting pro-environmental behavior cross-nationally: Values, the theory of planned behavior, and value-belief, norm theory. *Environment & Behavior,38*(4), 462-483. https://doi.org/10.1177/0013916505286012

Ortiz Sotomayor, A. (2015). *Local Action Strategies (LAS) for coral reef conservation 2011-2015: Puerto Rico*. https://repository.library.noaa.gov/view/noaa/8069

Oskamp, S. (2000). Psychological contributions to achieving an ecologically sustainable future for humanity. *Journal of Social Issues, 56*(3),373-390.

Pardini, A.U. & Katzev, R.D. (1983). The effect of strength of commitment on newspaper recycling. *Journal of Environmental Systems,* 13, 245-254. https://doi.org/10.2190/6PN9-MXFP-3BFF-CHHB

Parker, S. (2001). Marine tourism and environmental management on the Great Barrier Reef. In V.L. Smith & M. Brent (Eds.*), Hosts and guest revisited: Tourism issues of the 21st Century (pp.232-241)*. Cognizant Communication Cooperation.

Patt, A. G., & Schröeter, D. (2008). Perceptions of climate risk in Mozambique: Implications for the success of adaptation strategies. *Global Environmental Change*, *18*(3), 458-467. https://doi.org/10.1016/j.gloenvcha.2008.04.002.

Petty, R. & Cacioppo, J. (1986). *Communication and persuasion: Central and peripheral routes to attitude change*. Springer-Verlag. https://doi.org/10.1037/0022-3514.51.5.1032

Petty, R. & Wegener, D. (1999). The elaboration likelihood model: Current status and controversies. In S. Chaiken & Y.Trope (Eds.), *Dual process theories in social psychology* (pp.41-72). Guilford Press.

Plathong, S., Inglis, G., & Huber, M. (2000). Effects of self-guided snorkeling trails on corals in a tropical marine park. *Conservation Biology, 14*(6),1821-1830. http://doi.org/10.1111/j.1523-1739.2000.99301.x

Pollnac, R. B., Abbott-Jamieson, S., Smith, C., Miller, M.L., Clay, P.M., & Oles, B. (2008). Toward a model for fisheries social impact assessment. *Marine Fisheries Review, 68*(1-4), 1-18.

Prior, M., Ormond, R., Hitchen, R., & Wormald, C. (1995). The impact of natural resources of activity tourism: a case study of diving in Egypt. *International Journal of Environmental Studies, 48*(3-4), 201-209. https://doi.org/10.1080/00207239508710990

Professional Association of Diving Instructors [PADI]. (2017). Statistics. https://www.padi.com/sites/default/files/documents/2017%20PADI%20WW%20Statistics.pdf

Professional Association of Diving Instructors [PADI]. (2018). https://www.padi.com

Puerto Rico Tourism Company [PRTC]. (2009). *Puerto Rico tourism strategic plan: 2009 – 2013*, Compania de Turismo de Puerto Rico, pp.1-62.

Ragster, L. & Geoghegan, T. (1992). Management Training in the Caribbean, a necessity for sustainable development; The consortium approach. *Caribbean Perspectives. 2*, 1-17.

Rajecki, D.W. (1982). *Attitudes, themes, advances*. Sinauer Associates.

Ramsey, C., & Rickson, R. (1976). Environmental knowledge and attitudes. *The Journal of Environmental Education*, *8*(l), 10-18. https://doi.org/10.1080/00958964.1976.9941552

Roche, R.C., Harvey, C.V., Harvey, J.J., Kavanagh, A.P., McDonald, M., Stein-Rostaing, V.R., & Turner, J.R. (2016). Recreational diving impacts on coral reefs and the adoption of environmentally responsible practices with the SCUBA diving industry. *Environmental Management, 58*(1), 107-116. https://doi.org/10.1007/s00267-016-0696-0

Roggenbuck, J. (1992). Use of persuasion to reduce resource impacts and visitor conflicts. In M. Manfredo (Ed.), *Influencing human behavior*, pp. 149-248. Sagamore Publishing.

Rokeach, M. (1973). *The nature of human values*. The Free Press.

Rokicka, E. (2002). Attitudes towards natural environment: A study of local community dwellers. *International Journal of Sociology,32*(3), 78-90. https://doi.org/10.1080/15579336.2002.11770256

Rygel, L., O'Sullivan, D., & Yarnal, B. (2006). A method for constructing a social vulnerability index: An application to hurricane storm surges in a developed country. *Mitigation and Adaptation Strategies for Global Change*, *11*(3), 741-764. https://doi.org/10.1007/s11027-006-0265-6

Schahn, J. & Holzer, E. (1990). Studies of individual environmental concern: The role of knowledge, gender and background variables. *Environment and Behavior,22*, 767-786. https://doi.org/10.1177/0013916590226003

Schroter, D., Cramer,W., Leemans, R., Prentice,I.C., Araújo, M.B., Arnell, N.W., Bondeau, A., Bugmann, H., Carter, T.R., Gracia, C.A., de la Vega-Leinert, A.C., Erhard, M., Ewert, F., Glendining, M., House, J.I., Kankaanpää S., Klein, R.J., Lavorel, S.,Lindner, M.,…Zierl, B. (2005). Ecosystem service supply and vulnerability to global change in Europe. *Science, 310* (5752), 1333–1337. https://doi.org/ 10.1126/science.1115233.

Schwartz, S.H. (1977). Normative influences on altruism. *Advances in Experimental Social Psychology*, *10*, 221-279. https://doi.org/10.1016/S0065-2601(08)60358-5

Schwartz, S.H. (1994). Are there universal aspects in the structure and contents of human values? *Journal of Social Issues,50*(4), 19-45. https://doi.org/10.1111/j.1540-4560.1994.tb01196.x

Schwartz, S.H. & Bilsky, W. (1987). Toward a universal psychological structure of human values. *Journal of Personality and Social Psychology,53*(3), 550-562. https://doi.org/10.1037/0022-3514.53.3.550

Scott, D., & Shafer, C.S. (2001). Recreational specialization: A critical look at the construct. *Journal of Leisure Research*, *33*(3), 319-343. https://doi.org/10.1080/00222216.2001.11949944

Sheppard, B.H., Hartwick, J., & Warshaw, P.R (1988). The theory of reasoned action: A meta-analysis of past research with recommendations for modifications and future research. *Journal of Consumer Research*, *15*(3), 325–343. https://doi.org/10.1086/209170

Sherman, P. & Dixon, J. (1991) The economics of nature tourism: Determining if it pays. In Whelan, T. (Ed.), *Nature tourism*. Island Press.

Smit, B. & Wandel, J. (2006). Adaptation, adaptive capacity, and vulnerability. *Global Environmental Change,16*(3), 282-292. https://doi.org/10.1016/j.gloenvcha.2006.03.008

Spalding, M., Burke, L., Wood, S., Ashpole, J., Hutchison, J., & Zu Ermgasssen, P. (2017). Mapping the global value and distribution of coral reef tourism. *Marine Policy, 82*,104-113. https://doi.org/10.1016/j.marpol.2017.05.014

Steg, L., Dreijerink, L., & Abrahamse, W. (2005). Factors influencing the acceptability of energy policies: A test of the VBN theory. *Journal of Environmental Psychology,25*(4), 415-425. https://doi.org/10.1016/j.jenvp.2005.08.003

Stern, P. (2000). Toward a coherent theory of environmentally significant behavior. *Journal of Social Issues, 56*(3), 407- 424. https://doi.org/10.1111/0022-4537.00175

Stern, P., Dietz, T., Abel, T., Guagnano, G.A. & Kalof, L. (1999). A Value-Belief-Norm Theory of support for social movements: The case of environmentalism. *Human Ecology Review,6*(2), 81-97. https://www.humanecologyreview.org/pastissues/her62/62sternetal.pdf

Stern, P.C., Dietz, T., & Guagnano, G.A. (1995). The new ecological paradigm in social-psychological context. *Environment and Behavior, 27*, 723-743. https://doi.org/10.1177/0013916595276001

Stern, P., Dietz, T., & Kalof, L. (1993). Value orientation, gender, and environmental concern. *Environment and Behavior,25*, 322-348. https://doi.org/10.1177/0013916593255002

Stern, P. C., & Oskamp, S. (1987). Managing scarce environmental resources. In D. Stokols & I. Altman (Eds.), *Handbook of environmental psychology* 1043–1088. Wiley.

Thapa, B., Graefe, A., & Meyer, L. (2006). Specialization and marine based environmental behaviors among SCUBA divers. *Journal of Leisure Research, 38*(4), 601-615. https://doi.org/10.1080/00222216.2006.11950094

Todd, S. (2000). *Scuba diving in New York's Great Lakes: from novice to professional.* New York Sea Grant Institute Completion Report. SUNY, Department of Recreation and Leisure Studies.

Tratalos, J. & Austin, T. (2001). Impacts of recreational SCUBA diving on coral communities of the Caribbean island of Grand Cayman. *Biological Conservation*, *102*(1), 67-75. https://doi.org/10.1016/S0006-3207(01)00085-4

United States Coral Reef Task Force (2009). http://coralreef.gov/

Unruh, D.R. (1979). Characteristics and types of participation in social worlds. *Symbolic Interaction, 2,* 115- 130. https://doi.org/10.1525/si.1979.2.2.115

vanLiere, K. & Noe, F. (1981). Outdoor recreation and environmental attitudes: Further examination of the Dunlap-Heffernan thesis. *Rural Sociology,46* (3),505-513.

Vaske, J.J. & Donnelly, M.P. (1999). A value-attitude-behavior model predicting wildland preservation voting intentions. *Society & Natural Resources, 12*, *(6)* 523-537. https://doi.org/10.1080/089419299279425

Vaske, J.J., Graefe, A., Shelby, B. & Heberlein, T. (1986). Backcountry encounter norms: Theory, method, and empirical evidence. *Journal of Leisure Research, 18*(3), 137-153. https://doi.org/10.1080/00222216.1986.11969653

Vaske, J.J., & Needham, M.K. (2007). Segmenting public beliefs about conflict with coyotes in an urban recreation setting. *Journal of Park and Recreation Administration, 25*(4), 79-98.

Vogel, C., Moser, S., Kasperson, R., & Dabelko, G. (2007). Linking vulnerability, adaptation, and resilience science to practice: Pathways, players, and partnerships. *Global Environmental Change,17*(3-4), 349-364. https://doi.org/10.1016/j.gloenvcha.2007.05.002

Walsh, E.J. (1981). Resource mobilization and citizen protest in communities around Three Mile Island. *Social Problems, 29*(1), 1-21. https://doi.org/10.2307/800074

Watson, A.E., Williams, D.R., & Daigle, J.J. (1991). Sources of conflict between hikers and mountain bike riders in the Rattlesnake National Recreation Area. *Journal of Park and Recreation Administration*, 9(3), 59-71.

Watts, M.J. & Bohle, H.G. (1993). The space of vulnerability: The causal structure of hunger and famine. *Progress in Human Geography,17*(1), 43-67. https://doi.org/10.1177/030913259301700103

Webler, T. & Jakubowski, K. (2016). Mitigating damaging behaviors of snorkelers to coral reefs in Puerto Rico through a pre-trip media-based intervention. *Biological Conservation, 197*, 223-228. https://doi.org/10.1016/j.biocon.2016.03.012

Wells, S. & Hanna, N. (1992, August). Tourism time bomb. *New Internationalist, 234*. https://www.newint.org/features/1992/08/05/bomb/

White, A.T., Hale, L.Z., Renard, Y. & Cortesi, L. (1994). *Collaborative and community-based management of coral reefs: Lessons from experience.* Kumarian Press.

Zakai, D. & Chadwick-Furman, N.E. (2002). Impacts of intensive recreational diving on reef corals at Eilat, Northern Red Sea. *Biological Conservation*, *105*(2), 179-187. https://doi.org/10.1016/S0006-3207(01)00181-1

CHAPTER 3
Vulnerability Assessment of Snorkeling Activities in La Cordillera Nature Reserve, Puerto Rico

3.1 Introduction

The diversity and beauty of coral reefs make them an important biological, ecological, and economic resource. For instance, a healthy and productive coral reef ecosystem can benefit local economies through recreation and tourism. This includes "on the reef" tourism such as snorkeling, diving, glass bottom boat excursions, fishing, and kayaking as well as "reef adjacent" tourism which includes marinas, hotels, restaurants, and retail shops. The global annual value of these reef services has been estimated at 36 billion United States dollars (Spalding et al., 2017). However, research has demonstrated that tourism and marine recreational activities can threaten and degrade coral reef ecosystems. For example, snorkeling and diving can affect the health of coral reefs especially when visitors act inappropriately. Specific damaging behaviors include fins kicking coral, brushing up against the reef, holding on to branching coral and accidentally breaking a piece, standing on the reef, and trampling coral polyps (Allison, 1996; Barker, 2003; Hawkins & Roberts,1992; Kay & Liddle, 1989; Krieger & Chadwick, 2013; Liddle, 1991; Liddle & Kay,1987; Plathong et al., 2000; Prior et al., 1995; Riegl & Velimirov,1991; Tratalos & Austin, 2001). Scleractinian (hard) corals, which create the primary structure of the reef, are vulnerable to direct human contact since their structure is brittle and their polyps can be easily crushed (Tratalos & Austin, 2001). While snorkeling and diving may seem to be small compared to other stressors like warmer ocean temperatures and changes in the chemistry of ocean water, tourism activities do impact the health of coral reef ecosystems, and these impacts can be readily mitigated (Webler & Jakubowski, 2011).

Some scientists believe that even a single contact with the reef by a diver or snorkeler can cause a syndrome called "Shut Down Reaction" where tissues covering the coral skeleton slough off (Antonius, 1985). Hall (2001) found that minor human contacts damage the protective layer of tissue that covers the coral. Such tissue damage leaves coral more susceptible to algae colonization, which then collects sediment and can ultimately smother the corals (Walker & Ormond, 1982). Coral diseases caused by snorkeler or diver inflicted tissue loss can lead to shifts in the type, diversity, and percentage of corals that occupy reef ecosystems (Hawkins & Roberts, 1997). If human behaviors could be managed correctly, corals may be more capable of handling other stresses and thus less vulnerable to them (Gardner et al., 2003).

This research develops and demonstrates a method to characterize the vulnerability of coral reef resources in Puerto Rico to snorkeling by documenting exposure levels, sensitivities, and adaptive actions and applying this methodology at popular snorkeling reefs in La Cordillera Nature Reserve, Puerto Rico. These findings build a strong understanding of human impacts from snorkeling, which can support policy actions and educational opportunities that can reduce the vulnerability of coral reef ecosystems to this recreational activity.

3.2 Background

3.2.1 The Decline of Coral Reefs in the Caribbean

Coral reef ecosystems in the Caribbean have been declining for at least the last forty years, although pinpointing the beginning of the decline has been difficult (Appeldoorn et al., 2009). Scientists have documented early warning signs since the 1970s with the loss of elkhorn coral (*Acropora palmata*) and the loss of the long-spined black sea urchin (*Diadema antillarum*) in the 1980s, both from epizootics (Lessios et al.,1984). In the 1990's severe declines in several reef fishery catches were also documented (Appeldoorn et al.,1992). However, during this time, most of the coral reef research that had taken place in Puerto Rico focused on coral community characterization, monitoring programs, coral diseases, and environmental impact assessments (Garcia-Sais et al., 2008). To date, no research has been done on tourism activities, even though Puerto Rico's Coral Reef Management Plan, developed by coral reef managers from Puerto Rico does prioritize the study of recreational use at reefs as one of its top eight priority goals. This includes the development of strategies to reduce impacts from recreational use, protect the health of coral reefs, and enhance coral reef resilience.

3.2.2 Tourism in Puerto Rico

Despite their decline, coral reef ecosystems play an important economic role in Puerto Rico's tourism industry. This is reflected in the number of people who visit the island, the demand for services, and the number of people employed by the industry. The island has a population of 3.7 million residents and yet it receives more visitors each year than the number of residents. Approximately 5 million visitors traveled to Puerto Rico in 2015, an increase from 4.4 million in 2014. This contributed four billion dollars to the economy. Hotel development increased by 15% in the last decade and tourism- related employment increased by 81% between 1985 and 2010 (Hernandez-Delgado et al., 2012). While extensive growth is occurring in the industry, the effect of tourism and recreational misuse upon coral reef systems on the island of Puerto Rico is not well understood (Garcia-Sais et al., 2008).

3.2.3 Snorkeling at Coral Reefs

Snorkeling is a popular tourism activity around coral reefs in Puerto Rico. In general, it tends to be popular with tourists since it requires no formal classes, training, tests, or certifications. The activity requires a mask, snorkel, fins, and a minimum amount of swimming skill. Some individuals may choose to wear a flotation device if they do not know how to swim or want to feel more secure in deep water. Snorkelers can spend a good amount of time at the water's surface, effortlessly viewing fish, coral, and other marine organisms without having to lift their head for air. For these reasons, organized snorkeling trips are rather popular in Puerto Rico, especially for those interested in seeing marine life but have little experience. Most tourists are eager to at least give it a try. The increasing trends in activity-based marine vacations serve as a good indicator that more people are snorkeling each year at tropical destinations (Goodhead & Johnson, 1996). While it is hypothesized that the number of snorkelers far exceeds the number of divers visiting coral reef ecosystems, statistics to support this hypothesis are not available (Barker, 2003). And while some research has been done on the impact that divers have on coral reefs (Barker, 2003; Medio et al., 1997; Prior et al, 1995; Rouphael & Inglis, 2001) even less is known about the impact that snorkelers have on these ecosystems.

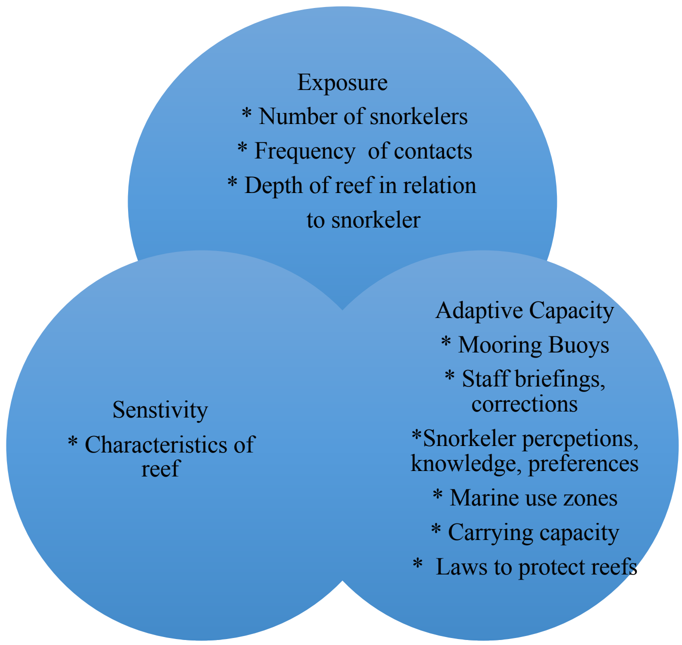
3.2.4 Vulnerability

Knowledge about the relative vulnerability of specific reefs to damage from snorkeling within Puerto Rico is necessary for informing and prioritizing management and conservation decisions for the tourism industry. Vulnerability is defined as the state of susceptibility of harm from exposure to stresses associated with environmental and social change (Adger, 2006). Vulnerability research consists of three main components - exposure, sensitivity and adaptive capacity (Adger, 2006; Gallopín, 2006). Gallopín (2006) defines exposure as the “degree, duration and/or extent into which the system is in contact with, or subject to, the perturbation.” Sensitivity is, “the degree to which the system is modified or affected by an internal or external disturbance or set of disturbances. Adaptive capacity is “the system’s ability to adjust to a disturbance, moderate potential damage, take advantage of the opportunities, and cope with the consequences of a transformation that occurs” (295 – 296).

Determining the vulnerability of coral reefs to recreational activities includes measuring the exposure of reefs to recreational snorkelers, characterizing the sensitivity of reefs to potentially harmful snorkeler behaviors, and characterizing the adaptive capacity of the system by examining opportunities to influence management options (Figure 3.1). In the context of this research, exposure refers to the number of potentially harmful actions that recreational snorkelers can do to inflict harm on coral reef ecosystems as well as the spatial relationship between the snorkeler and the reef. Qualities that make some corals experience more harm when exposed to the same stressor (the snorkeler) include the morphology of the coral and the topography of the reef. Adaptive actions in this case refer to decisions and actions taken by a variety of individuals connected to the tourism industry and the knowledge, perceptions, and behaviors of snorkelers. For instance, the government can decide to install mooring buoys or not. Vessel captains can decide which reefs to visit and where to moor. The crew of the vessel decides how to prepare tourists for the snorkel experience. Finally, a snorkeler can decide to behave responsibly while at the reef or not.

Figure 3.1

Vulnerability assessment for snorkelers around coral reef ecosystems



Note. The components of a vulnerability assessment for recreational activities includes measuring exposure to snorkelers, characterizing the sensitivity of reefs, and characterizing the adaptive capacity of the system.

The use of indicators can provide a framework for measuring vulnerability that can provide both quantitative and qualitative insights into the outcomes and perceptions of vulnerability (Adger, 2006). The choice of indicators to use when analyzing exposure, sensitivity, and adaptive capacity in a specific context depends on the vulnerability of whom to what (Alwang et al., 2001; Carpenter et al., 2001; Rygel et al., 2006). For assessing the vulnerability of select reefs to snorkeler behaviors, inductive indicators will be utilized in this research for two reasons. First, the system can be described using several (but not many) variables. Second, sufficient data are available to indicate the variable and the potential harm. For example, one can induce that the variable "number of fin kicks to a coral" can indicate harm since it increases the incidence for breakage.

3.3 Review of Literature that Focuses on the Exposure of Coral Reefs to Snorkeling Activities

3.3.1 Carrying Capacity

Carrying capacity of an ecosystem refers to the maximum level of recreational use (in terms of numbers of people and activities that can be accommodated by an area) before an unacceptable or irreversible decline in ecological values occur (Inskeep,1991; Jameson et al.,1999; Pigram & Jenkins, 1999). Research in many parts of the world has identified a correlation between the number of visitors to a reef and the degradation of reef conditions, supporting the claim that recreational activities can be a serious threat to coral reefs (Allison, 1996; Hawkins & Roberts, 1992; Kay & Liddle, 1989; Krieger & Chadwick, 2013; Liddle, 1991; Liddle & Kay, 1987; Plathong et al., 2000; Prior et al., 1995; Riegl & Velimirov, 1991; Tratalos & Austin, 2001). Up to a certain level of activity, snorkel impacts appear to be minor, but beyond some “critical level” those impacts quickly become significant (Burgett, 1990; Davis & Tisdell, 1995). The controversial and difficult challenge is to identify critical levels and attempt to limit snorkelers to a number below that threshold.

For example, the daily use by thousands of visitors has left the near shore reefs in Hanauma Bay, Hawaii mostly dead (Wells & Hanna, 1992). Prior to the establishment of a beach road in the 1950s, the reef ecosystem was used for traditional food gathering. With a road in place, a number of private tour operators started to run tours to the bay for snorkeling excursions and fish feeding. This use led to an improved road, parking lots, restrooms, and picnic facilities. The rapid rise in the number of tourists due to these infrastructural changes resulted in the area exceeding 10,000 visitors per day (Burgett, 1990). Other reefs in other areas of the world have suffered this same fate. Researchers recommended Hanauma Bay’s carrying capacity be set at

1,000 visitors per day but this management guidance was never enforced (Burgett,1990). Some consider Hanauma Bay a “sacrifice area” defined as a location where the mass tourists can be channeled to concentrate their negative effects (Orams,1999).

There is little research on carrying capacities for snorkelers at coral reefs. Some researchers have suggested that it is problematic to determine the actual carrying capacity for a specific reef due to the need to manage these resources over long time periods while the rate of growth of recreational demand is extremely rapid (Prior et al., 1995). However, the carrying capacity of a coral reef will depend strongly on the behavior of people participating in snorkeling activities. For example, Hol Chan Marine Reserve in Brazil receives approximately 50,000 visitors per year. Researchers conducted a study to determine the factors leading to unacceptable tourism impacts within the Reserve. Methods included following groups and recording behavior and impacts as well as asking visitors to complete a questionnaire to find out what information they are learning from guides and how they report their group's behavior. The study revealed that limiting numbers would be difficult and not the most effective solution. It also revealed that behavior modification and education were the most important factors in decreasing the impacts of tourism (Green Reef Environmental Institute et al., 2002).

The types of snorkeling activities occurring at coral reefs need to be considered. Snorkel activities can be classified as consumptive or non-consumptive. Consumptive activities by snorkelers include collecting shells, coral, and fish, activities that affect carrying capacity since such actions deplete important resources. Non-consumptive activities, such as wildlife watching, free-diving, and photography can also have a direct impact on the reef (Spalding et al., 2017). All activities and reef characteristics should be factored into determining carrying capacity of a site and include the morphology, topography, and size of the reef.

3.3.2 Direct Observation of Snorkeler Behaviors which Result in Coral Contacts

Research on the contacts that snorkelers make with coral reefs is scarce. A contact is defined as any part of the snorkeler or equipment touching the reef. Barker (2003) did the only in-situ empirical study of snorkelers. She observed 180 snorkelers in St. Lucia, following them from the time they entered the water until they exited. 20.6% contacted the reef with a frequency of 0.05 contacts per minute. Finning caused the greatest number of contacts (97%), followed by hand touches (1%). The highest rates of contact occurred at the beginning of the trip in shallow water. Snorkelers using cameras contacted reefs twice as much as those without cameras.

3.3.3 Snorkeler Threats to Reefs - Sedimentation

Snorkelers standing, sitting, kneeling or kicking sandy bottoms can cause the re-suspension of sediment. This exposes coral polyps to additional sedimentation loads (Neil, 1990; Rogers,1990; Zakai & Chadwick-Furnam, 2002). Talge (1990) observed snorkelers in the Florida Keys and found that they tread water often. This action stirs up large clouds of sediment. Sedimentation reduces growth and reproduction in coral reef species (Hawkins & Roberts, 1994; Nemeth & Nowlis, 2001; Richmond, 1996). Coral polyps that are constantly exposed to sedimentation expend a great deal of energy to rid the colony of particles instead of using this energy for growth and reproduction (Dodge et al., 1974; Richmond, 1996; Rogers, 1990). This can lead to a decline in coral cover, change of coral communities, and increased partial mortality (Rogers,1990).

Suspended sediment particles in the water column decrease light penetration. Light is a necessary component for the symbiotic algae that live with corals since it provides the chemical energy necessary for photosynthesis. Sediments that land on coral can also disrupt the exchange of gases necessary for photosynthesis. Barker (2003) observed snorkelers on St. Lucia and found that sedimentation rates were highest at shallow shore entries, when snorkelers adjusted their equipment, and when snorkelers were vertical but would gradually decrease with increasing distance from shallow entry.

3.3.4 Snorkeler Threats to Reef - Scratching/Abrasions

Scratches or abrasions on corals that are caused by snorkelers are considered direct mechanical damage (type 1 damage). Type 1 damage may expose corals to type 2 damage defined as an infection, disease, or tissue loss that results from other opportunistic marine organisms. Organisms that cause type 2 damage include algae, barnacles, microscopic pathogens, crown-of thorns stars, brittle stars, and various species of fish (Riegl & Velimirov, 1991). Hawkins and Roberts (1992) studied coral reefs in Palau, Malaysia and found that broken, abraded, and damaged corals were more likely to be infected by type 2 damage by pathogenic organisms. In addition, coral reefs were less likely to recover from such invasions and had a higher risk of mortality when impacted by both type 1 and type 2 damage (Hall, 2001).

3.3.5 Depth of Coral in Relation to Walking, Standing, Kneeling or Sitting on the Reef

Shallow water reefs and reefs exposed at low tide are vulnerable to people walking on them and thus trampling the polyps (Barker, 2003; Hawkins & Roberts,1993; Kay & Liddle, 1989; Woodland & Hooper, 1977). The major concern is that trampling damage is cumulative and, as more snorkelers partake in these activities, coral survival rates will decline. These shallow areas suffer from more damage especially when they serve as snorkel entry points (Barker, 2003; Kay & Liddle,1989).

In the US Virgin Islands, Rogers (1990) monitored 50 marked corals at a shallow water reef used by snorkelers over a 7- month period and found that 90 percent of individual corals were disturbed from trampling. In Hawaii, Liddle and Kay (1987) found that the initial phase of trampling caused the most damage, branching corals were broken first, and additional damage to other species accumulated rapidly.

3.4 Review of Literature that Focuses on the Sensitivity of Coral Reefs to Snorkeling Activities

Sensitivity refers to qualities of the human-natural system that make reefs experience disproportionate harm when exposed to the same stress. The literature provides evidence that two qualities of reefs are instrumental in shaping sensitivity to visitor contact: topography and morphology.

3.4.1 Reef Topography

The topography of a snorkel site plays an important role in determining how often a snorkeler may contact the reef. This comes into play in two ways. First, topography can attract snorkelers to swim in tighter places and, therefore, produce more opportunity to accidently contact coral. Second, snorkelers are inspired to spend more time visiting the portion of the reef that has varied topography. Sites typified by plateaus have a higher rate of contact than other sites (Barker & Roberts, 2004). Salm (1986) found that when people dive or snorkel over homogenous, flat, shallow reefs, they are more likely to cover greater areas since they are limited in opportunities to explore the reef. However, a group of snorkelers swimming over corals with an irregularly shaped topography, will have more options to explore and greater diversity to view, most likely spending more time around a smaller percentage of the reef.

3.4.2 Reef Morphology

Reef morphology, the form and structure of coral species, plays a significant role in determining the vulnerability of the reef to physical damage (Table 3.1). These sessile invertebrates can be ranked according to how susceptible they are to structural damage

(Chadwick-Furman, 1997). Fragile, branching corals (hydrocorals) are among the first to be broken when exposed to physical contacts from humans or equipment (Liddle,1991; Liddle & Kay,1987). These corals are also the most vulnerable to breakage by natural causes which includes strong storms and predation (Chadwick-Furnam, 1997). Thin branching corals that have secondary branches are also more susceptible to breakage. Intermediate ranked vulnerable corals include thick and stubby branching coral, columnar, foliose, and soft coral. Hard branching coral species tend to have a slower growth rate compared to soft corals. However, soft branching corals may be more sensitive since they move with the water current, possibly increasing snorkeler contacts (Fox et al., 2003; Hall, 2001; Sheppard & Loughland, 2002; Stobart et al., 2005).

Encrusting corals and stony corals are classified as the least vulnerable. Encrusting species have a major advantage, over their branched relatives since they remain close to the substrate they are encrusting. Massive stony corals are classified as the least vulnerable to damage most likely because of their dense skeletons and lack of branching structures (Chadwick-Furman,1997). Boulder-shaped coral are seldom damaged by strong wave action unless they are dislodged from their holdfasts (National Ocean Service, 2016).

Table 3.1

Coral categories by morphology

Coral Categories	Morphology	Sensitivity	Taxonomy Groups & Examples
Massive (Boulder) Coral	Characteristically ball or boulder-shaped and relatively slow growing. Can be egg size or as large as a house.	Stable, seldom damaged by strong wave action unless dislodged from its holdfast.	*Faviidae* (Brain coral)

Table 3.1 (continued).

Encrusting Coral	Low spreading forms that usually adhere to hard rocky surfaces. Grows larger in diameter versus upward like many other forms of coral.	Major advantage over branching relatives since they remain close to the substrate they are encrusting; can withstand high wave activity.	*Astrocoeniina* (Star coral, fire coral)
Branching Coral (Thick)	Exceptionally thick and sturdy antler-like branches, usually fast growing with branches increasing by 5 – 10 cm per year.	Typically found in areas of high wave activity.	*Acroporidae* (Elkhorn)
Branching Coral (Stubby, finger-like)	Irregular, stubby branches with blunt and enlarged tips.	Stubby branches can withstand wave activity.	*Poritidae* (Finger coral)
Soft Corals	Lack hard, rigid, permanent skeletons various branches, stalks.	Move with water current which can increase sensitivity.	*Anthothelidae* (Gorgonians, sea fans)
Foliose Coral	Whorl-like growth structures that have been compared to the open petals of a flower.	Folds and convolutions greatly increase its surface area which can result in increased exposure to mechanical damage.	*Fungiida* (Lettuce coral)
Columnar Coral (Pillars)	Digit-like, columns	When exposed to storm conditions is much more susceptible to breakage.	*Meandrinidae* (Pillar Corals)
Table Coral	Broad horizontal surfaces. Pattern of growth increases the exposed surface area of the coral to the water column.	Increased surface area can result in increased exposure to mechanical damage.	*Fungiida* (Sheet coral, Saucer coral)

Table 3.1 (continued).

Branching Coral (Thin)	Branches that also have secondary branches	When exposed to storm conditions, are much more susceptible to breakage.	*Acroporidae* (Staghorn)
Branching hydrocorals	Colonies form multiple branching structures in all directions, will encrust and take on shape of other coral.	When exposed to natural conditions, (water motion) are most sensitive to breakage.	*Millepornina* (Hydrocorals, lace corals)

Note. Coral morphology, the form and structure of coral species listed from least to most sensitive, plays a significant role in determining the vulnerability of the reef to physical damage. Coral descriptions are from National Ocean Service (2016).

Three studies examined the impacts that snorkelers have on reefs and all found a correlation between heavily used snorkeling areas and an increase in the number of broken and damaged corals. Gil et al. (2015) collected data over three years on the benthic community as well as coral and algae cover to examine the effect of intensive tourism on corals in Akumal Bay Mexico. The number of snorkelers recreating in the Bay increased by 400% while coral cover decreased by 79% in the areas with the largest number of snorkelers. Observation of the benthic community found that snorkeling had a negative effect on certain coral morphologies and the number of herbivorous fishes decreased. Mounding corals were more resilient to contacts than branching and plating corals. At the North Male Atoll in the Maldives, Allison (1996) measured recently broken corals along transects and the spatial distribution of snorkelers using swim and shoreline surveys. He found that breakage correlated to snorkeling activity (R^2=0.69, p=0.0014). Allison also discussed that more damage was done by less competent snorkelers, when partners stopped together, and when standing snorkelers were jostled by waves.

Breakage rates were highest at sites with easy access for snorkeling as well as an abundance of branching and thus breakable coral colonies. The greatest coral breakage was found in the area referred to as snorkeler channel (where a majority of skilled and inexperienced snorkelers congregated and stood on corals) (Allison, 1996).

Plathong et al. (2000) examined the effects of underwater trails on coral reef flats in the central section of the Great Barrier Reef Marine Park in Australia. They monitored changes in benthic life forms associated with two highly used snorkeling trails, two unused trails, and two undisturbed trails. They found that the use of snorkeling trails caused large, significant changes in the number of broken and damaged corals. Observations determined that coral damage was always at least six times greater along the actively utilized trails than along the unused trails. By monitoring trails that only differed by the presence or absence of snorkelers, the researchers were able to show that greater than 95% of the damage was caused by snorkelers.

3.5 Adaptive Actions that Mitigate Exposure

Adaptive capacities are the skills, experiences, strategies, and resources that are needed to implement actions that can reduce vulnerability (Smit & Wandel, 2006). These "adaptive actions" can reduce exposure, change sensitivity, or alter the human-natural system. Such measures can protect reefs in priority areas while still promoting tourist activity. Decision makers who take adaptive actions that shape the vulnerability of coral reef ecosystems in Puerto Rico include: The Department of Natural and Environmental Resources, The Puerto Rico Tourism Company, tour operators (including owners, captains, and staff), and the snorkelers themselves.

3.6. Snorkel Tour Operators

In La Cordillera, bringing visitors to snorkel at coral reefs is an important business. There are at least eight large catamarans that leave from Fajardo (Figure 3.2) daily, during the high season, bringing hundreds of visitors to several possible reefs within the reserve which includes Icacos Island, Lobos, Tortugas, and Palominos Island. The decision of where to go is largely left to the captain and is a key element in determining the exposure of reefs to visitors and, therefore, understanding the vulnerabilities of these systems.

The crews of these vessels also shape the exposure of the reef to visitor contacts. They orient visitors to the reef, provide a snorkel lesson, give instructions for how to experience the reef, encourage or discourage types of behavior, and provide oversight and correction.

3.7 Visitors Who Snorkel

Visitors include residents of Puerto Rico and tourists. At the reef, visitors make decisions that shape the exposure of the reef to harmful actions. They decide where and how long to snorkel or dive, how to manage their movements in the water (snorkelers may intentionally stand on the reef to clear their mask or hold on to the reef to take a photo), and they decide whether or not to engage in activities such as fish feeding or collecting. A diver or snorkeler’s views on the conditions of the reef (water visibility, diversity of marine life, health of the reef) have also been useful for management strategies (Klint et al., 2012; Lucrezi et al., 2013; Musa, 2002).

3.7.1 Values, Beliefs, and Norms of Snorkelers

There have only been a few studies that examined the values, attitudes, intentions, and personal norms of divers and snorkelers towards coral reefs in recreation and tourism settings. Loomis et al. (2008) studied the behavioral norms of snorkelers in the Florida Keys and found that most snorkelers felt they had a strong obligation to never break off or take pieces of coral. Most snorkelers felt they had an obligation to pick up garbage from the sea floor. Loomis et al. (2008) stated that these findings suggest that snorkelers recognize the value of coral reefs and feel a willingness to protect the coral even at the expense of having to correct someone else.

Needham et al. (2010) tested the value orientation of close to three thousand recreationists at three specific coral reef sites in Hawaii. Recreationists included divers, snorkelers, surfers, sunbathers, and swimmers. He found that the largest number of users had strong protectionist orientations. No one surveyed had only an anthropocentric orientation towards the reef. There was no correlation between site selection, age, or residency and value orientation. However, Needham et al. (2010) did find that females, snorkelers, swimmers, and sunbathers had stronger protectionist value orientations towards the reef.

3.7.2 Snorkelers and Recreation Specialization

Recreation specialization is defined as a temporal linear progression in an activity performed by outdoor recreationists (campers, anglers, snorkelers) in which participants move from general interest and low involvement to specialized interest and high involvement (Bryan, 1977). Each level of specialization involves distinctive behaviors and skills and includes other factors such as equipment preference, type of experiences sought, desired setting for the activity, attitudes toward resource management, preferred social context, and vacation patterns (Loomis et al., 2008).

Loomis et al. (2008) found that specialized snorkelers have a greater financial and emotional investment in snorkeling as a recreational activity and, as level of specialization in snorkeling increases, frequency of participation in the activity will also increase. However, snorkelers had very little variation in the types of sources they utilized to gain additional information including where to snorkel and how to improve one’s skills. Loomis et al. (2008) also found that information about snorkeling was not intentionally sought out regardless of specialization level.

Snorkelers reported talking to other snorkelers as their only source of information sharing. They attributed this to the lack of training or certification needed to snorkel.

3.7.3 Snorkeler Interventions

Webler and Jakubowski (2016) developed a coral reef etiquette message for snorkelers to view before boarding a vessel. Puerto Rico's Coral Reef Conservation Local Action Strategies emphasize messaging to discourage negative behaviors but when evaluated were found to be inconsistent with social science theories of behavior and behavior change. For example, none of the messages referred to self-efficacy - the ability of snorkelers to avoid doing harm. They also contradicted descriptive social norms by showing images associated with improper behavior (e.g. garbage on the reef, motor boats scarring the reef). New coral reef etiquette video messages were developed based on the Value-Belief-Norms (VBN) theory (Stern et al, 1999, Stern 2000) and the Theory of Planned Behavior (Ajzen, 1991) (Table 3.2). As many variables from both theories were included.

Table 3.2

Examples of reef etiquette messages

Message	Value, Belief, Norm Component
Snorkelers come to Puerto Rico to experience its remarkable coral reefs.	*Asserts positive environment *Attitude towards reefs
Of course, we would never deliberately do anything to hurt marine life.	*Reinforcement of benevolence
However, even experienced snorkelers can accidentally impact the reef. Here are a few things you need to know about how snorkelers can affect coral reefs and suggestions for practicing good reef etiquette.	*Awareness of consequences

Table 3.2 (continued).

Corals build a strong skeleton but their "skin" is fragile. Even the lightest touch with your hands or fins can damage sensitive coral.	*Awareness of self-consequences
Keeping a little distance from coral reefs and sea life helps ensure your safety and protects the reef!	* Self-efficacy
Some corals can burn. Keep your distance.	* Awareness of consequences
Some animals that live in the reef can bite or sting.	* Awareness of consequences
Waves and currents can push you into reefs resulting in scrapes, bruises, and cuts.	* Awareness of consequences
For all these reasons, it's a good idea to keep a little space between you and the reef.	* Prescriptive norm to protect oneself
Coral is not like grass, it will die if you stand on it.	* Awareness of consequences
Any silt your fins kick up can land on coral, smothering it over time.	* Awareness of consequences
Photographers can get clear and colorful pictures without holding on to the reef. Calm and slow movements are less likely to startle fish and result in great pictures.	* Self-efficacy
Leave sand, empty shells or bits of deal coral.	* Prescriptive norm
Coral reefs need these non-living resources to remain vibrant.	* Prescriptive norm

Note. Messages developed by T. Webler and K. Jakubowski (2016) based on the VBN (value, belief, norm) Theory of Environmental Change.

After watching the video, Webler and Jakubowski (2016) asked people to read and sign a pledge stating their commitment to specific behaviors (Table 3.3). Commitment techniques have been shown to be effective in promoting a diverse variety of behaviors (McKenzie-Mohr & Smith, 1999). Specifically, written commitments have been found to be more effective then verbal commitments (Pardinie & Katzev,1983).

Table 3.3

Coral reef pledge stating commitment to specific behaviors around coral reefs

Most visitors to coral reefs never touch, kick, or stand on the coral. They are careful not to stir up the sand near the coral with their fins. Coral are fragile and, if injured, are slow to recover. Keeping a safe distance from the reef is the best way to ensure these beautiful reefs are here for future generations. If you need to fix your mask or snorkel, it is best to swim away from the reef first. ***I pledge to be a responsible visitor*** *to the reef by:*

- *Being aware of where my fins are at so I don't kick the coral*
- *Treading water instead of standing on the reef*
- *Not stirring up silt near the reef*
- *Keeping a safe distance from all marine organisms.*

Signature *Date*

79 unique individuals were a part of the treatment group who observed the video and signed a pledge. Only 19 potentially damaging behaviors were observed. No one in the treatment group had more than four contacts. 89% of people in the treatment group had no reef contacts. Frequency of potentially damaging contacts for snorkelers in the treatment group was 0.052 contacts per minute, a five-fold reduction from the baseline of 0.26 contacts per minute (Webler & Jakubowski, 2016).

3.8 Methodology

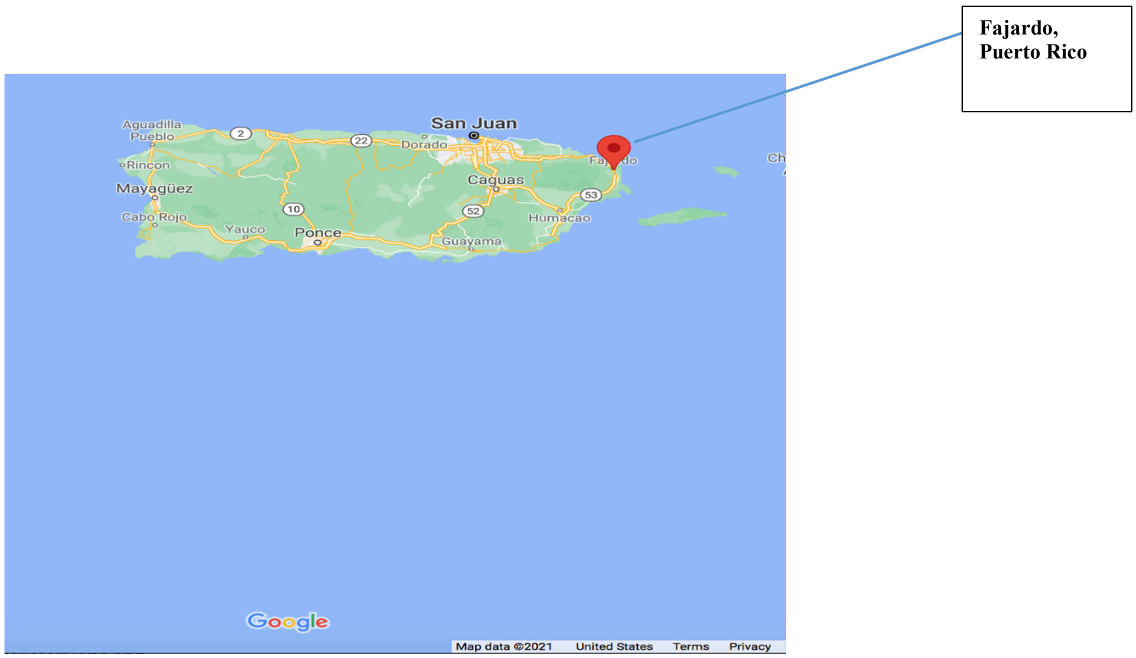
My research included designing a methodology to measure the exposure and sensitivity of coral reefs in La Cordillera Nature Reserve, Puerto Rico to snorkelers, as well as to gain an understanding of the adaptive actions of captains, and crew who make key decisions about which reefs to visit and how to prepare snorkelers for their experience in order to reduce exposure. I then applied and evaluated this approach to select reefs within La Cordillera Nature Reserve.

3.8.1 Study Site

Fajardo, a small city located in the east region of the island, is a popular destination for marine recreational activities (Figure 3.2).

Figure 3.2

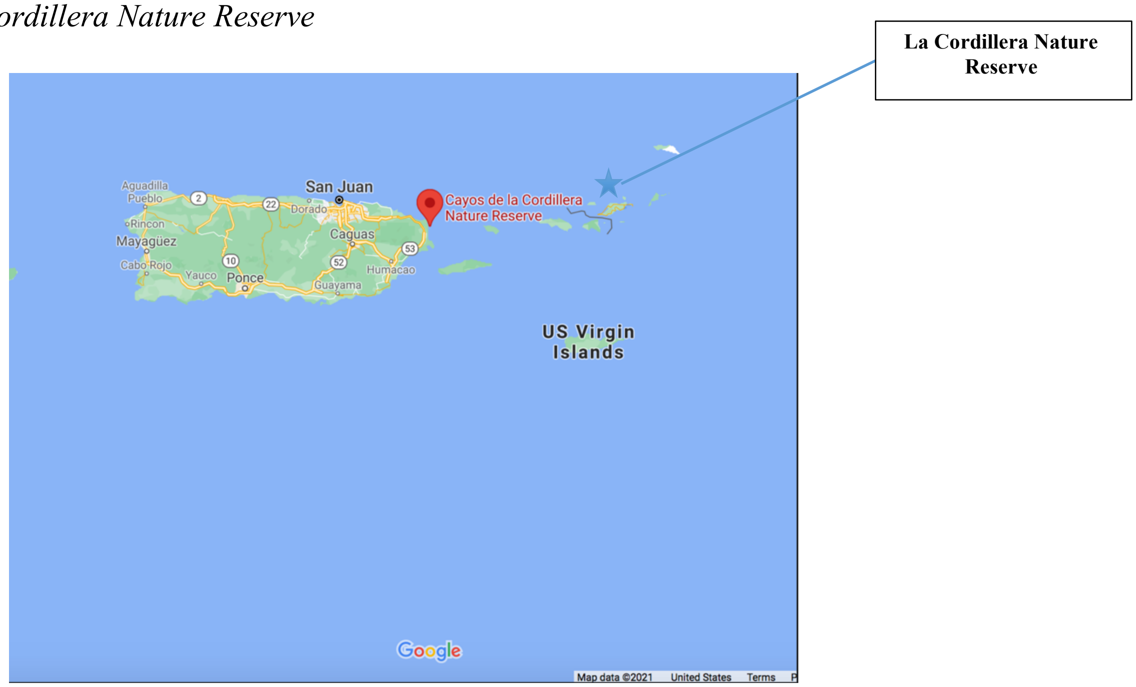
Map of Puerto Rico identifying Farjardo on the northeast coast



Note. Maps Data: Google ©2021

The development of the El Conquistador Hotel in the 1960's launched the tourism industry in Fajardo which now is home to five large marinas, including Marina Puerto del Ray, the largest in the Caribbean. A majority of the registered vessels in Puerto Rico (greater than 65,000) are located in this area. While the tourism industry continues to grow rapidly, the effect of tourism and recreational misuse upon coral reef systems on the island of Puerto Rico is not well understood (Garcia-Sais et al., 2008). Tourism benefits are often measured as economic achievements and not ecological ones. Concerns about ecological degradation are often seen as impeding tourism benefits. In Fajardo, sewage discharge, vessel groundings, anchoring, oil pollution, illegal dumping of garbage, recreational overfishing, and collecting of coral as souvenirs have all contributed to localized coral reef degradation and mortality at the reefs in the waters at La Cordillera Nature Reserve (Figure 3.3) located off the coast of Fajardo (Hernandez-Delgado, 2005).

Figure 3.3
Location of La Cordillera Nature Reserve



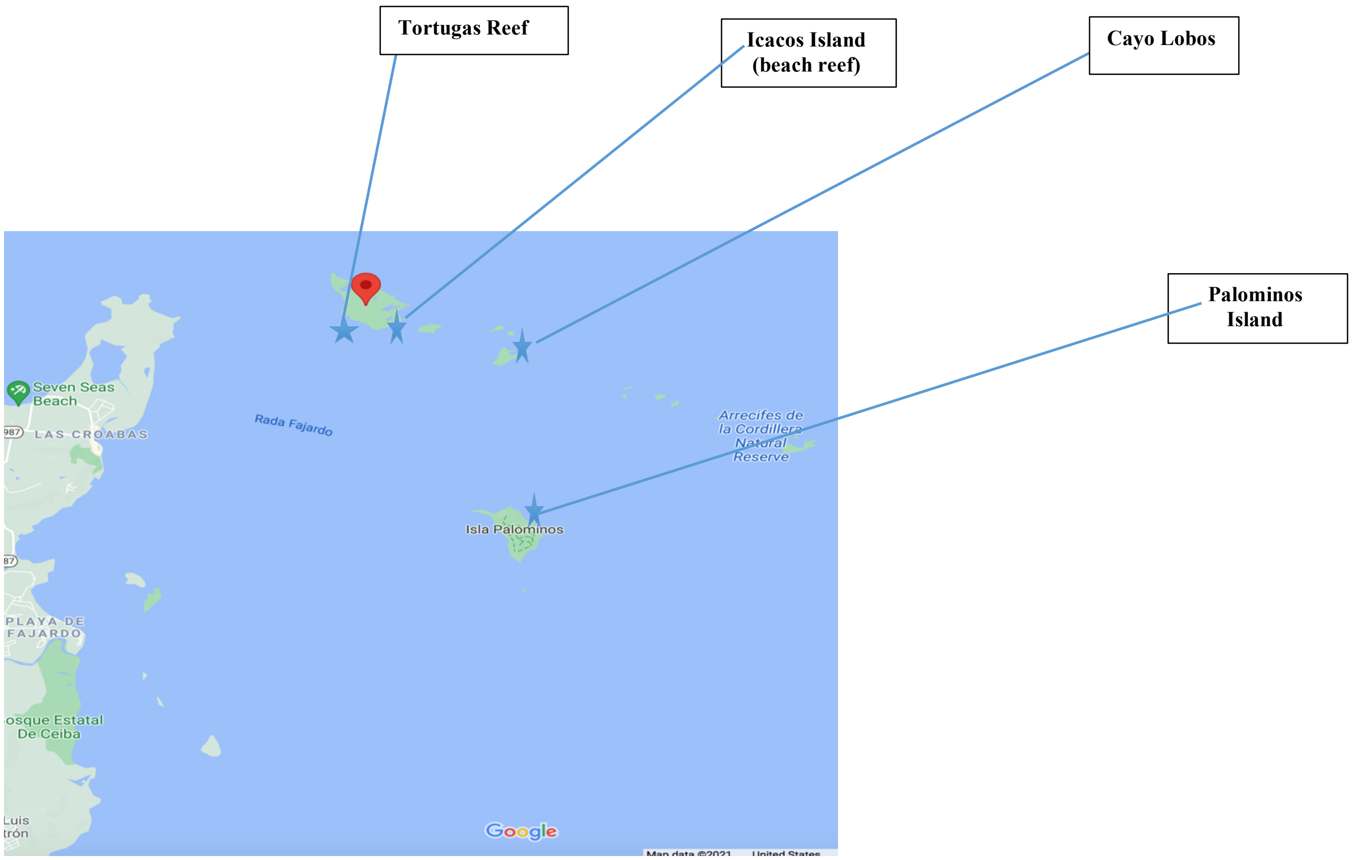
Note. Maps Data: Google ©2021

La Cordillera Nature Reserve (Cayos de la Cordillera Nature Reserve), a chain of ten small islands with reefs, is home to a variety of protected marine life and managed by the Puerto Rico Department of Natural and Environmental Resources. The islands are uninhabited, quiet and secluded. Opportunities for snorkeling, diving, swimming, and sailing are available because the waters are generally calm and clear. There are up to eight large catamarans that leave from

Fajardo daily during the high season, bringing hundreds of visitors to the different islands including Icacos Island, Cayo Lobos, and Isla Palominos (Figures 3.4).

Figure 3.4

Tortugas Reef along Icacos Island, Cayo Lobos, and Isla Palominos



Note. Maps Data: Google ©2021

3.8.2 The Design and Application for Snorkelers

The following variables were measured as part of the design and application for a vulnerability assessment. Exposure included: the types and frequency of contacts by snorkelers, the number of snorkelers over the reef, the duration of time individuals spent snorkeling over the reef, and the depth of the coral in relation to the location of snorkelers. The variables measured for sensitivity included the morphology and topography of the reef. The adaptive actions characterized included crew decisions about snorkeling trips, their attitudes, and believes about coral reefs, and their interactions with snorkelers before entering the water and during the snorkel. Snorkelers' perceptions as well as attitudes and beliefs about coral reefs were also factored into the assessment. Table 3.4 lists the variables designed and measured to complete the vulnerability assessment for snorkelers.

Table 3.4

Variables measured as part of a vulnerability assessment for snorkelers

Vulnerability Assessment	Variable	Measured
Exposure	Number of snorkelers over the reef during the entire time at the reef	10 days of observations from catamarans (5 during the high season and 5 during the low season) to count the number of snorkelers over the reef every five minutes for the duration of the snorkel.
Exposure	Type and number of contacts/per minute/per snorkeler	Random in water observation of 200 snorkelers for a five-minute period to record the number, type, and severity of contacts with the reef.
Exposure	Reef Depth	Record depth every five meters along five randomly selected 30-meter line transects through the area of the reef where most of the snorkeling activity took place.
Sensitivity	Reef Topography	Five randomly selected 30-meter line transect videos established through the area of the reef where most of the snorkeling activity took place to characterize reef as either plateau, slanting, varied, or wall.

Table 3.4 (continued).

Sensitivity	Coral Morphology	Five randomly selected 30-meter line transect videos established through the area of the reef where most of the snorkeling activity takes place. Coral based on its structural morphology from less vulnerable to more vulnerable – 10 categories: massive boulder corals, encrusting coral, branching coral (thick), branching coral (stubby), soft corals, foliose coral, columnar coral (pillars), table coral, branching coral (thin), branching hydrocorals
Adaptive Action	Staff Decisions	Key informants (owners, vessel captains, crew, dive instructors, dive masters interviewed.
Adaptive Action	Operator Briefings	Pre-snorkel briefings given to snorkelers by vessel crew.
Adaptive Action	Snorkeler knowledge, perceptions, and beliefs	100 snorkelers surveyed during the return trip.

3.8.3 Collaboration with Tour Operators

Tour operation owners or managers were approached, the project was explained, and permission to attend snorkel trips free of charge was requested. I explained that I would observe people in the water without their consent or knowledge. I also asked permission to survey tourists on the return sail. Most owners were strongly supportive and allowed me to attend trips as long as there was space available on the vessel. In return I sent each operator a report of our findings for their vessel. A few owners were not supportive, but allowed me to attend if I paid for the trip. On those trips, I made observations of snorkelers in the water, but was unable to survey tourists on the return trip back to port.

3.8.4 Snorkeler Observation Protocol

In developing the in-water observation protocol, I drew on the previous work of Barker (2003), who had made in-water observations of snorkelers. However, little research had been done at the time on observing the behaviors of snorkelers. Dr. Thomas Webler was instrumental in developing and guiding this process. Approximately eight tour operators make daily trips to La Cordillera Nature Reserve (Figures 3.3 & 3.4) each day on catamarans docked at Villa Marina Yacht Harbor or Puerto Del Rey Marina in Fajardo. Operators follow a similar schedule visiting two reefs per day. The first reef is usually Icacos Island beach entry reef which includes beach access, lunch, and time for snorkeling or swimming (away from the reef). The second reef is either (1) Cayo Lobos, (2) Tortugas Reef, or (3) Palominos Island Reef (Figure 3.4). These visits are specifically for snorkeling, swimming around the vessel (not near coral) or remaining on the vessel to relax. There is no beach access at the second reef visited.

3.8.5 Observing Snorkeler Behavior (Types and Frequency of Contacts per Minute)

I boarded the vessel with snorkel tourists in Fajardo, and sailed to the first and second snorkel sites within La Cordillera Nature Reserve. Onboard I kept my purpose and intent private to avoid influencing snorkelers. Data about the snorkeling trip was recorded (Table 3.5).

Table 3.5
Information recorded for each snorkeling trip

Data related to the snorkeling trip
Date
Time of trip
Tour operator
Weather conditions
Briefing (Yes/No)
Number of tour operators and recreational vessels at reef

Once at the reef, tour operators gave a briefing onboard the vessel before snorkelers went into the water. To prevent the staff from changing their behavior with guests or to alter their briefings, I kept the details of my research limited even with the crew. After the briefing and while individuals gathered and donned their gear, I would depart the catamaran in an attempt to be the first in the water. I would wait for the first snorkeler to arrive at the reef. If a tourist asked about my clipboard and data recording sheets, I stated that I was a graduate student collecting data on coral reefs and the fish in Puerto Rico. At the first reef, snorkelers disembarked to the beach, and waded into the water to reach the reef. At the second reef location the vessel moored or anchored and tourists approached the reef from the deep water since shore access to the reef was not an option.

The following protocol was utilized to select and observe snorkelers and the types of behaviors (contacts) observed at the reef. This was developed in order to randomly select individuals and minimize observing the same individual more than once. Only adult individuals wearing fins, mask, and snorkel were observed. Starting with the first individual to begin snorkeling at the reef, I started a timer and followed 1.5 - 2 meters behind the visitor. Using an underwater slate and waterproof, data sheets, I counted and recorded the different types of behaviors observed (Table 3.6). I also recorded identifying information (color of bathing suit, tattoo, or other identifying features) as well as gender so that the individual could be approached to fill out a survey afterwards.

Observations of the individual ended when he or she left the area of the reef or five minutes passed. At the end of each observation period, I would turn right and immediately begin observing the next person in view over the reef. If that individual had already been observed, I would continue turning to the right until a new snorkeler was identified. These data collection and experimental protocols were approved by a Human Subjects Review Committee at Antioch University New England.

Table 3.6

Data collected for each snorkeler observation

Snorkeler observation data
Gender
Personal flotation device (Yes, No)
Use of camera (Yes, No)
Fed fish
Distinguishing characteristic(s) (for follow-up survey)
Number of minutes observed
Types of contacts observed/number of times
Silting
Fin kicks
Standing, sitting, kneeling
Touching coral
Brushing up against coral
Touching other organisms
Picking up organisms, rocks, dead coral
Collecting

The unit of analysis was a snorkeler's behavior for 5 minutes during one snorkel trip. The dependent variables were the frequency, type, and severity of contact with coral or living organisms and intentionality of contact. Contact behaviors examined included seven behaviors that expose reefs to harm: kicking coral with fins, touching coral or other living things with hands, standing/sitting on coral, kicking up sediment near coral, picking up living or dead coral, breaking coral, and collecting.

Behaviors observed were written in code and slashes were made in each coded box for specific behaviors. Several independent variables were recorded including gender, use of a flotation device, and use of a camera. Dispersed in between observations were written the names of fish encountered and corals observed to further disguise my work.

3.8.6 Measuring the Time People Spend Snorkeling at a Reef

To get a measurement of how many people snorkel during a visit to each reef, I conducted a pilot study and attended a total of 10 additional catamaran trips to count individuals snorkeling over the reef. I have defined two sampling periods to capture the number of snorkelers and the duration of time they spend over the reef: November through April (peak tourist season) and May through October (low tourist season). During these trips, I boarded a vessel taking snorkelers to the reef and remained on board to observe and count snorkelers. For safety reasons, crew moor or anchor the vessel at a location which makes it easy to view all snorkelers in the water from onboard the catamaran.

When the vessel was moored or anchored, I started my observations by counting the number of people over the reef at five-minute intervals until the vessel was no longer moored or anchored and departed the reef. I was familiar with the reef locations and could easily tell, from the deck of the vessel, if people were over the coral. All snorkelers (which included snorkelers from other vessels and independent snorkelers), whether in a horizontal or vertical position in the water, were counted if they were over the reef. I also asked crew to estimate the number of snorkelers at a given time in the water and compared these estimates with my observations in order to evaluate the accurateness of my observations. At each snorkel site, I also counted the number of vessels (both tour operators and private vessels at the reef every five minutes for the entire stay).

3.8.7 Design for Measuring the Characteristics of the Reef (for Exposure and Sensitivity) Where Snorkelers Visit

In order to collect data on the relationship between the depth of the reef in comparison to where people snorkel (for exposure), as well as the topography and morphology of the reef (sensitivity), I drew on previous researchers who have collected data on the characteristics of a reef at dive and snorkel locations (Allison, 1996; Plathong et al., 2000; Rouphael & Inglis, 1997).

I selected the two most popular reefs visited annually, Icacos Island (the reef with beach access) and Tortugas Reef (located off the southwest coast of Icacos Island). At each reef, depth was recorded every 5 meters along five randomly selected 30-meter line transects through the area of the reef where most of the snorkeling activity took place. Depths were taken from the surface of the water to the very top of the reef manually using a weighted line marked in 0.5 meter increments. Depths were recorded on waterproof, recording sheets.

The morphology of benthic biota at each of the snorkel sites was described using video transects. Five randomly selected 30-meter line transects were established through the area of the reef where most of the snorkeling activity took place at Icacos Island and Tortugas Reef. The reef coral assemblages beneath each transect line were filmed using an underwater video camera. Snorkeling slowly, video recordings were made from above and parallel to the reef. Video was analyzed to characterize the morphology of coral (Table 3.1) using the classification system of Rouphael & Inglis (1995), Plathong et al. (2000), and the National Oceanic Service's (2016) coral morphology classification system. Corals were classified as one of the following ten categories: massive, branching (thick, stubby, thin, hydrocorals), columnar, encrusting, foliose, table, and soft. Video was also analyzed to characterize reef topography (plateau, fringing, rocky outcrops, varied, or wall). When validation on identification was needed, I consulted with a coral reef scientist (W.H. Schreiner, personal communication, June 2016).

3.8.8 Survey Visitors Using a Survey Instrument to Gather Data on Visitors' Attitudes, Perceptions and Experience

Since visitor satisfaction was anticipated to be a key factor in the decision-making by captains and staff, I surveyed snorkelers. The survey instrument can be found in Appendix A. Survey data were collected by interview (with prior permission of the owner and the captain). On the return cruise, I randomly selected snorkelers to interview by starting with the first snorkeler located at the bow of the vessel, port side. I approached the first snorkeler and asked if he/she would be willing to share that day's snorkeling experiences at the Reserve. I stated that this information would be utilized for the management of the coral reefs within the Reserve. When an interview was completed I continued to move in a clockwise fashion around the deck of the vessel interviewing as many snorkelers as possible during the 40-minute return cruise. The survey questions were a mixture of open-ended and closed questions. The closed questions were answered on a Likert scale and were based on satisfaction with the snorkel experience, as well as perceptions, attitudes, and knowledge about the coral reef ecosystem. Individuals were also asked to self-report on the number of contacts they made with the reef that day, skill level, and experience.

3.8.9 Interview Tour Operators, Captains, and Crew who Make Key Decisions of which Reefs to Visit and How They Prepare Visitors for the Experience of Snorkeling

The crew of snorkel vessels play an important role in the exposure of the reef to visitor contacts. They orient visitors to the reef, give instructions for how to experience the reef, encourage or discourage types of behavior, and provide oversight and correction. Ten face-to-face semi-structured interviews of key informants were conducted. I asked captains, senior crew members, and operation managers if I could interview them. I selected these individuals based on their level of involvement in the decision-making process. Interview questions are included in Appendix B. Interviews took place on the mainland before or after a snorkeling trip. I obtained an informed consent form from each interviewee, which is included in Appendix C. Interviews were voice recorded, transcribed, coded, and analyzed for similar concepts. All personal information was kept confidential.

3.8.10 Snorkeler Briefings

When I attended a trip on a new vessel, I recorded the briefing so I could compare the messages in the briefings. I also listened and took notes on every additional briefing. Briefings were transcribed and compared.

3.8.11 Limitations

Since this is a sample study I only collected data from some of the snorkelers who participated in tour operations in La Cordillera Nature Reserve in Puerto Rico. I may have observed individuals who were snorkeling independently, but the majority were affiliated with a tour operation. I was able to validate this based on gear and personal flotation devices when worn. I did not observe snorkelers at any other reef locations around the island of Puerto Rico. Even on tour excursions, not every snorkeler was observed or asked to complete a survey. I did attempt to make sure that the sample used is representative of the overall population of snorkelers in Puerto Rico. (Stern & Kalof, 1996, 29). To do this I divided the number of days that I observed snorkelers between the peak tourism and low tourism season. A majority of the snorkelers during the peak season (November through April) are non-residents while the low season (May through October) consisted of both non-residents and residents. Although even during the low season, very few snorkelers that I interviewed were residents.

In addition, while I counted eight different tour operator catamarans bringing snorkelers out to La Cordillera Nature Reserve on a regular basis, most of my observations were made from only two catamarans. These two catamarans are larger vessels and often had a spot available for me to participate free of charge (especially during the peak tourist season) while the smaller catamarans usually did not have a spot for a free passenger.

3.8.12 Problems Encountered During this Research

While I did not have observation data on the number of snorkelers taken out to the reef for every day that tour operators make trips, my plan was to compare my direct observational data with the tour operator numbers to postulate an average daily number of snorkelers brought to La Cordillera Nature Reserve on a yearly basis. Despite repeated efforts, I was unable to obtain this information from the individual tour operators or the Department of Natural and Environmental Resources.

3.9 Results

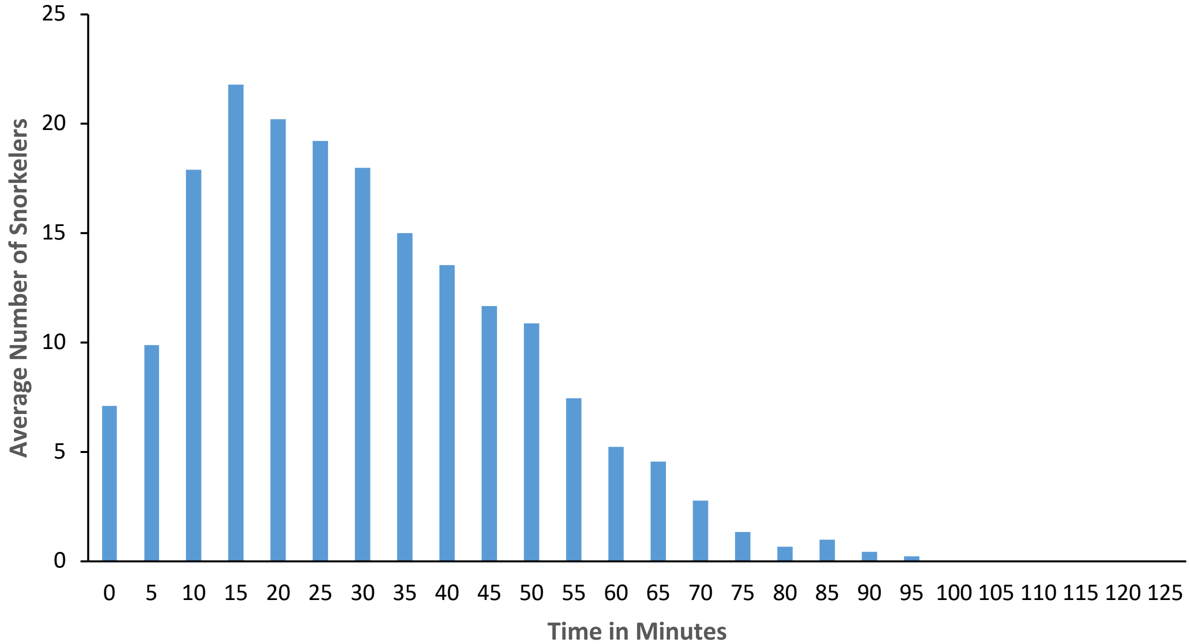
3.9.1 Number of Snorkelers at the Reef

To count the number of snorkelers over the reef, I participated in 10 snorkeling trips, five during the peak season (November – April) and five during the off season (May - October). Tour operators reported that September and October are the slowest months and often use some days during this time period for vessel maintenance. A majority of the operators follow a similar schedule visiting two reefs per day. The first reef is usually Cayo Icacos, a beach entry reef which includes beach access for sunbathing, lunch, and time for swimming. Catamarans depart from the dock at 10:00 am each day. Depending on the weather, water conditions, or need to get to La Cordillera Nature Reserve quickly (in order to secure a mooring during the peak season), captains will use motor and sail (or just motor). The catamarans start arriving at Icacos Island by

10:45 am and the first snorkelers are in the water by 11:05 am. Tour operators spent a mean time of 108 minutes at Icacos Island beach reef. In order to count the number of snorkelers over the reef, I observed the first snorkeler in the water and continued to count snorkelers every five minutes for the duration of the trip. On all ten occasions, I was able to begin my observations before anyone was in the water over the reef. I counted snorkelers affiliated with a tour operator as well as anyone snorkeling who arrived at the reef on a private vessel. The average number of snorkelers at the reef per 5-minute intervals was 6. The highest mean number of snorkelers in the water was at time 15 minutes (21 snorkelers) and then it steadily declined (Figure 3.5). The maximum number of snorkelers observed during one 5-minute period was 27 and the minimum was zero. No snorkelers were in the water after 100 minutes. The average number of catamarans at Icacos Island (beach reef) was three. Captains reported that on certain days during the peak season, holidays, or three-day weekends there are usually seven catamarans each transporting approximately 50 to 80 passengers. On a holiday or holiday weekend there was often over 100 small private recreational boats at Icacos Island. One crew member informed me that during one holiday, she observed approximately 300 snorkelers over the reef at once. Several crew members stated that regardless of how many snorkelers are at the reef, they thought that most spend approximately 15 – 20 minutes snorkeling at Icacos Island.

Figure 3.5

Mean number of snorkelers over the beach reef at Icacos Island



The second reef that operators visit is either Tortugas Reef, or less frequently Palominos Island Reef or the reef at Cayo Lobos. These visits are specifically for snorkeling, swimming around the vessel, or remaining onboard since there is no beach access at the second site (Figure 3.6). The average number of snorkelers at the reef per 5-minute intervals was 18. The highest average number of snorkelers over Tortugas Reef was at time 25 minutes (34 snorkelers) and then it steadily declined (Figure 3.7). The maximum number of snorkelers observed during one 5-minute period was 67 and the minimum was zero. No snorkelers were in the water after 95 minutes. (Figure 3.7). The average number of catamarans at Tortugas Reef was three.

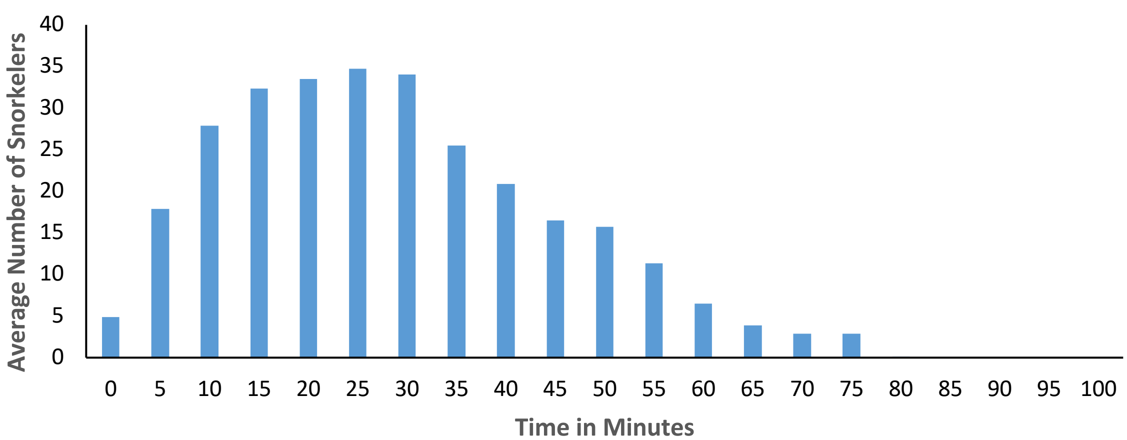
Figure 3.6

Snorkelers at Tortugas Reef

Note. Photograph by K. Jakubowski (2012).

Figure 3.7

Mean number of snorkelers at Tortugas Reef



3.9.2 Snorkeler Characteristics and Behaviors Underwater

289 observations of snorkelers near coral were made in La Cordillera Nature Reserve, for a total of 1342 minutes, with 71% (N = 205) of these observations lasting for a total of 5 minutes. Males comprised 57% (N = 165) of the observations while 43% (N=124) of those observed were female (Figure 3.8). A majority of snorkelers, 70% (N = 202), did not wear personal flotation devices (Figure 3.9). Of those observed, 15% (N = 43) carried or used a camera while snorkeling (Figure 3.10). 7% (N = 20) of snorkelers were observed feeding fish (Figure 3.11).

Figure 3.8

Percentage of male and female snorkelers observed

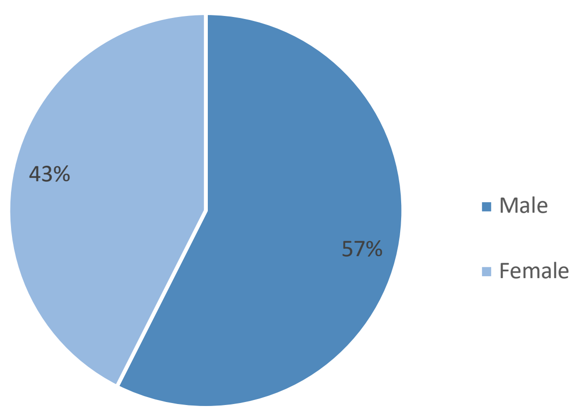


Figure 3.9

Percentage of snorkelers observed wearing a personal flotation device in La Cordillera Nature Reserve

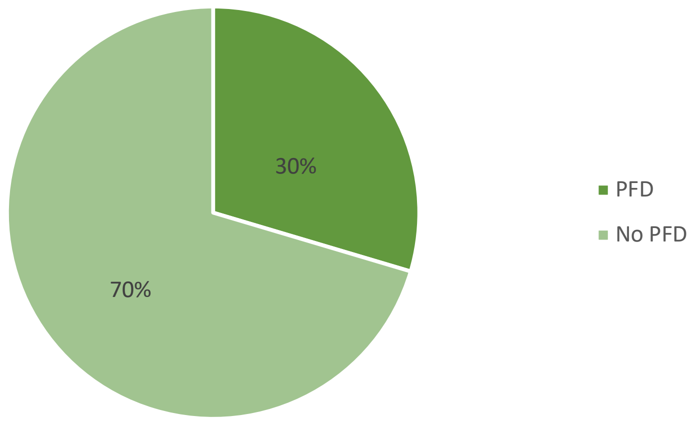


Figure 3.10

Percentage of snorkelers observed using a camera while snorkeling in La Cordillera Nature Reserve

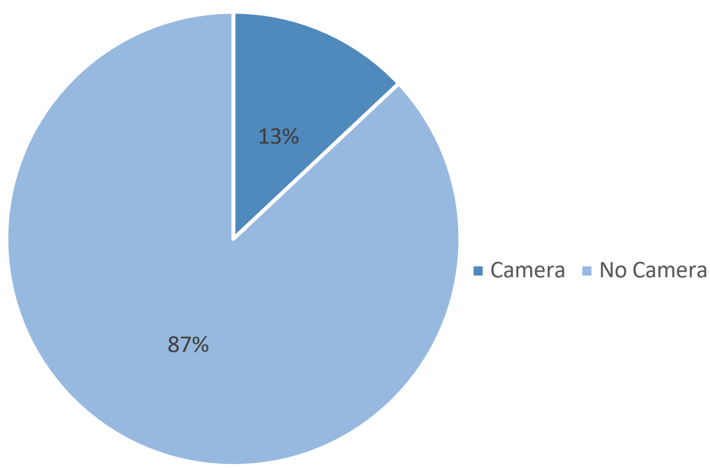
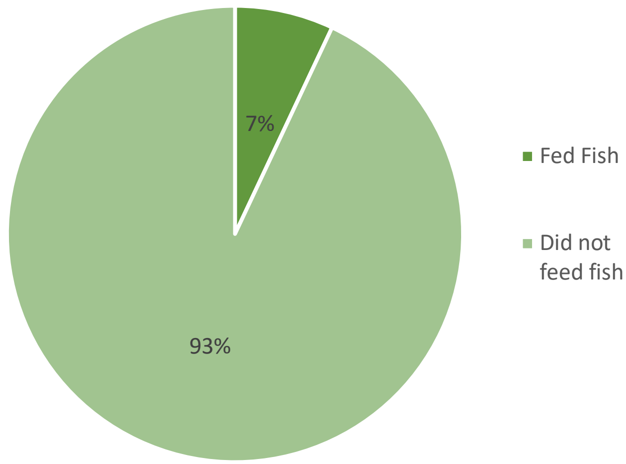


Figure 3.11

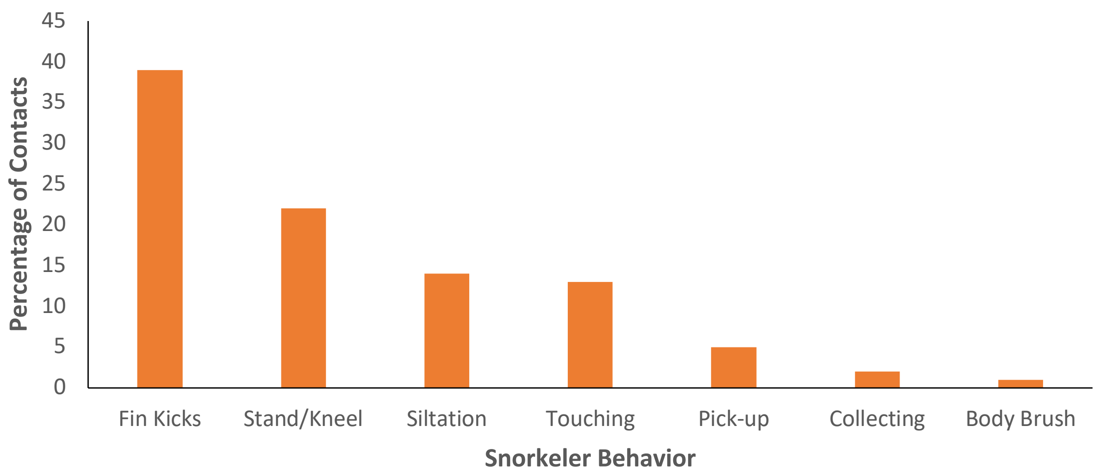
Percentage of snorkelers observed feeding fish in La Cordillera Nature Reserve



A total of 363 behaviors were observed around the corals. A majority of the contacts were the result of fin kicks (39%) (N=142) followed by sitting, standing or kneeling (22%) (N = 80), siltation (14%) (N = 51), touching the reef (13%) (N = 47), picking up marine life (5%) (N = 18), collecting (2%) (N = 7), and brushing up against the reef (1%) (N = 4) (Figure 3.12).

Figure 3.12

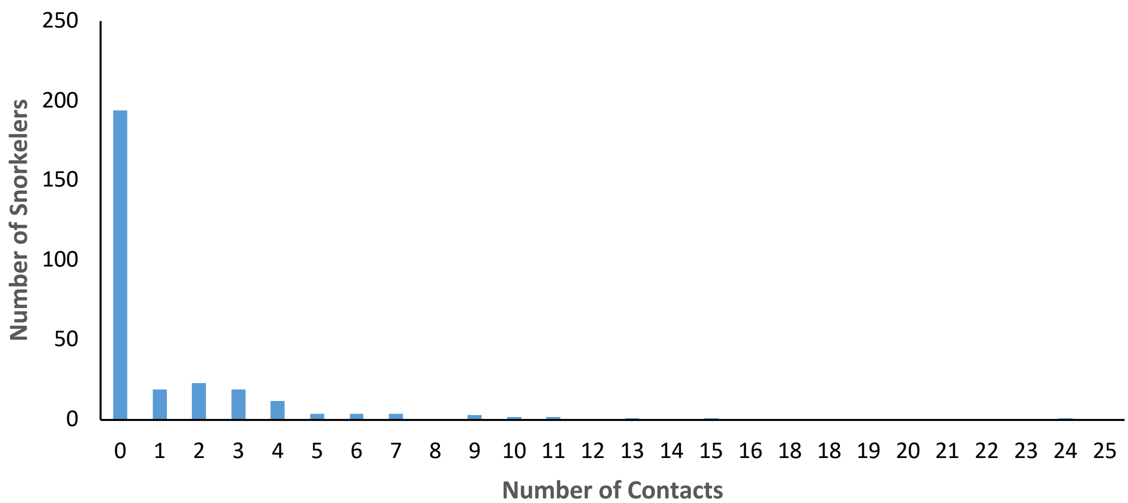
Percentages of specific snorkeler behaviors observed



Overall, 194 of the 289 snorkelers observed (67%) made no contact with the reef. Seven percent of snorkelers had one contact with the reef, 8% (N = 23) had two contacts, 7% (N = 20) had three contacts, and 4% (N = 12) had four contacts. 19 individuals contacted the reef more than 4 times. (Figure 3.13).

Figure 3.13

Snorkeler contacts with the reefs at La Cordillera Nature Reserve



The highest number of contacts (11) was observed in two individuals. The frequency of potentially damaging contacts to living corals for snorkelers in La Cordillera Nature Reserve was 0.27 contacts per snorkeler per minute. Table 3.7 shows that the number of contacts by snorkelers within La Cordillera Nature Reserve, Puerto Rico was 5 times higher than snorkelers in St. Lucia (Barker & Roberts, 2004). Multiple regression analysis using three independent variables (gender, use of a personal flotation device, and camera use) confirmed that males in the group produced a statistically significant higher frequency of contacts when snorkeling than women ($p < 0.05$). There was no statistically significant difference between the contact rates of those wearing personal flotation devices and snorkelers who did not ($p > 0.05$) or between snorkelers using cameras and those who did not ($p > 0.05$).

Table 3.7

A comparison of the contact rates for snorkelers

Study	Location	N	Mean
Barker et al., 2004	St. Lucia	180	0.05
Webler & Jakubowski, 2016	Puerto Rico	289	0.28

Figures 3.14 through 3.21 are images taken of snorkelers at the La Cordillera Nature Reserve exhibiting different contact behaviors at the reefs.

Figure 3.14

Siltation caused by a snorkeler

Note. Snorkeler walking along a sandy bottom near Cayo Icacos beach reef resulting in siltation. Photograph by K. Jakubowski (2012).

Figure 3.15

Fin contacts by snorkelers

Note. Snorkelers contacting a shallow rocky outcrop with coral at Tortugas Reef. Photograph by K. Jakubowski (2012).

Figure 3.16

Snorkeler walking on the reef

Note. Snorkelers walk on the shallow corals at Cayo Icacos beach reef. Photograph by K. Jakubowski (2012).

Figure 3.17

Snorkeler standing on the reef

Note. *Coral at Tortugas Reef.* Photograph by K. Jakubowski (2012).

Figure 3.18

Snorkeler picking up shells at the reef

.

Note. Picking up shells at Cayo Icacos beach reef. Photograph by K. Jakubowski (2012).

Figure 3.19

Snorkeler resting on the reef

Note. Shallow Rocky Outcrop at Tortugas Reef. Photograph by K. Jakubowski (2012).

Figure 3.20

Snorkeler collecting shells at the reef

Note. At Icacos Island (beach reef). Photograph by K. Jakubowski (2012).

Figure 3.21

Snorkelers feeding fish at Tortugas Reef

Note. At Tortugas Reef off of Icacos Island. Photograph by K. Jakubowski (2012).

3.9.3 Anecdotal Evidence

In addition to these quantitative data, I witnessed three different snorkelers bringing pieces of live coral back onto the vessel. Another snorkeler came back to the vessel asking for first aid supplies to tend to a cut on his leg. He admitted to standing on the coral to fix his fins and cutting himself on a sharp edge. I also observed a snorkeler from a private vessel spear fishing.

3.9.4 Reef Characteristics at Icacos Island (Beach Entry Reef)

The reefs at Icacos Island (beach entry reef) are classified as fringing and shallow. There is also reef rock present with scattered coral colonies within the snorkeling area. Most snorkelers reach the reef via beach access although I did observe a few snorkelers access the reef by snorkeling directly from the boat (Figures 3.22 and 3.23).

Figure 3.22

Icacos Island

Note. The first location (beach reef) where snorkelers can spend time on the beach at Icacos Island. Photograph by K. Jakubowski (2012)

Figure 3.23

Snorkelers departing catamaran at Icacos Island

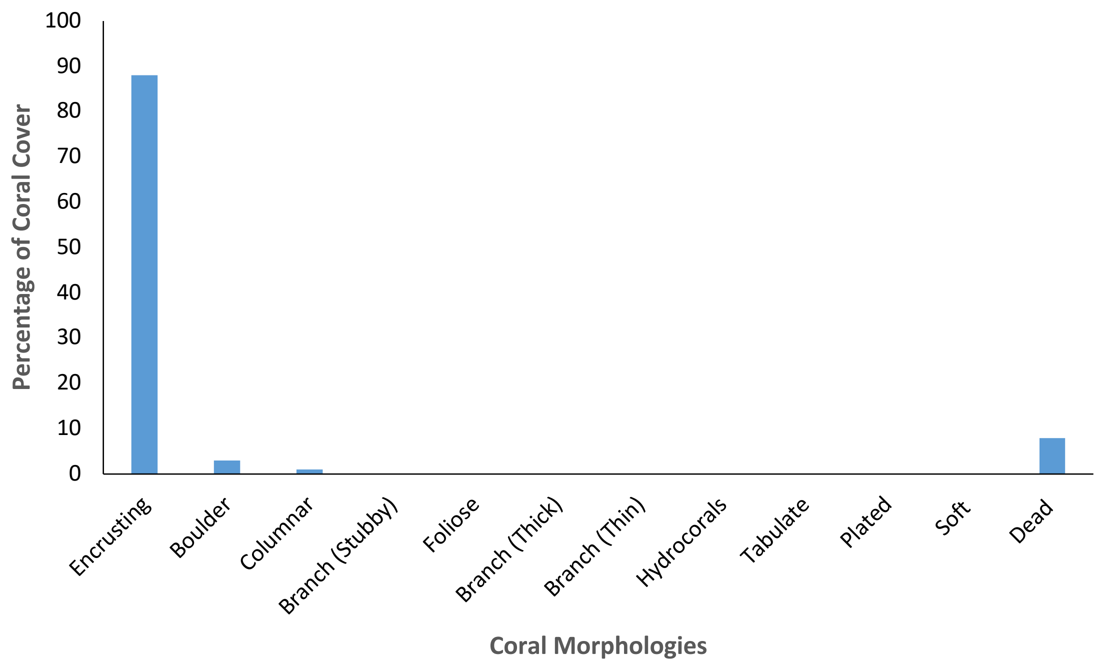
Note. Snorkelers departing from catamaran to walk on to the beach as instructed in order to snorkel at Icacos Island (beach reef). Photograph by K. Jakubowski (2012)

Tour operators instruct snorkelers to walk along the beach until they reach the reef. Snorkelers are then instructed to enter into the water right before the reef and then snorkel parallel to the reef and along the entire perimeter of the reef. Snorkelers are told not to swim over the coral because it is a shallow reef. Even with these instructions, I found numerous snorkelers over the shallow parts of the reef. The average reef depth measured 1.4 meters from the surface of the water to the top of the coral. At several locations along the transects, the reef was very shallow (0.3 – 1.0 meters).

Where snorkelers swim, there are a few rocky outcrops found in the soft bottom sand. These rocky outcrops are covered in algae and patchy corals (Goenaga & Cintron, 1979; Hernandez-Delgado, 2005). Eel grass boarders the reef. Encrusting coral (*Porites astreoides*) occupied the largest proportion (88%) (N = 250) of the substratum transects at Icacos Island beach entry reef each as represented in Figure 3.24. Only a small percentage of the transects had boulder coral (*Diploria labyrinthiformis)* (3%) (N = 9), and columnar coral (*Dendrogyra cylindrus)* (1%) (N = 4). Non-living and coral rubble (mostly *Acropora palmate)* occupied 8 % (N = 21) of the transect. No other coral morphologies were observed. 91% (N = 259) of the coral species in this transect are encrusting and boulder, both classified as stable (less sensitive) to physical stressors and the remaining 8% (N = 21) of coral was non-living. Very few fish were observed at Icacos Island beach entry reef.

Figure 3.24

Mean percentages of coral morphologies observed at Icacos Island beach entry reef



Note. Encrusting corals were the most common type of coral at Icacos Island beach reef.

3.9.5 Reef Characteristics at Tortugas Reef

Tortugas Reef is located off the southwest side of Icacos Island and provides visitors with a much larger area to snorkel. The corals at Tortugas Reef are classified as fringing and vary in depth. There are a number of patchy reefs and rocky outcrops from soft bottoms at Tortugas Reef (Goenaga & Cintron, 1979; Hernandez-Delgado, 2005). These are covered with a variety of biota including different types of algae, several coral species, black sea urchins (*Diadema antillarum),* sponges, brittle sea stars, sea fans, and soft corals. While the sandy bottom is on average 5 meters below the surface, several of the rocky outcrops and portions of the reef that plateau are shallow. The average depth along the reef transects where most snorkelers were recreating was

2.7 meters but in several locations less than 0.5 meters. I observed snorkelers swimming over the shallow parts of the reef and standing, kneeling, and placing an extended hand on the reef to rest (Figure 3.25).

Figure. 3.25
Image of snorkeler resting on reef

Note. Snorkelers may stand and lean on shallow reefs to rest. Photograph by K. Jakubowski (2012)

When the vessel arrives at the reef, snorkelers disembark into approximately 4 meters of water and a sandy bottom. There are often large numbers of fish directly surrounding the catamarans each day. This is most likely because leftover bread and lunch meat are thrown into the water on a regular basis from the commercial vessels to encourage fish to swim near the vessel (Figure 3.26).

Figure 3.26

Food Scraps in Water at Tortugas Reef

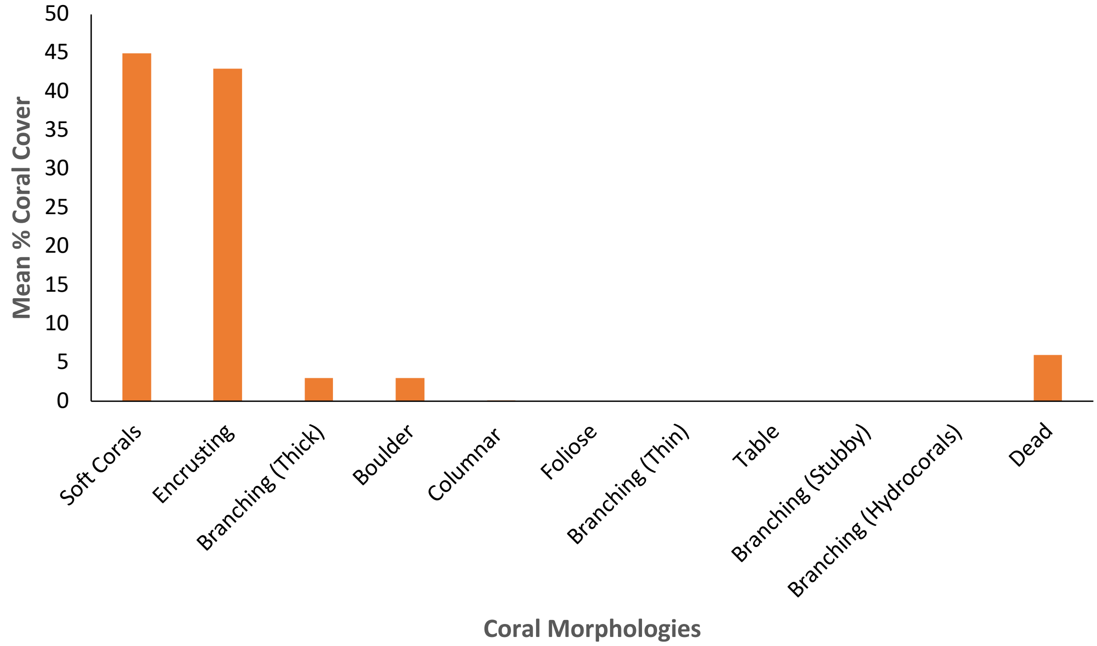
Note. Photograph by K. Jakubowski (2012)

While there is an abundance of fish around the boat, there is not much diversity in species. The three species most commonly seen around the vessels are sergeant majors (*Abudefduf saxatilis*), yellowtail snapper (*Ocyurus chrysurus*), and blue tang (*Paracanthurus hepatus*). Snorkelers spend some time feeding the fish that are swarming the vessel and then swim towards the reef.

At Tortugas reef, soft corals were the most abundant (45%), (N = 226), followed by encrusting corals (43%), (N = 218) as seen in Figure 3.27. Six percent of the corals in the transect were dead (N = 30) including a massive brain coral and large sea fan. Thick branching corals (3%), (N = 15) and boulder corals (3%), (N = 15) were less abundant. 50% of the branching coral observed was damaged. Columnar corals were uncommon (.1%), (N = 1). Other fish observed in the transects at Tortugas Reef can be found in Table 3.8.

Figure 3.27

Mean percentages of coral morphologies at Tortugas Reef



Note. Soft corals were the most abundant at Tortugas Reef followed by encrusting corals, dead corals, thick branching corals, and boulder corals.

Table 3.8

Fish observed at Tortugas Reef in La Cordillera Nature Reserve

Scientific Name	Common Name
Thalassoma bifasciatum	Bluehead Wrasse
Paracanthurus Hepatus	Blue Tang
Equetus punctatus	Spotted Drum
Chaetodon capistratus	Foureye Butterflyfish
Hemiramphus brasiliensis	Atlantic Needlefish
Diodon hystrix	Porcupinefish

Table 3.8 (continued).

Anisotremus virginicus	Porkfish
Diodon hystrix	Pufferfish
Holacanthus ciliaris	Queen Angelfish
Epinephelus guttatus	Red Hind
Holacanthus tricolor	Rock Beauty Angelfish
Hypoplectrus guttavarius	Shy Hamlet
Lactophrys triqueter	Smooth Trunkfish
Bodianus rufus	Spanish Hogfish
Sparisoma viride	Spotlight Parrotfish
Holocentrus adscensionis	Squirrelfish
Acanthurus tractus	Ocean Surgeonfish
Aulostomus maculatus	Atlantic Trumpet fish

3.9.6 Staff Briefings and Interventions

Of the 27 snorkeling trips I attended, every trip included two briefings (one at each reef) delivered by a captain or senior crew member. I recorded and transcribed briefings from five different vessels. While briefings varied between vessels (some were more in-depth than others), all briefings had similar messages. Common themes contained in the briefings are found in Table 3.9. All crew from the same vessel delivered similar messages. The tour operation with the most detailed coral reef etiquette messages informed snorkelers during the briefing of their “one and done” rule. The rule states that if you are observed intentionally making contact with the reef you are given a warning. If you contact the reef again, you need to come out of the water and are no longer allowed to snorkel. A different operation's crew member joked throughout the briefing. While the jokes made people laugh and most likely pay more attention, I felt the nature of the jokes could potentially weaken the coral reef etiquette messages. For example, this particular crew member joked that personal flotation devices were available for the lazy people. This could discourage individuals from wearing them which could lead to more individuals resting on the coral when tired.

On three different occasions I observed crew members comment about snorkelers standing on the reef, but no interventions to correct these behaviors were given. Several crew members from different catamarans carried a whistle and would blow it if snorkelers were observed contacting the reef. Verbal directions were then given to guide the snorkelers away from the reef. This was observed on six occasions. I also observed a female snorkeler, who was a guest from one of the vessels, correct the behavior of a group of snorkelers who were standing on the reef.

Crew members interviewed stated that briefings are difficult to deliver, especially when there are a lot of snorkelers onboard. Not every snorkeler pays attention. The vessel is crowded, people are excited, and easily distracted. I observed snorkelers donning equipment, taking pictures, looking at the scenery, checking their devices, or quietly chatting within their group during briefings. Crew members stated that it often feels like you are giving instructions to a "brick wall" or to "empty faces."

Table 3.9

Common themes contained in snorkeler briefings from different vessels

Message	Vessel #1	Vessel #2	Vessel #3	Vessel #4	Vessel #5
Provided an orientation for where to snorkel around the reef.	Yes	Yes	Yes	Yes	Yes
Provided specific directions for entering the water to reach the reef from the "beach entry" reef at Icacos Island.	Yes	Yes	Yes	Yes	Yes
Stated that some corals are shallow and exposed at low tide. Do not swim over shallow corals stay on the perimeter.	Yes	Yes	Yes	Yes	No
Offered a snorkeling lesson for beginners on board the vessel.	Yes	Yes	Yes	Yes	No
Offered a snorkeling lesson for beginners in the water.	No	No	Yes	Yes	No
Provided message not to touch, stand, kneel, jump, sit, or walk on coral reefs.	Yes	Yes	Yes	Yes	Yes
Stated that corals are not rocks, they are living, fragile, ecosystems.	Yes	Yes	Yes	Yes	Yes
Provided message about not standing up or fixing your mask over the reef.	Yes	Yes	Yes	Yes	No

Table 3.9 (continued).

Stated not to touch anything. Corals are sharp and if contacted can scrape or cut you.	Yes	Yes	Yes	Yes	No
Stated sea urchin spines can be harmful if contacted.	Yes	Yes	Yes	Yes	Yes
Stated some types of coral can sting and burn you if touched.	Yes	Yes	Yes	Yes	Yes
Stated not to take anything living from the reef.	No	Yes	Yes	No	No
Discussed equipment contacts, for example masks and fins do not float. If you drop something let crew know so they can attempt to retrieve it.	Yes	Yes	Yes	No	No

3.9.7 Captain and Crew Interviews

Ten key informant interviews were conducted with crew members from tour operations based out of Fajardo in order to gain a better understanding of how decisions are made regarding which reefs to visit, if crew interact with snorkelers to promote reef etiquette behaviors, and personal perceptions of the reef. I analyzed responses of these key informants in order to understand reasons that factor into these decisions.

All ten key informants said that weather, specifically storms that involved lightening or swells caused by wind, was the main factor that determined if a trip would run, and if so which reefs they would visit on a given day. Other themes identified in the key informant interviews included passenger safety and anticipated visitor satisfaction. These factors can also be shaped by weather. Other factors that played a role in a few key informant decisions included snorkeler experiences and skill level. Although, a majority of the key informants stated that snorkeler skill and experience were less important in their decision-making process since most snorkelers participating in excursions were beginner snorkelers.

Key informants responded that crowding was another major factor. The availability of a mooring buoy on a crowded day was a point of contention mentioned by all key informants. There are only four mooring buoys at Tortugas Reef even though there are up to eight catamarans that have Puerto Rico Department of Environment and Natural Resources (DNER) permits to go to the reserve. The mooring buoys have the word "diving" written on them. If a small private vessel has a mask on board, they are allowed to use the mooring without penalty. Tour operator captains are then forced to anchor their large vessels in the sand or turtle grass (*Thalassia testudinum).* Anchoring in the sand raises a safety issue for a large vessel since it can be dragged through the sand. Vessels anchored in the sand can shift and move which then becomes a safety issue for snorkelers who are regularly getting on and off the vessel. Often times the commercial moorings are utilized by private, recreational vessels visiting the Reserve. Key informants felt that in addition to needing more moorings at the reef, the moorings should be designated for commercial operators only, and there should be more enforcement regarding commercial use only.

All key informants felt that dive and snorkel operators should practice good reef etiquette and that educating snorkelers before they got into the water was the most important factor in protecting the coral reefs. Several issues were identified as possible barriers to coral reef protection. The informants felt a majority of the snorkelers participating in excursions would be classified as beginner and lacked the skills and knowledge needed. For some guests, this snorkeling experience was their first time visiting the ocean. They also felt that some snorkelers do not understand that corals are alive and that most snorkelers are more interested in seeing a diversity of fish.

While key informants felt education was the most effective method to reduce contacts with the reef, they felt that briefings were not enough. As previously mentioned, crew stated that if there is a large group on the catamaran (anywhere from 40 to 80 participants) it can be difficult to make sure everyone is paying attention. Some snorkelers are busy taking pictures, applying sunscreen, getting their equipment together, or even quietly chatting with other members in their group. Crew realize that there is a fine line between making sure the visitors are having a great time and disciplining snorkelers who are not practicing good reef etiquette. While they expressed their concern over the damage and degradation at the reef, several informants stated they were also concerned about tips (additional income), poor reviews on websites that promote their operations, and job security. One informant even suggested she was concerned about the effect my findings would have on her field of work. Another informant said she was conflicted since a healthy reef was necessary for her "rice and beans" but a satisfied customer was also necessary for her income.

Most key informants stated that they would respond to a negative behavior at the reef by either blowing a whistle or hollering to get the attention of a snorkeler who was behaving inappropriately. One key informant stated that her staff were trained to correct inappropriate behaviors, but if a snorkeler continued to intentionally harm the reef, the individual would not be allowed to snorkel for the remainder of the trip. Several key informants stated they would give a snorkel lesson onboard. One informant stated that she gets in the water with individuals who need a lesson in order to be able to let them practice and correct their technique before snorkeling by the coral.

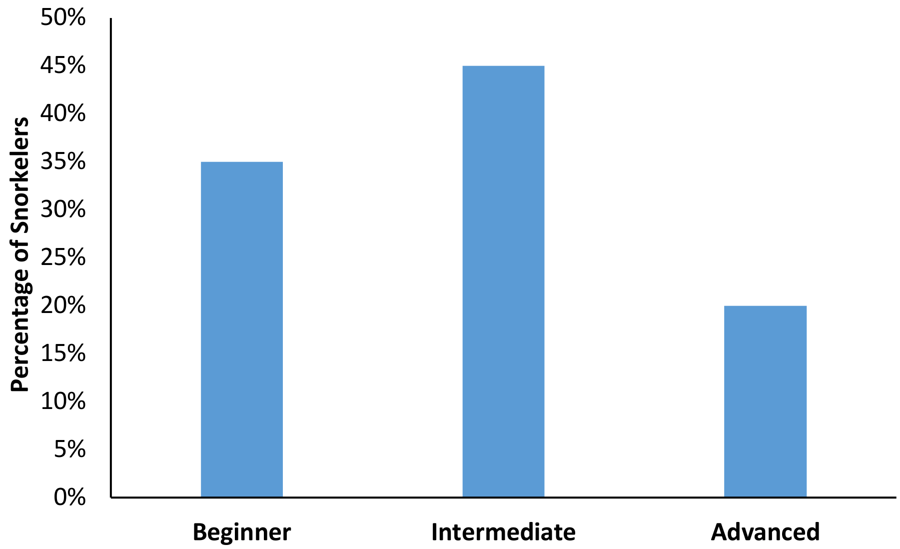
Every key informant expressed their love and appreciation for the marine life in Puerto Rico. They shared stories about being exposed to the marine environments of Puerto Rico at an early age. A family member (father, mother, cousin, older sibling, close family friend) was usually given credit for this exposure. Key informants credited these individuals and experiences as one of the main reasons for their involvement in the marine profession, fondness of the coral reef environment, and concern about the health of the coral reefs in Puerto Rico.

3.9.8 Snorkeler Perceptions

179 individuals were surveyed during the return trip back to port. Ninety-five percent (N = 170) of those surveyed were not residents of Puerto Rico and were participating in the snorkeling excursion as part of their vacation. Snorkelers were asked to self report on their snorkel skill level to measure experience. As shown in Figure 3.28, 35% (N = 63) of the snorkelers surveyed considered themselves beginners while 45% (N = 80) felt they had intermediate snorkeling skills and 20% (N = 36) stated they were advanced snorkelers.

Figure 3.28

Snorkelers at La Cordillera Nature Reserve self report their snorkeling skill level



To measure environmental awareness, three questions in the survey addressed snorkelers' perceptions and knowledge about the health and diversity of life at the reef as well as the clarity of the water. As shown in Table 3.10 more than half (55%) (N = 99) were satisifed with seeing a healthy reef. Approximately 54% (N = 96) percent of snorkelers responded that they were satisfied with the diversity of marine life around the coral reefs (Table 3.11). Table 3.12 indicates that a majority (71%) (N = 126) felt the reefs within the Reserve had good water visibility.

Table 3.10

Snorkeler satisfaction with the health of the coral reefs at La Cordillera NatureReserve

Healthy Reef	N	Mean Percentage
Extremely Satisfied	58	32
Very Satisfied	41	23
Moderately Satisfied	29	16
Slightly Satisifed	17	10
Not at All Satisfied	8	4
Not Sure	26	15
Total	179	100

Note. (Snorkel Surveys 2011-2015)

Table 3.11
Snorkeler satisfaction with the diversity of marine life at the coral reefs at La Cordillera Nature Reserve

Diversity of Marine Life	N	Mean Percentage
Extremely Satisfied	48	27
Very Satisfied	48	27
Moderately Satisfied	54	30
Slightely Satisfied	15	8
Not at all Satisfied	7	4
Not Sure	7	4
Total	179	100

Note. (Snorkeler Survey 2011-2015)

Table 3.12
Snorkeler satisfaction with water visibility around coral reefs at La Cordillera Nature Reserve

Water Visibility	N	Mean Percentage
Extremely Satisfied	64	36
Very Satisfied	62	35
Moderately Satisfied	37	21
Slightly Satisfied	3	1
Not at all Satisfied	6	3
Not Sure	7	4
Total	179	100

Note. Snorkeler Survey 2011- 2015

A Pearson's correlation was completed to explore the relationship between snorkeler experience and satisfaction of viewing a healthy reef, seeing a diversity of marine life, and snorkeling in water with good visibility. A statistical significance was found between snorkelers who categorized themselves as advanced snorkelers and those who strongly disagreed with seeing a healthy reef ($p < 0.05$).

3.10 Discussion

Coral reefs are an important resource for tourism in Puerto Rico. However, snorkeling activities can threaten the reefs that people enjoy and tour operators depend upon for their economic security. In order to demonstrate the vulnerability of coral reef resources in Puerto Rico to snorkeling, a method to characterize vulnerability was developed and applied. Inductive indicators were utilized in this research since sufficient data was available to indicate the variable and the potential harm. My findings indicate that some reefs within La Cordillera Nature Reserve Puerto Rico are vulnerable to snorkeling activities. Exposure to contacts, which includes the depth of the coral in relationship to the snorkeler, may be a potential factor since both reefs (beach entry reef at Icacos Island and Tortugas Reef) have shallow areas (less than one meter). Research has shown that corals located in shallow areas suffer from damage especially when they serve as snorkel entry points (Barker, 2003; Kay & Liddle, 1989). Shallow water reefs and reefs exposed at low tide are vulnerable to people walking on them and thus trampling the polyps (Barker, 2003; Hawkins & Roberts,1993; Kay & Liddle, 1984; Woodland & Hooper, 1977). Beach entry and shallow reefs can also increase the exposure of corals to sedimentation. Barker (2003) found that sedimentation rates were highest at shallow shore entries, when snorkelers adjusted their equipment, and when snorkelers were vertical but would gradually decrease with increasing distance from entry. At these reefs, there are also topographic features (fringing reefs, rocky outcrops, plateaus, and tight spaces) that can lead to more contacts.

I did not assess the reefs at Palominos Island or Lobos Cay because tour operators did not make many trips to either location during my time collecting data. These reefs were often only visited when there were significant swells at Tortugas Reef. For example, I only went to Palominos Island reef one time and observed 15 snorkelers. However, I did note in my field data some characteristics about the reef. Palominos Island reef is rather deep (approximately 5 meters) and, therefore, difficult for snorkelers to unintentionally contact the reef unless they were free diving. I asked several captains why they did not visit this reef more. The overall response was that Palominos Island has a healthy reef but there are not a lot of fish present. The captains I spoke with felt that snorkelers have a more enjoyable experience when they see a lot of fish and Palominos Island does not offer that opportunity.

Another component of exposure, the number of potentially damaging contacts, was high, (0.28 contacts per minute) at La Cordillera Nature Reserve when compared to St. Lucia (0.05 contacts per minute), the only other location where snorkeler contact rates were observed. When this frequency is multiplied by the number of visitor-minutes spent at reefs on a yearly basis, the scale of the problem can appear to be a significant factor in increasing vulnerability. For example, during the height of the tourist season, eight catamarans can bring approximately 40 (but up to 80 on some vessels) individuals to the reef. However, it is important to note that not every person brought out to the La Cordillera Nature Reserve with a tour operator actually snorkels. Many people will stay on the vessel, swim right around the boat, or sit on the beach (at reef locations where beach access is available). I can compare the average number of snorkelers at time 15 and 25 (peak times for Icacos Island beach reef and Tortugas Reef), and then calculate the total number of snorkelers at these peak times for one year (8,030 and 12,775 snorkelers respectively). However, these snorkelers do not spend the entire time in the water at the reef. After these peak times, the number of snorkelers at the reef steadily declined. Several crew members interviewed did state that the number of people at the reef did not matter. They felt that what mattered more than number of snorkelers at the reef was how snorkelers behave. A key informant stated that one vessel with snorkelers not practicing reef etiquette can do more potential harm than several vessels with snorkelers taking measures to not contact the reef. Researchers at Hol Chan Marine Reserve in Brazil found similar conclusions (Green Reef Environmental Institute et al., 2002). Their study revealed that behavior modification and education were the most important factors in decreasing the impacts of tourism, more so than limiting the number of snorkelers at the Reserve (Green Reef Environmental Institute et al., 2002).

The findings of this research indicate that the frequency of potentially damaging behaviors in Puerto Rico is high (0.28 contacts per minute), when compared to the only other study done, (0.05 contacts per minute) in St. Lucia (Barker, 2003). While more research is needed, I can conclude that snorkelers contact the reef at a much higher rate in Puerto Rico than St. Lucia. This indicates the reefs at Icacos Island are exposed to more contacts which increases their vulnerability.

In both the Puerto Rico and St. Lucia studies, fin contacts were the most potentially damaging behavior. Fins add length to a snorkeler's legs, bringing the snorkeler closer to the reef. Most of the fin contacts I observed appeared unintentional and most likely caused by poor snorkeling technique. When maneuvering around the water, snorkelers (especially beginners) were often unaware that their fin had contacted the reef. I also observed that snorkelers tend to engage in more potentially damaging behaviors with the reef when snorkeling in a group vs. individually. Groups of snorkelers tend to pause to take their heads out of the water and discuss what they are seeing. During this time, they usually become vertical in the water and their fins are often contacting the coral, or they are standing on it. Standing on the reef was the second most common behavior (24%) observed. Unskilled snorkelers will stand on the reef to fix their equipment, rest, or find their friends. While it may be harder to stop snorkelers from kicking the reef with their fins, measures to reduce exposure from standing are possible.

Two species of branching corals at Puerto Rico's coral reef ecosystems (*Acropora palmate* and *Acropora cervicornis*) have been declining over the past twenty-five years. Scientists have attributed this to hurricane damage, white-band disease, and coral eating mollusks (Causey et al., 2002). In 2005, a Biological Review Team was contracted by NOAA to review the status of these species of branching corals and found that at one time elkhorn (*Acropora palmata*) and staghorn (*Acropora cervicornis)* corals were the most abundant and most important species on many Caribbean coral reefs. They played an important ecological role in terms of reef formation and the provision of habitat for other reef organisms (Boulon et al., 2005). The team concluded that the loss of these species would likely compromise the growth of coral reefs and other ecosystem functions. These corals are classified as vulnerable species since their morphology makes them more sensitive to fin kicks and their shape (branching) makes them more sensitive to breaks caused by grasping hands. At the two reefs studied, no thin branching corals were present and thick branching corals comprised only 3% of the transect survey. Of this small percentage of branching coral, 50% was damaged. At Icacos beach reef, 91% of the coral species and 88% of the species at Tortugas reef were classified as stable and less sensitive to physical contacts. The most common encrusting coral, *Porites astreoides* was present at both reefs and is classified as a rapid colonizer (Hernandez-Delgado, 2005). Rapid colonizers are successful in ecosystems that are disturbed. Coral reef biologists state that physical damage from hurricanes was the greatest threats to the reefs at Cayo Icacos, followed by disturbances created by anthropogenic physical damage. Impacts from snorkelers, therefore, may be contributing to a change in reef community structure. This has been reported on the Island of Bonaire in the Caribbean, where impacts from heavily dived areas are thought to have caused the loss of massive corals at the expense of faster growing corals (Hawkins et al., 1999). The morphology of the corals at Icacos Island in La Cordillera Nature Reserve indicate that less sensitive, faster growing species can handle stressors while others cannot.

Tour operator crew recognized the need for coral reef conservation and expressed a strong desire about taking measures to protect the reefs from damage by snorkelers, vessels, and pollution. A majority of key informants stressed that healthy coral reefs were essential for both ecological and economic reasons. Crew also mentioned their struggles with satisfying snorkeler expectations while protecting the reef.

Barker (2003) and Medio et al. (1997) both acknowledge the role that operators can play in promoting responsible behaviors by divers and snorkelers around the reefs. While all vessel crew gave informative briefings, this method was not the most effective way of providing coral reef etiquette messages that may reduce exposure. Many are willing to instruct snorkelers to behave appropriately and intervene where necessary. Individuals working to manage the behaviors of tourists and recreationists visiting protected and natural areas have often applied persuasion communication to convince visitors to observe safety rules, minimize their impact on the natural world, and avoid conflicts with other visitors. For these reasons, persuasion communication via the peripheral route can be considered a promising mechanism for managing the behaviors of snorkelers.

The core of persuasion communication is the message, designed to sway the attitude of the receiver. Attitude change through the peripheral route to persuasion occurs from less thoughtful processing of the communication (Petty & Cacioppo, 1986). The targeted recreationists for this approach would be classified as individuals vacationing, recreating, and most likely paying little or no attention to the content of the message. They will most likely spend no time processing or integrating any part of the message into their value system (Roggenbuck, 1992). For these message recipients, the delivery of the message has a greater impact on resulting in a behavior change in the recipient than does the actual message. In other words, "who said it" is more important that "what is said" (Roggenbuck, 1992). If the message needs to be delivered in an environment that is distracting, loud, or chaotic this approach may be the best option (Roggenbuck, 1992). A large catamaran of snorkelers consuming food, drinking alcohol, listening to music and having fun is a good example of an environment in which the peripheral route to persuasion may be the best option.

In Puerto Rico, Webler & Jakubowski (2016) experimented with a video message delivered before snorkelers embarked on the vessel and a signed pledge to promote proper snorkeling etiquette. From March 2012 until June 2012, hundreds of snorkelers watched the video and signed the pledge before they boarded a tour operator led excursion. The pledge expressed commitment to specific behaviors. Post-treatment in-water observations found an 87% reduction in the coral contact rate. Furthermore, the percentage of snorkelers who never touched the reef shot up from 64% to 93%. This research suggests the delivery of the pre-trip messaging together with a written pledge can change behaviors, thus improving the ability of ecotourism operators to help sustain reefs as well as the economic livelihoods of their employees.

In addition to the message, method of delivery, and signed pledge, I believe more active involvement by crew is necessary to reduce the number of contacts that snorkelers make with the reef. I believe crew should be present in situ to intervene when snorkeler contacts are made, especially intentional contacts such as standing or sitting on the reef. A majority of key informants said they corrected behaviors from the vessel, but having crew members in the water may be more effective.

I would also recommend that all beginner snorkelers, 35% in this research, be required to take an in-water snorkel lesson. I expect the number of individuals who are classified as beginner is much higher since this information was self-reported. In-water lessons with small groups of individuals would also be an opportunity to provide education about coral reef etiquette and marine life.

Environmental awareness questions about the health and diversity of marine life at the reefs indicated that more than half the snorkelers felt the reefs were healthy and diverse. These perceptions do not correlate with the scientific data about the state of the coral reefs in Puerto Rico (Hernandez-Delgado, 2005). Snorkelers in Puerto Rico were satisified with an abundance of fish and not necessarily the diversity of this abundance. Seeing an abundance of fish has been found to be an important attribute for snorkelers and divers in research conducted at other coral reef ecosystems (Mundet & Ribera, 2001; Musa, 2002; Williams & Polunin, 2000). It is important to note there was a signficiant correlation between those who reported being advanced snorkelers and less satisfication with seeing healthy reefs and a diversity of marine life in Puerto Rico.

A final theme that resonated among key informants was a need for improvement in the relationship between tour operators and government officials in charge of managing the activities that take place within the Reserve. Tour operator staff interviewed believe they are not getting the support they need from the government and their voices are not being heard when it comes to actions that would help the tourism industry while protecting the quality of the coral reefs. Several informants stated that each snorkeler taken to the reef has to pay a small fee for conservation of the reserve and yet they felt no additional measures were being taken with these funds. For example, an increased number of mooring buoys are needed at Icacos Island at both the beach entry site and La Tortugas. Currently, there are only three mooring buoys at each location and yet there can be up to eight large tour operation vessels at the reef each day. Often times the commercial moorings are utilized by recreational vessels visiting the Reserve. On one given weekend day, I counted 175 small vessels at the reef. Key informants felt that more enforcement for better compliance by these tourists not affiliated with snorkeling excursions is needed at the Reserve. Additional research needs to be conducted to determine what impacts these smaller vessels and the activities they are participating in are having at the Reserve, as part of a larger vulnerability assessment.

3.11 Conclusion

Healthy coral reef ecosystems are essential to the people of Puerto Rico since they sustain the livelihoods of many island residents by providing income and employment opportunities from tourism. These activities can also increase participant knowledge and appreciation about these ecosystems. For these and other reasons, coral reef related tourism has been and should be promoted in Puerto Rico and other areas around the world. However, the fast pace at which coral reef tourism has expanded, and the infrastructure associated with recreational activities around these reefs, has been linked to the degradation of corals (Barker, 2003). While I did not specifically investigate the ecological damage of snorkeler contacts with the reef, researchers have correlated snorkeler activity and reef conditions at many locations, supporting the claim that snorkeling and scuba diving can be a serious threat to coral reefs (Allison, 1996; Hawkins & Roberts, 1992; Kay & Liddle, 1989; Krieger & Chadwick, 2013; Liddle, 1991; Liddle & Kay, 1987; Plathong et al., 2000; Prior et al., 1995; Riegl & Velimirov, 1991; Tratalos & Austin, 2001). If coral reefs become severely degraded, they will no longer serve as aesthetically pleasing settings for snorkel activities: this will have a significant impact on both the ecology of coral reef communities and the livelihoods and way of life of the people who depend on these ecosystems.

In developing a methodology to test the vulnerability of coral reefs to snorkeling, I conclude that snorkeling activities within La Cordillera Nature Reserve, Puerto Rico specifically at Icacos Island beach entry Reef and Tortugas Reef contribute to increasing the vulnerability of the reef ecosystems within the Reserve. However, increasing adaptive capacity and implementing management actions to reduce vulnerability, specifically actions that decrease exposure is a tangible possibility. Reducing contacts is one such measure. Gardner et al., (2003) state that if human behaviors could be managed correctly, corals would be capable of handling natural stresses more effectively. Actions to do this include revised briefings and educational messages, via different formats, that reinforce etiquette at the reef as a social norm as well as engage and empower snorkelers to want to not contact the reef. Crew members can get in the water and provide a brief lesson for beginners. They can also serve as coral guards, monitoring snorkelers throughout their excursions and encouraging good behaviors. Crew can choose to bring snorkelers to deeper locations (greater than 3 meters), which would reduce both intentional (touching, standing, and sitting) contacts as well as those that snorkelers are often unaware of (fin kicks).

Tour operators also asked for better communication with managers and government officials involved in tourism at the reef. Tour operators can collaborate with coral reef managers as part of the Coral Reef Management Plan. Management options that could reduce contacts include the installation of additional mooring buoys and stronger enforcement of all tourist activities at the reef. These strategies are all tangible actions for managing snorkel tourism in order to reduce the vulnerability of coral reefs. Strategies can be evaluated and adapted as necessary as part of a management plan. Without such actions, degradation of the reefs at La Cordillera Nature Reserve in Puerto Rico will most likely continue to escalate.

3.12 References

Adger, W. (2006). Vulnerability. *Global Environmental Change*, *16*(3), 268-281. https://doi.org/10.1016/j.gloenvcha.2006.02.006

Ajzen, I. (1991). The theory of planned behavior. *Organizational Behavior and Human Decision Processes*, 50,179-211.

Allison, W.R. (1996). Snorkeler damage to reef corals in the Maldive Islands. *Coral Reefs*, *15*(4), 215-218. https://doi.org/10.1007/BF01787454

Alwang, J., Siegel, P.B., & Jørgensen, S.L. (2001). *Vulnerability: A view from different disciplines*. Social Protection Discussion Paper Series No. 0115. Social Protection Unit, Human Development Network. The World Bank. https://documents.worldbank.org/curated/en/636921468765021121/Vulnerability-a-view-from-different-disciplines

Antonius, A. (1985). Coral reef pathology: A review. *Proceedings 4th International Coral Reef Symposium, Manila,*2:3-6. https://agris.fao.org/agris-search/search.do?recordID=XB8310992

Appeldoorn, R., Beets, J., Bohnsack, J., Bolden, S., Matos, D., Meyers, S., Rosario, A., Sadovy, Y., & Tobias, W. (1992). Shallow water reef fish stock assessment for the U.S. Caribbean. *NOAA Tech. Mem.* NMFS-SEFSC-304.

Appeldoorn, R., Yoshioka, P., Ballantine, D. (2009). Coral reef ecosystem studies: Integrating science and management in the Caribbean. *Caribbean Journal of Science, 45*(2-3),134-137. https://doi.org/10.18475/cjos.v45i2.a2

Barker, N.H.L. (2003). *Ecological and socio-economic impacts of dive and snorkel tourism in St. Lucia, West Indies* (Doctoral dissertation, University of York). ProQuest Dissertations and Theses Global.

Barker, N.H.L. & Roberts, C.M. (2004). Scuba diver behavior and the management of diving impacts on coral reefs. *Biological Conservation,120*(4), 481-489. https://doi.org/10.1016/j.biocon.2004.03.021

Boulon, R., Chiappone, M., Halley, R., Jaap, W., Keller, B., Kruczynski, B., Miller, M, &Rogers, C. (2005). *Atlantic Acropora Status Review Document*. Report to National Marine Fisheries Service, Southeast Regional Office. https://www.yumpu.com/en/document/view/30684931/atlantic-acropora-status-review-southeast-regional-office-noaa

Bryan, H. (1977). Leisure value systems and recreational specialization: The case of the trout fishermen. *Journal of Leisure Research,9*(3*),*174-187. https://doi.org/10.1080/00222216.1977.11970328

Burgett, J. (1990). Diving deeper into Hanauma: Identifying conceptual barriers to effective management. In M. Miller and J. Auyong (Eds.), *Proceedings of the 1990 congress on coastal and marine tourism*. (Vol 1., pp. 100-105). National Coastal Resources Research Institute.

Carpenter, S., Walker, B., Anderies, J.M., & Abel, N. (2001). From metaphor to measurement: Resilience of what to what? *Ecosystems, 4*(8), 765-781. https://doi.org/10.1007/s10021-001-0045-9

Causey, B., Delaney, J., Diaz, E., Dodge, R., Garcia, J., Higgins, J., Jaap, W., Matos, C., Schmahl, G., Rogers, C., Miller, M., & Turgeon, D. (2002). *Status of coral reefs in the US Caribbean and Gulf of Mexico: Florida, Texas, Puerto Rico, US Virgin Islands and Navassa.* https://nsuworks.nova.edu/cgi/viewcontent.cgi?article=1007&context=occ_facreports.

Chadwick-Furman, N.E. (1997). Effects of SCUBA diving on coral reef invertebrates in the U.S. Virgin Islands: Implications for the management of diving tourism. In: den Hartog, J.C. (Ed.), *Proceedings of the Sixth International Conference on Coelenterate Biology*. Nationaal Naturhistorisch Museum, 91–100.

Davis, D. & Tisdell, C. (1995). Recreational scuba-diving and carrying capacity in marine protected areas. *Ocean and Coastal Management*, *26*(1),19-40. https://doi.org/10.1016/0964-5691(95)00004-L

Dodge, R.E., Aller, R.C., & Thompson, J. (1974). Coral growth related to resuspension of bottom sediments. *Nature, 247*, 574-577.

Fox, H.E., Pet, J.S., Dahuri, R. & Caldwell, R.L. (2003). Recovery in rubble fields: Long-term impacts of blast fishing. *Marine Pollution Bulletin, 46*(8), 1024-1031. https://doi.org/10.1016/S0025-326X(03)00246-7

Gallopín, G.C., (2006). Linkages between vulnerability, resilience, and adaptive capacity. *Global Environmental Change 16 (3),* 293-303. https://doi.org/10.1016/j.gloenvcha.2006.02.004

Garcia-Sais, J., Appeldoorn, R., Battista, T., Bauer, L., Bruckner, A., Caldow, C., Carrubba, L., Corredor, J., Diaz, E., Lilyestrom, C., Garcia-Moliner, G., Hernandez-Delgado, E., Menza, C., Morell, J., Pait, A., Sabater, J., Weil, E., Williams, E., & Williams, S. (2008). The state of coral reef ecosystems of Puerto Rico. In: J.E. Waddell and A.M. Clarke (Eds.), *The state of coral reef ecosystems of the United States and Pacific Freely Associated States: 2008*. NOAA Technical Memorandum NOS NCCOS 73. NOAA/NCCOS Center for Coastal Monitoring and Assessment's Biogeography Team (pages 75 – 116).

Gardner, T.A., Côté, I.M., Gill, J.A., Grant, A., & Watkinson, A. R. (2003). Long-term region-wide declines in Caribbean corals. *Science*, *301*(5635), 958-960. https://doi.org/10.1126/science.1086050

Gil, M., Renfro, B., Figueroa-Zavala, B., Penie′, I., & Dunton, K. (2015). Rapid tourism growth and declining coral reefs in Akumal, Mexico. *Marine Biology, 162*, 2225-2233. https://doi.org/10.1007/s00227-015-2748-z

Goenaga, C. & Cintron, G. (1979). *Inventory of the Puerto Rican Coral Reefs.* Office of the Coastal Zone Management Program of the Department of Natural Resources. http://drna.pr.gov/wp-content/uploads/2017/02/Goenaga-and-Cintron-1979-Inventory-of-the-Puerto-Rican-coral-reefs.pdf

Goodhead, T. & Johnson, D. (1996). *Coastal recreation management, The sustainable development of maritime leisure*. Tayolor and Francis. https://doi.org/10.4324/9781315024851

Green Reef Environmental Institute. (2002).https://ambergriscaye.com/greenreef/

Hall, V. R. (2001). The response of *Acropora hyacinthus* and *Montipora tuberculosa* to three different types of colony damage: Scraping injury, tissue mortality and breakage. *Journal of Experimental Marine Biology and Ecology*, *264*(2), 209-223. https://doi.org/10.1016/S0022-0981(01)00318-5

Hawkins, J.P. & Roberts, C.M. (1992). Effects of recreational SCUBA diving on fore-reef slope communities of coral reefs. *Biological Conservation*, *62*(3), 171-178. https://doi.org/10.1016/0006-3207(92)91045-T

Hawkins, J.P., & Roberts, C.M. (1993). Effects of recreational SCUBA diving on coral reefs. Trampling on reef flat communities. *Journal of Applied Ecology*, *30(1)*, 25-30. https://doi.org/10.2307/2404267

Hawkins, J. P. & Roberts, C.M. (1994). The growth of coastal tourism in the Red Sea: Present and future effects on coral reefs. *Ambio, 23*(8),503-508.

Hawkins, J.P. & Roberts, C.M. (1997). Estimating the carrying capacity of coral reefs for scuba diving. In Lessios, H.A., Macintyre, I.G., & McGee, M. (Eds.), *Proceedings of the Eighth International Coral Reef Symposium.* Smithsonian Tropical Research Institute, Balboa, Panama, Volume 2, 1923-1926.

Hawkins, J.P., Roberts, C., Van't Hof, T., De Meyer, K., Tratalos, J., & Aldam, C. (1999). Effects of recreational scuba diving on Caribbean coral and fish communities. *Conservation Biology, 13*(4), 888-897. https://doi.org/10.1046/j.1523-1739.1999.97447.x

Hernández-Delgado, E.A. (2005). *Natural history, characterization, distribution and current status of Puerto Rico coral reefs. Puerto Rico biodiversity: Terrestrial vertebrates and ecosystems.* Natural History Series. San Juan, Puerto Rico: Editorial Instituto de Cultura Puertorriqueña, 281-356.

Hernández-Delgado, E.A., Ramos-Scharrón, C.E., Guerrero, C., Lucking, M.A., Laureano, R., Méndez-Lázaro, P.A., & Meléndez-Díaz, J.O. (2012). Long-term impacts of tourism and urban development in tropical coastal habitats in a changing climate: Lessons learned from Puerto Rico. In: M. Kasimoglu (Ed.)., *Visions from global tourism industry-creating and sustaining competitive strategies* (357-398). InTech Publications.

Inskeep, E. (1991). *Tourism planning*. Van Nostrand Reinhold.

Jameson, S.C., Ammar, M.S.A., Saadalla, E., Mostafa, H., & Riegl, B. (1999). A coral damage index and its application to diving sites in the Egyptian Red Sea. *Coral Reefs*,*18*(4), 333- 339. https://doi.org/10.1007/s003380050208

Kay, A.M. and Liddle, M.J. (1984). Tourist impacts on reef corals. *Report to the Great Barrier Reef Marine Park Authority*, March, 1984.

Kay, A.M., & Liddle, M.J. (1989). Impact of human trampling in different zones of a coral reef flat. *Environmental Management*, *13*(4), 509-520. https://doi.org/10.1007/BF01867685

Klint, L.M., Jiang, M., Law, A., Delacy, T., Filep, S. Calgaro, E., Dominey-Howes, D., & Harrison, D. (2012). Dive tourism in Luganville, Vanuatu: Shock stressors and vulnerability to climate change. *Tourism in Marine Environments, 8*(1-2), 91-109. https://doi.org/10.3727/154427312X13262430524225

Krieger, J.R. & Chadwick, N.E. (2013). Recreational diving impacts and the use of pre- dive briefings as a management strategy on Florida coral reefs. *Journal of Coast Conservation*, *17*(1), 179-189. https://doi.org/ 10.1007/s11852-012-0229-9

Lessios, H.A., Robertson, D.R., & Cobit, J.D. (1984). Spread of *Diadema* mass mortality through the Caribbean. *Science, 226*, 335-338. http://doi.org/10.1126/science.226.4672.335

Liddle, M.J. (1991). Recreation ecology: Effects of trampling on plants and corals. *Trends in Ecology and Evolution*,*6* (1), 13-17. https://doi.org/ 10.1016/0169-5347(91)90141-J

Liddle, M.J. & Kay, A.M. (1987). Resistance, survival and recovery of trampled corals on the Great Barrier Reef. *Biological Conservation*, *42*(1), 1-18. https://doi.org/10.1016/0006-3207(87)90049-8

Loomis, D., Anderson, L., Hawkins, C., Paterson, S. (2008). *Understanding coral reef use: Scuba diving in the Florida Keys by residents and non-residents.* The Florida Reef Resilience Program. The Nature Conservancy Florida Keys Program, 1 – 141. http://frrp.org/FRRP%20documents/frrp_snorkeling.pdf

Lucrezi, S., Saayman, M., & van der Merwe, P. (2013). Managing diving impacts on reef ecosystems: Analysis of putative influences of motivations, marine life preferences, and experience on divers' environmental perceptions. *Ocean and Coastal Management, 76*, 52 – 63. https://doi.org/10.1016/j.ocecoaman.2013.02.020

McKenzie-Mohr, D., & Smith, W. (1999). *Fostering sustainable behavior: An introduction to community-based social marketing* (2nd ed.). New Society Publishers. https://www.uwsp.edu/cnr-ap/UWEXLakes/Documents/ecology/shoreland/marketing/fostering_sustainable_behavior_dmm.pdf

Medio, D., Ormond, R. & Pearson, M. (1997). Effect of briefings on rates of damage to coral by SCUBA divers. *Biological Conservation*, *79*(1)*,* 91-95. https://doi.org/10.1016/S0006-3207(96)00074-2

Mundet, L. & Ribera, L. (2001). Characteristics of divers at a Spanish resort. *Tourism Management, 22*(5), 501-5 10. https://doi.org/ 10.1016/S0261-5177(01)00016-4

Musa, G. (2002). Sipadan: A SCUBA-diving paradise: An analysis of tourism impact, diver satisfaction and tourism management. *Tourism Geographies, 4*(2), 195-209. https://doi.org/10.1080/14616680210124927

National Ocean Service [NOS]. (2016). https://oceanservice.noaa.gov/education/tutorial_corals/media/supp_coral03d.html

Needham, M.D. (2010). Value orientation toward coral reefs in recreation and tourism settings: A conceptual and measurement approach. *Journal of Sustainable Tourism,18* (6), 757-772. https://doi.org/ 10.3727/154427312X13388607171204

Neil, D. (1990). Potential for coral stress due to sediment re-suspension and deposition by reef walkers. *Biological Conservation*, *52*(3), 221-227. https://doi.org/10.1016/0006-3207(90)90127-B

Nemeth, R. S. & Nowlis, J.S. (2001). Monitoring the effects of land development on the near-shore reef environment of St. Thomas, USVI. *Bulletin of Marine Science*, *69*(2), 759-775.

Orams, M. (1999). *Marine tourism: Development, impacts, and management*. Routledge.

Pardini, A.U. & Katzev, R.D. (1983). The effect of strength of commitment on newspaper recycling. *Journal of Environmental Systems,* 13, 245-254. https://doi.org/10.2190/6PN9-MXFP-3BFF-CHHB

Petty, R. & Cacioppo, J. (1986). *Communication and persuasion: Central and peripheral routes to attitude change*. Springer-Verlag. https://doi.org/10.1037/0022-3514.51.5.1032

Pigram, J.J. & Jenkins, J.M. (1999). *Outdoor Recreation Management.* Routledge.

Plathong, S., Inglis, G. J. & Huber, M. E. (2000). Effects of self-guided snorkeling trails on corals in a tropical marine park. *Conservation Biology, 14*(6), 1821-1830. https://doi.org/10.1111/j.1523-1739.2000.99301.x

Prior, M., Ormond, R., Hitchen, R., & Wormald, C. (1995). The impact of natural resources of activity tourism: a case study of diving in Egypt. *International Journal of Environmental Studies, 48*(3-4), 201-209. https://doi.org/10.1080/00207239508710990

Richmond, R.H. (1996). Reproduction and recruitment in corals: Critical links in the persistence of reefs. In: C.E. Birkeland, (Ed.), *Life and Death of Coral Reefs.* (pp.175-197). Chapman & Hall.

Riegl, B. & Velimirov, B. (1991). How many damaged corals in Red Sea reef systems? A quantitative survey. *Hydrobiologia, 216-217*(1), 249-256. https://doi.org/10.1007/BF00026471

Rogers, C.S. (1990). Responses of coral reefs and reef organisms to sedimentation. *Marine Ecology Progress Series*, *62,* 185-202. https://doi.org/ 10.3354/meps062185

Roggenbuck, J. (1992). Use of persuasion to reduce resource impacts and visitor conflicts. In M. Manfredo (Ed.), *Influencing Human Behavior*, pp. 149-248. Sagamore Publishing.

Rouphael, A.B. & Inglis, G.J. (1997). Impacts of recreational SCUBA diving at sites with different reef topographies. *Biological Conservation*, *82*(3), 329-336. https://doi.org/10.1016/S0006-3207(97)00047-5

Rouphael, A.B & Inglis, G.J (2001). “Take only photographs and leave only footprints”?: An experimental study of the impacts of underwater photographers on coral reef dive sites. *Biological Conservation*, *100*(3),281–287. https://doi/org/10.1016/S0006-3207(01)00032-5

Rouphael, T., & Inglis, G. (1995). The effects of qualified recreational SCUBA divers on coral reefs. *CRC Reef Research Centre. Technical Report No. 4*, Townsville, Australia, 1-39

Rygel, L., O'Sullivan, D., & Yarnal, B. (2006). A method for constructing a social vulnerability index: An application to hurricane storm surges in a developed country. *Mitigation and Adaptation Strategies for Global Change*, 11, 741-764. https://doi.org/10.1007/s11027-006-0265-6

Salm, R.V. (1986). Coral reefs and tourist carrying capacity; The Indian Ocean experience. *Industry and Environment,9*(1), 11-15.

Sheppard, C. & Loughland, R. (2002). Coral mortality and recovery in response to increasing temperature in the southern Arabian Gulf. *Aquatic Ecosystem Health Management, 5*(4),395-402. https://doi.org/10.1080/14634980290002020

Smit, B. & Wandel, J. (2006). Adaptation, adaptive capacity and vulnerability. *Global Environmental Change,16*(3), 282-292. https://doi.org/10.1016/j.gloenvcha.2006.03.008

Spalding, M., Burke, L., Wood, S., Ashpole, J., Hutchison, J., & zu Ermgasssen, P. (2017). Mapping the global value and distribution of coral reef tourism. *Marine Policy, 82*,104-113. https://doi.org/10.1016/j.marpol.2017.05.014

Stern, P. (2000). Toward a coherent theory of environmentally significant behavior. *Journal of Social Issues, 56*(3), 407- 424. https://doi.org/10.1111/0022-4537.00175

Stern, P., Dietz, T., Abel, T., Guagnano, G.A. & Kalof, L. (1999). A Value-Belief-Norm Theory of support for social movements: The case of environmentalism. *Human Ecology Review,6*(2), 81-97. https://www.humanecologyreview.org/pastissues/her62/62sternetal.pdf

Stern, P. & Kalof, L. (1996). *Evaluating social science research*. Oxford University Press.

Stobart, B., Teleki, K., Buckley, R., Downing, N., & Callow, M. (2005). Coral recovery at Aldabra Atoll Seychelles: Five years after the 1998 bleaching event. *Philosophical Transactions of the Royal Society,363*(1826), 251-255. https://doi.org/10.1098/rsta.2004.1490

Talge, H. (1990). Impact of recreational divers on coral reefs in the Florida Keys. In W.C. Jaap (Ed.), *Advances in Underwater Science. Proceedings of the American Academy of Underwater Science 10th Annual Scientific Diving Symposium* (pp. 364-374).

Tratalos, J. & Austin, T. (2001). Impacts of recreational SCUBA diving on coral communities of the Caribbean island of Grand Cayman. *Biological Conservation*, *102*(1), 67-75. https://doi.org/10.1016/S0006-3207(01)00085-4

Walker, D.I. & Ormond, R.F.G. (1982). Coral death from sewage and phosphate pollution at Aqaba, Red Sea. *Marine Pollution Bulletin,13*(1), 21-25. https://doi.org/10.1016/0025-326X(82)90492-1

Webler, T., & Jakubowski, K. (2011). *Characterizing harmful behaviors of snorkelers and SCUBA divers to coral reefs in Puerto Rico: Interim Project Report.* Social and Environmental Research Institute: Greenfield MA, 15pp.

Webler, T. & Jakubowski, K. (2016). Mitigating damaging behaviors of snorkelers to coral reefs in Puerto Rico through a pre-trip media-based intervention. *Biological Conservation, 197*, 223-228. https://doi.org/10.1016/j.biocon.2016.03.012

Wells, S. & Hanna, N. (1992, August). Tourism time bomb. *New Internationalist, 234*. https://www.newint.org/features/1992/08/05/bomb/

Williams, I.D. & Polunin, N.V.C. (2000). Differences between protected and unprotected reefs of the western Caribbean in attributes preferred by dive tourists. *Environmental Conservation 27*(4), 382-391. https://assets.publishing.service.gov.uk/media/57a08d88ed915d3cfd001aaa/S0376892900000436a.pdf

Woodland, D. J. & Hooper, N.A. (1977). The effect of human trampling on coral reefs. *Biological Conservation*, *11*, 1-4. https://doi.org/10.1016/0006-3207(77)90020-9

Zakai, D. & Chadwick-Furman, N.E. (2002). Impacts of intensive recreational diving on reef corals at Eilat, Northern Red Sea. *Biological Conservation*, *105*(2), 179-187. https://doi.org/10.1016/S0006-3207(01)00181-1

Chapter 4
Vulnerability Assessment of Scuba Diving Activities in La Cordillera Nature Reserve, Puerto Rico

4.1 Introduction

Coral reef ecosystems make up only one percent of the ocean floor and yet have global ecological significance. Reef ecosystems are one of the most highly productive and diverse of all ecosystems providing ecological benefits and supporting many services for humans (Spurgeon, 1992). One such service that depends on coral reef ecosystems is tourism, which has been increasing as indicated by the exponential rise in visitors in the Caribbean (Neil, 1990; Tilmant, 1987). Activities associated with "on the reef" tourism include diving, snorkeling, glass bottom boat excursions, fishing, and kayaking as well as "reef adjacent" tourism which includes marinas, hotels, restaurants, and retail shops. Individuals who scuba dive are especially attracted to reef ecosystems for both their visual appeal and the variety of life found around reefs. While scuba diving may seem like a small impact compared to other large-scale impacts like warming ocean temperatures and changes in water chemistry, (at one time diving was considered to be a benign activity), research has shown that these activities can have a significant impact on the health of coral reef ecosystems (Allison,1996; Hawkins & Roberts, 1992; Kay & Liddle, 1989; Krieger & Chadwick, 2013; Liddle, 1991; Liddle & Kay, 1987; Plathong et al., 2000; Prior et al.,1995; Riegl & Velimirov, 1991; Tratalos & Austin, 2001). For example, scuba diving can affect the health of coral reefs especially when visitors act inappropriately. Specific damaging behaviors include fins kicking coral, brushing up against the reef, holding on to branching coral and accidentally breaking a piece, equipment contacting the reef, and siltation (Barker, 2003; Camp & Frazer, 2012; Chung et al., 2013; Harriott et. al.,1997; Krieger & Chadwick, 2013; Medio et al., 1997; Prior et al., 1995; Roche et al., 2016; Rouphael & Inglis, 2001; Talge, 1990;

Zakai & Chadwick-Furman, 2002).

Some scientists believe that even a single contact with the reef by a diver or snorkeler can cause a syndrome called "Shut Down Reaction" where tissues covering the coral skeleton slough off (Antonius, 1985). Hall (2001) found that minor human contacts damage the protective layer of tissue that covers the coral. Such tissue damage leaves coral more susceptible to algae colonization, which then collects sediment and can ultimately smother the corals (Walker & Ormond, 1982). Broken and damaged stony corals (Scleractinia) direct energy from normal growth and reproduction and use that energy to repair damaged and missing structures (Chadwick-Furman & Loya, 1990). Energy directed away from growth, development, and reproduction can affect the ability of corals to populate the reef. In addition, coral diseases caused by diver inflicted tissue loss can lead to shifts in the type, diversity, and percentage of corals that occupy reef ecosystems (Hawkins & Roberts, 1997).

Talge (1993) conducted an in-situ study to determine the effect touching and fin kicks by divers had on selected corals in the Looe Key National Marine Sanctuary in Florida. Corals were intentionally touched and kicked, once a week. After six weeks, the head and plate-like stony corals experienced a subtle color change. While no abnormalities were found in tissue samples taken from these corals, it is believed that the color change was a result of coral polyps contracting quickly and tightly when touched. Additional touching might cause the coral polyps to pull in even further causing an apparent color loss. It is important to acknowledge that this research method consisted of one diver making several contacts with selected corals once a week for a period of ten weeks. No attempt was made to evaluate the health of the coral but divers can mechanically break hard corals by grasping, scraping, or kicking (Liddle, 1991; Kay & Liddle, 1989; Liddle & Kay, 1987; Talge, 1993). These activities can be damaging in regions where scuba diving is chronic, concentrated, and steadily increasing in popularity. Yet, recreational impacts can be readily mitigated (Webler & Jakubowski, 2016). If human behaviors could be managed correctly, corals may be more capable of handling other stresses and thus less vulnerable to them (Gardner et al., 2003).

This research develops and demonstrates a method to characterize the vulnerability of coral reef resources in Puerto Rico to diving by documenting exposure levels, sensitivities, and adaptive actions and applying this methodology at popular diving reefs in La Cordillera Nature Reserve, Puerto Rico. These findings build a strong understanding of human impacts, which can support policy actions and educational opportunities that can reduce the vulnerability of coral reef ecosystems to this recreational activity.

4.2 Background

4.2.1 The Decline of Coral Reefs in the Caribbean

Coral reef ecosystems in the Caribbean have been declining for at least the last forty years, although pinpointing the beginning of the decline has been difficult (Appeldoorn et al., 2009). Scientists have documented early warning signs since the 1970s with the loss of elkhorn coral (*Acropora palmata*) and the loss of the long-spined black sea urchin (*Diadema antillarum*) in the 1980s, both from epizootics (Lessios et al.,1984). In the 1990's severe declines in several reef fishery catches were also documented (Appeldoorn et al.,1992). However, during this time, most of the coral reef research that had taken place in Puerto Rico focused on coral community characterization, monitoring programs, coral diseases, and environmental impact assessments (Garcia-Sais et al., 2008). To date, no research has been done on tourism activities, even though Puerto Rico's Coral Reef Management Plan, developed by coral reef managers from Puerto Rico, does prioritize the study of recreational use at reefs as one of its top eight priority goals.

This includes the development of strategies to reduce impacts from recreational use, protect the health of coral reefs, and enhance coral reef resilience.

4.2.2 Tourism in Puerto Rico

Despite their decline, coral reef ecosystems in Puerto Rico play an important economic role with an average value of nearly $1.1 billion dollars per year (Federal Emergency Management Agency [FEMA], 2018). In addition to protecting coastal infrastructure, food security, and reducing storm damage, coral reefs have an important role supporting the island's vibrant tourism industry. This is reflected in the number of people who visit the islands of Puerto Rico, the demand for services, and the number of people employed by the industry. Puerto Rico has a population of 3.7 million residents and yet it receives more visitors each year than the number of residents. Approximately 5 million visitors traveled to Puerto Rico in 2015, an increase from 4.4 million in 2014. This contributed four billion dollars to the economy. Hotel development increased by 15% in the last decade and tourism- related employment increased by 81% between 1985 and 2010 (Hernandez-Delgado et al., 2012). While extensive growth is occurring in the industry, the effect of tourism and recreational misuse upon coral reef systems surrounding the island of Puerto Rico is not well understood (Garcia-Sais et al., 2008).

Tour guide books and on-line resources boast about Puerto Rico's astounding water visibility and geologic diversity along each of its main coastlines which offer divers of various skills and interests a great deal of variety. The east coast, where my research was conducted, is described as having healthy, sloping reefs and several small islands to explore (Professional Association of Diving Instructors [PADI], 2018).

4.2.3 Scuba Diving at Coral Reefs

The development of SCUBA (self-contained underwater breathing apparatus) has expanded the abilities of humans to see and appreciate the underwater world, by providing a mechanism to breath underwater. On an international scale, scuba diving has been recognized as a form of marine-based leisure and tourism and is considered a multi-billion-dollar business (Dimmock, 2009; Garrod, 2009; Orams, 1999). The industry includes recreational vessels for day trips, live-aboard vessels for extended trips, dive shops, dive operators, dive magazines, dive clubs, dive videos, dive-oriented resorts, and even floating hotels. Scuba diving is a fairly involved recreational activity that requires training, certification, continuing education, and the rental or purchase of equipment. However, it is considered one of the world's fastest growing recreation sports. Reasons for this growth include safer equipment, ability for marine vessels to access remote scuba sites, and a continued growing interest in the underwater world (Davis & Tisdell, 1995; Dimmock, 2009; Harriott et al., 1997; Parker, 2001). According to the Professional Association of Diving Instructors (PADI), as of 2017, approximately 25 million people worldwide received a scuba certification since 1967 (PADI, 2018). PADI reports that it averages over 900,000 additional diver certifications each year (PADI, 2017). Since scuba certifications do not expire, there really is no method to track the activity level of every certified individual.

In addition, an important and growing component of the recreational scuba diving industry is "Discover Scuba." This brief course, offered at resorts and dive shops, is geared towards non-scuba certified vacationers interested in exploring the underwater world. The class provides a quick and easy, but carefully supervised, introduction to diving. Without needing certification, the concern with "Discover Scuba" is the number of inexperienced tourists participating in these excursions at coral reefs not being tracked globally (Barker, 2003; Davis & Tisdell, 1995). In addition, these first-time divers may be more likely to engage in behaviors that are harmful to coral reefs.

A similar problem exists with cruise ship travelers who participate in dive excursions. Research has found that cruise ship divers are more likely to contact reefs and break coral when compared to non-cruise ship divers (Barker, 2003). Barker attributes these findings to the 'non-specialist' level of cruise ship visitors, such as Discover Scuba. Cruise ship diving is usually only one of several off-ship activities that people attempt to try and, therefore, may attract a greater number of unskilled participants who may not take the activity as seriously.

Finally, some island resorts have the ability to offer unlimited, unsupervised day and night dives from shore (Barker, 2003). While these divers are certified, there is no way to track how often these individuals participate in such opportunities or how they behave while underwater.

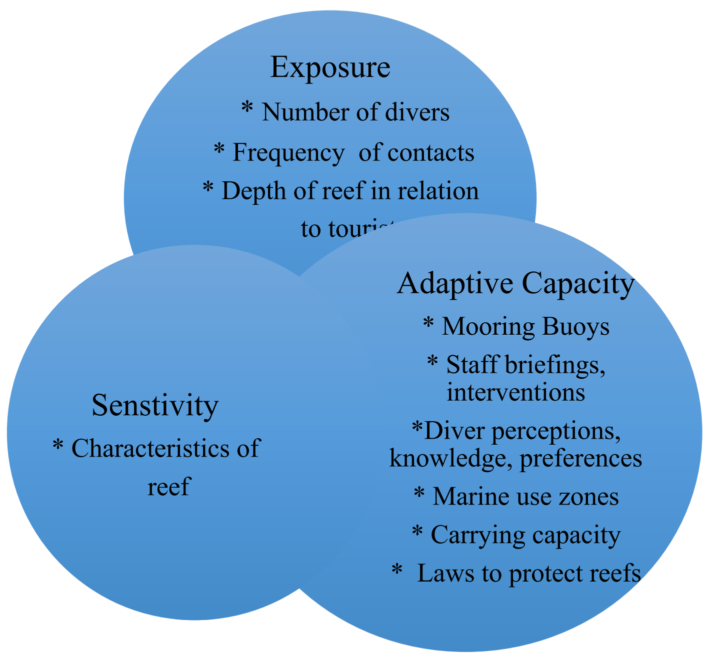
4.2.4 Vulnerability of Reefs to Scuba Diver Behaviors

Knowledge of the relative vulnerability of specific reefs to damage from scuba diving within Puerto Rico is necessary for informing and prioritizing management and conservation decisions for the tourism industry. Vulnerability is defined as the state of susceptibility of harm from exposure to stresses associated with environmental and social change (Adger, 2006). Vulnerability research consists of three main components - exposure, sensitivity and adaptive capacity (Adger, 2006; Gallopín, 2006). Gallopín (2006) defines exposure as the “degree, duration and/or extent to which the system is in contact with, or subject to, the perturbation.” Sensitivity is, “the degree to which the system is modified or affected by an internal or external disturbance or set of disturbances”. Adaptive capacity is “the system’s ability to adjust to a disturbance, moderate potential damage, take advantage of the opportunities, and cope with the consequences of a transformation that occurs” (295 – 296).

Determining the vulnerability of coral reefs to recreational activities includes measuring the exposure of reefs to recreational divers, characterizing the sensitivity of reefs to potentially harmful diver behaviors, and characterizing the adaptive capacity of the system by examining opportunities to influence management options (Figure 4.1).

Figure 4.1

Vulnerability assessment of coral reef ecosystems to scuba divers



Note. Vulnerability assessments include measuring exposure to divers, characterizing the sensitivity of reefs, and characterizing the adaptive capacity of the system.

In the context of this research, exposure refers to the number of divers at the reef, the frequency of potentially harmful actions that recreational divers can inflict on coral reef ecosystems and the spatial relationship between the diver and the reef. Qualities that make some corals experience more harm when exposed to the same stressor (the diver) include: the morphology of the coral, the topography of the reef, and the perceptions of divers. Adaptive actions in this case refer to decisions and actions taken by a variety of individuals connected to the tourism industry. For instance, the government can decide to install mooring buoys or not. Vessel captains can decide which reefs to visit and where to moor. The crew of the vessel decides how to prepare tourists for the dive experience. Finally, a diver can decide to behave responsibly while at the reef or not.

The use of indicators can provide a framework for measuring vulnerability that can provide both quantitative and qualitative insights into the outcomes and perceptions of vulnerability (Adger, 2006). The choice of indicators to use when analyzing exposure, sensitivity, and adaptive capacity in a specific context depend on the vulnerability of whom to what (Alwang et al., 2001; Carpenter et al., 2001; Rygel et al., 2006). For assessing the vulnerability of select reefs to snorkeler behaviors, inductive indicators will be utilized in this research for two reasons. First, the system can be described using several (but not many) variables. Second, sufficient data are available to indicate the variable and the potential harm. For example, one can induce that the variable "number of fin kicks to a coral" can indicate harm since it increases the incidence for breakage.

4.3 Review of Research that Focuses on the Exposure of Coral Reefs to Diving Activities

4.3.1 Number of Divers at the Reef

Research in many parts of the world has identified a correlation between the number of visitors to a reef and the degradation of reef conditions, supporting the claim that scuba diving can be a serious threat to coral reefs (Allison, 1996; Hawkins & Roberts, 1992; Kay & Liddle, 1989; Krieger & Chadwick, 2013; Liddle, 1991; Liddle & Kay, 1987; Plathong et al., 2000; Prior et al., 1995; Riegl & Velimirov, 1991; Tratalos & Austin, 2001). Up to a certain level of activity, diver-induced impacts appear to be minor, but beyond some "critical level" those impacts quickly become significant (Burgett, 1990; Davis & Tisdell,1995). The controversial and difficult challenge is to identify critical levels and attempt to limit divers to a number below that threshold. The carrying capacity of an ecosystem refers to the maximum level of recreational use (in terms of numbers of people and activities that can be accommodated by an area) before an unacceptable or irreversible decline in ecological function occurs (Inskeep,1991; Jameson et al.,1999; Pigram & Jenkins, 1999).

The coral reefs in Similan National Marine Park, Phuket, Thailand serve as an example of how tourism can impact a reef system. The reefs in the marine park were once considered to be in excellent condition and, therefore, an ideal location for scuba diving. The region received a small number of divers per year before the 1990s. However, in the mid-1990s, a popular magazine for divers rated the area's coral reefs in the park among the world's best locations to view marine biodiversity. Consequently, the tourism market and associated infrastructure exploded in the region. While in the early 1980s there were only two or three dive companies in the area, by the year 2000, there were more than 85 dive companies catering to over 100,000 divers a year. Some of the damage to the reefs in Similan National Marine Park is a potential result of such a rapid increase in recreational tourism (Dearden et al., 2006).

Limiting the number of people that can visit a reef is a proposed management strategy. Such measures can reduce crowding and environmental degradation. However, it is a complicated management strategy since it is difficult to estimate how many scuba divers a reef can support. The concept is more than just the number of people at the reef but also includes the type of activities at the reef, how the reef is managed, knowledge and behaviors of visitors, and tour operator decisions. The location of the reef and its morphology, topography, and depth, as well as water conditions, and other environmental stressors must all be considered.

The current estimate for divers at coral reef locations studied globally, is on average between 4000-7000 divers per site/per year (Dixon et al.,1993; Harriott et al., 1997; Hawkins & Roberts, 1997; Mundet & Ribera, 2001; Musa, 2002; Prior et al.,1995; Riegl &Velimirov, 1991; Zakai & Chadwick-Furman, 2002). Barker (2003) found that the most popular sites in St. Lucia and elsewhere received upwards of 10,000 divers or more (well above the recommended carrying capacity threshold at other locations).

Diving activities can be classified as consumptive or non-consumptive. Consumptive activities by divers include collecting shells, coral, and fish and affect carrying capacity since such actions deplete important resources. Non-consumptive activities, such as wildlife watching, free-diving, and photography can also have a direct impact on the reef by human contact (Spalding et al., 2017). Therefore, all activities should be considered when estimating carrying capacity as a management plan.

Several studies examined the impacts that divers have on coral reefs and all found a correlation between heavily used dive areas and an increase in the number of broken and damaged corals. At reefs in the northern Red Sea, Riegl and Velimirov (1991) classified and quantified the damage to corals at reefs frequented by dive tourists and reefs with low or no visitors. Data on the number of visitors to each reef were not recorded, but they found more broken coral and tissue loss at the heavily used sites. Their study ruled out wave action as the cause of the difference. Krieger and Chadwick (2013) assessed coral damage on reefs near Key Largo dive sites in the Florida Keys National Marine Sanctuary. Six patch reefs were selected ranging from low to high visitation rates estimated by the number of mooring buoys at each dive site. The lowest damage occurred on the reef with the fewest mooring buoys and the highest damage on the reef with the most mooring buoys, because more visitors were being brought to reefs with moorings.

Reef characteristics should also be factored into determining carrying capacity of a site and include the morphology, topography, and size of the reef. Dixon et al. (1993) found that in Bonaire Marine Park, divers seldom venture further than 300 meters in any direction from the mooring buoy. By analyzing coral cover, they identified that the carrying capacity for this marine park was between 4000 and 6000 dives per site per year. Hawkins and Roberts (1997) identified the percentage of damaged coral colonies in the Red Sea Ras Mohammed National Park and determined that the carrying capacity for this area should be between 5,000 and 6,000 dives per site per year. Zakai & Chadwick-Furman (2002) found that the carrying capacity for dive sites in the United States, Virgin Islands should be 500 divers per site per year. This rather low carrying capacity was attributed to the high sensitivity of the various reef organisms (sea fans, branching hydro-corals, soft corals, and erect sponges) in the study area (Table 4.1). Sipadan Island, off the coast of Borneo, became a diver's paradise in the early 1980s which raised concern over the exploitation of the island. The Federal Security Council of Sipadan limited the total number of divers allowed per day to 100. This limitation was not based on scientific research and resulted in dissatisfied resort owners who felt they were entitled to take more customers to the island (Musa, 2002).

The Medes Islands, a small, protected archipelago in the Western Mediterranean, is considered a popular scuba diving destination (Jenner & Smith, 1992). In the mid-1980s the tourism market was declining and the tourism sector decided to use diving as a way to improve the market. A video of a scuba diver surrounded by beautiful marine life, hand feeding a grouper, attracted an increased number of divers to the area. By 1990, it was estimated that over 100,000 dives were made in the area (Zabala, 1999). Overcrowding and environmental degradation became a big concern in this area that was legally protected and yet had no management strategies in place. By 1995, the government approved an order that limited the maximum number of divers to 450 per day (Mundet & Ribera, 2001). These findings suggest that establishing a carrying capacity for coral reef ecosystems is site specific and depends on a variety of factors.

Table 4.1
Suggested carrying capacities for diving at different reef locations around the world

Dive Location	Carrying Capacity	Study
Bonaire National Park	4000 – 6000 divers per site/year	Dixon et al., 1993
Medes Island	450 divers/per year	Mundet & Ribera, 2001
Red Sea Ras Mohammed National Park	5000 - 6000 divers per site/year	Hawkins &Roberts, 1997
Sipadan, Malaysia	100 divers per day	Musa, 2002
US Virgin Islands	500 divers per site/per year	Zakai & Chadwick-Furman, 2002

4.3.2 Direct Observation of Diver Behaviors which Result in Contacts with the Coral

Several in situ studies have observed divers under water and calculated their frequency of contacts with coral reefs (Table 4.2). A contact is defined as any part of the diver or equipment touching the reef. All of these studies found that a majority of diver contacts with the reef are the result of fins contacting the reef. Talge (1990) observed divers in the Looe Key National Marine Sanctuary in Florida to determine the frequency and nature of the physical contacts that divers made with the coral reef system. Of the 135 scuba divers observed, 951 contacts were recorded.

A majority (74%) of these contacts were the result of fins hitting the coral. Pushing off the reef (16%) was the second most common contact. The mean number of contacts was 0.11 contacts per minute. Talge (1990) also found divers who wore gloves had more interactions with the reef than those without gloves and male divers made more contacts with the reef than female divers.

Prior et al. (1995) observed divers at a popular resort along the Red Sea. They observed divers who were unaware they were being watched in order to determine the kinds of behavior, damage caused by such behavior, and the consequences of such damage. Like Talge (1990), Prior et al. (1995), concluded that the largest source of coral damage was from fins contacting the coral. The second most common and avoidable contact occurred when divers contacted the coral's skeleton while taking photographs. This was followed by reef contact from trailing equipment, holding on to corals, standing on the reef, and the least exhibited behavior - deliberately touching the coral. The mean number of contacts was 0.14 contacts per minute, slightly higher than the contact rate observed by Talge (1990).

Medio et al. (1997) observed divers who were not aware that they were being watched at dive locations within Ras Mohammed National Park in the Red Sea. Randomly selected pairs of divers were observed for seven minutes and the number of contacts made with the substrata was recorded. Divers contacted the reef 0.2 times per minute. As Talge (1990) and Prior et al. (1995) found, a majority of contacts (71%) were caused by fins contacting the reef. Voluntary hand contacts (61%) were the second most common contact with the reef. Like Prior et al. (1995), Medio et al. (1997) found that divers photographing the reef were accountable for a significant number of contacts (72%).

Harriott et al., (1997) observed divers at four different popular dive sites in Eastern Australia and found the mean number of contacts ranged between 35 - 121 per 30 minutes. The majority of contacts were fin kicks. Coral damage ranged from an average of 0.6 breaks per dive to 1.9 breaks per dive.

At Agincourt Reef in the Cairns section of the Great Barrier Reef Marine Park, Rouphael and Inglis (2001) accompanied and observed 214 qualified scuba divers for ten minutes each. 70% of reef contacts were caused by a small number of divers (4%) who were also participating in underwater photography. Finning was the major cause of coral contact (58%), followed by voluntary holding onto the coral (3%). The overall frequency of contacts per minute was much smaller (0.04) compared to the other studies discussed.

Zakai & Chadwick-Furman, (2002) observed 251 scuba divers for ten minutes each at different reef locations in Eilat, Israel on the Red Sea. They distinguished among the following behaviors: hand contact, fin contact, tank contact, hose contact, stony coral breakage, and raising of sediments. They reported a rate of about one of these behaviors per minute per diver.

During the high diving season in Key Largo, Florida, Camp and Fraser (2012) observed the frequency and timing of contacts that divers had with coral reefs and whether these behaviors were intentional. Of the 83 divers observed, 97% made at least one physical contact with the reef and the average number of contacts per minute was 0.33.

At seven different locations around Hong Kong, Chung et al. (2013) observed the underwater behavior of 81 recreational divers. Divers were observed for the entire duration of the dive and made 5.9 contacts per dive on average. The majority of the behaviors were kicking, trampling, and colliding with the coral due to poor buoyancy control. As found in previous studies, divers using camera equipment had more contacts with the reef than divers not using cameras. Divers were also asked to complete a survey at the end of their dive. 93% of the surveyed divers thought the damage inflicted on corals by their own underwater activities was small or negligible.

On reefs at Key Largo, Florida, Krieger and Chadwick-Furman (2013) observed 240 divers and reported a contact rate of 0.3/min with fin contacts, hand contacts, and equipment contacts being the most frequent. Divers with cameras and/or gloves caused the most damage.

In the Philippines, Roche et al. (2016) observed 100 divers, each for an entire dive at 30 specific reef locations. The contact rate was 0.12 contacts per minute. 88% contacted the reef during the observed dives. Fin kicks (46%), hand touches (20%), and equipment (16%) were the top three contributors to contacts.

One of the most thorough studies of tourism behavior at coral reefs is the doctoral thesis work done by Nola Barker (2003) on St. Lucia. She accompanied 353 divers on scuba trips and recorded each of their behaviors while diving in order to determine what impact divers had on the reefs and how the reef environment affects a diver's perceptions and experiences of the reef. She found that 74% of the 353 divers observed made at least one unintentional contact with the reef during a dive. Fin contacts were the most common behavior, followed by touching and holding corals, and damage caused by loose and dangling equipment. Barker found that divers using a camera versus those not using a camera had significantly more contacts with the reef, confirming earlier work by Prior et al. (1995), Medio et al. (1997), and Rouphael and Inglis (2001). Most contacts with coral occurred during the first ten minutes of the dive. Overall, fin kicks were the most common behavior (81.4%), followed by touching and holding corals (10.1%), and damage caused by loose and dangling equipment. All of these studies found that similar behaviors were responsible for the majority of the damage to coral reefs. The overall frequency of contacts per minute was much higher (0.25 contacts/min) compared to most of the other studies discussed (Barker, 2003).

Table 4.2

Frequency of contacts by divers at other coral reef ecosystems

Study	Location	N	Contacts (per minute)
Barker (2003)	St. Lucia	353	0.25
Camp & Fraser (2012)	Key Largo, Florida	83	0.33
Chung et al. (2013)	Hong Kong	81	5.9
Harriott, Davis & Banks (1997)	Eastern Australia		35-121 per 30 minutes
Krieger & Chadwick (2013)	Key Largo, Florida	240	0.3
Medio et al. (1997)	Ras Mohammed National Park, Red Sea		0.2
Prior et al. (1995)	Red Sea		0.14
Roche et al. (2016)	Philippines	100	0.12
Rouphael & Inglis (2001)	Agincourt Reef Cairns, Australia	214	0.04
Talge (1990)	Looe Key National Marine Sanctuaries, Florida	135	0.11
Zakai & Chadwick-Furnam, (2002)	Red Sea, Eilat, Israel	251	1.0

4.3.3 Diver Threats to Coral - Sedimentation

Divers close to sandy bottoms can cause the re-suspension of sediment, exposing coral polyps to additional sediment loads (Neil, 1990; Rogers,1990; Zakai & Chadwick-Furnman, 2002).

Sedimentation reduces growth and reproduction in coral reef species (Hawkins & Roberts, 1996; Nemeth & Nowlis, 2001; Richmond, 1996). Coral polyps that are constantly exposed to sedimentation expend a great deal of energy to rid the colony of particles instead of using this energy for growth and reproduction (Dodge et al., 1974; Richmond, 1996; Rogers, 1990). This can lead to a decline in coral cover, change of coral communities, and increased partial mortality (Rogers,1990). Nowlis et al. (1997) found that sediment pollution was an important cause of coral death in St. Lucia. Divers who re-suspend sediments in areas with high sediment pollution could intensify existing sedimentation pollution.

Suspended sediment particles in the water column decrease light penetration. Light is a necessary component for the symbiotic algae that live with corals since it provides the chemical energy necessary for photosynthesis. Sediments that land on coral can also disrupt the exchange of gases necessary for photosynthesis.

4.3.4 Diver Threats to Coral - Hunting/Collecting

Searching for marine organisms is a common and popular activity among skilled divers. Species that draw attention include lobsters, octopus, morays, attractive invertebrates, turtles, and unique fish that live on the substratum. Uyarra et al. (2009) assessed the damage to corals caused by divers observing cryptic fish, specifically seahorses and frogfish. Dive operators are aware of the locations of these species and thus profit from repetitive visits to the same locations on the reef with each new group of divers. These repetitive visits lead to both direct impact damage and the effects of overuse. Uyarra et al. (2009) found that 75% of divers came in contact with the reef in the presence of cryptic species. They also found that the patterns of coral damage around cryptic fish reflected diver contact. The number of scars on corals in Bonaire and the Caribbean differed significantly between frogfish/seahorse dive sites and sites not visited by divers.

Damage to corals decreased with increasing distance from the location of these organisms. In addition, the patterns of coral breakage were similar to those of scarring. The number of live coral increased significantly with distance from a seahorse or frogfish dive site. There were also more dead corals, fewer sponges, and a tendency for less live coral at seashore/frogfish sites. These findings support the conclusion that the presence of cryptic organisms is a quality that makes reefs more sensitive to contacts and damage.

There is a paucity of research on the impacts caused by recreational divers hunting and collecting organisms around coral reefs. Species like the Caribbean octopus and other popular mollusks are highly sought specimens. Considering many of these species are also cryptic, divers most likely come in close proximity to the reef and thus contact may be unavoidable.

4.3.5 Diver Threats to Coral - Scratching/Abrasions

Scratches or abrasions on corals that are caused by diver contacts are considered direct mechanical damage (type 1 damage). Type 1 damage may expose corals to type 2 damage, defined as an infection, disease, or tissue loss that results from other opportunistic marine organisms. Organisms that cause type 2 damage include algae, barnacles, microscopic pathogens, crown-of thorns starfish, brittle starfish, and various species of fish (Riegl & Velimirov, 1991). Hawkins and Roberts (1992) studied coral reefs in Palau Malaysia and found that broken, abraded, and damaged corals were more likely to be infected by type 2 damage by pathogenic organisms. In addition, coral reefs were less likely to recover from such invasions and had a higher risk of mortality when impacted by both type 1 and type 2 damage (Hall, 2001).

4.4 Review of Literature that Focuses on the Sensitivity of Coral Reefs to Scuba Diver Activities

4.4.1 Reef Topography

The topography of a dive site plays an important role in determining how often a diver may contact the reef. This comes into play in two ways. First, topography can attract visitors to swim in tighter places and, therefore, produce more opportunity to accidently contact coral. Second, divers are inspired to spend more time visiting the portion of reef that has varied topography. Sites typified by plateaus had a higher rate of diver contact than other sites (Barker & Roberts, 2004). Salm (1986) found that when people dive over homogenous, flat, shallow reefs, they are more likely to cover greater areas since they are limited in opportunities to explore the reef. However, a group of divers swimming over corals with an irregularly shaped topography, will have more options to explore and a greater diversity to view. This group will most likely spend more time around a smaller percentage of the reef. On reefs with steep slopes (walls), benthic organisms will be less sensitive to divers who are more skilled (able to control buoyancy) whereas less skilled divers may touch or grasp the wall for support.

4.4.2 Reef Morphology

Reef morphology is defined as the form and structure of coral species. Coral characteristics can shape the vulnerability of the reef to physical damage (Table 4.3). These sessile invertebrates can be ranked according to how susceptible they are to structural damage (Chadwick-Furman, 1997). Fragile, branching corals (hydrocorals) are among the first to be broken when exposed to physical contacts from humans or equipment (Liddle, 1991; Liddle & Kay, 1987). These corals are also the most vulnerable to breakage by natural causes which includes strong storms, and predation. Intermediate ranked vulnerable corals include branching corals, soft corals, encrusting corals, and stony corals. Soft branching corals are considered to have some resilience to diver contacts (Fox et al., 2003; Hall, 2001; Sheppard & Loughland, 2002; Stobart et al., 2005). Encrusting species have a major advantage over their branched relatives since they remain close to the substrate they are encrusting. Hard coral species tend to have a slower growth rate compared to soft corals which can make them more sensitive if damaged. Massive stony corals are classified as the least vulnerable to damage most likely because of their dense skeletons and lack of branching structures (Chadwick-Furman, 1997). These massive boulder-shaped stony corals are also seldom damaged by strong wave action unless they are dislodged from their holdfasts (National Ocean Service [NOS], 2016).

Table 4.3

Coral categories by morphology

Coral Categories	Morphology	Sensitivity	Taxonomic Groups & Examples
Massive Coral (Boulder)	Characteristically ball or boulder-shaped and relatively slow growing. can be egg size or as large as a house.	Stable, seldom damaged by strong wave action unless dislodged from its holdfast.	*Faviidae* (Brain Coral)
Encrusting Coral	Low spreading forms that usually adhere to hard rocky surfaces. Grows larger in diameter verses upward like many other forms of coral.	Major advantage over branching relatives since they remain close to the substrate they are encrusting. Can withstand high wave activity.	*Astrocoeniina* (Star coral, fire coral)
Branching Coral (Thick)	Exceptionally thick and sturdy antler-like branches, usually fast growing with branches increasing by 5 – 10 cm per year.	Typically found in areas of high wave activity.	*Acroporidae* (Elkhorn)

Table 4.3 (continued).

Branching Coral (Stubby, finger-like)	Irregular, stubby branches with blunt and enlarged tips.	Stubby branches can withstand wave activity.	*Poritidae* (Finger coral)
Soft Corals	Lack, hard, rigid, permanent skeletons various branches, stalks	Move with water current which can increase sensitivity	*Anthothelidae* (Gorgonians sea fans)
Foliose Coral	Whorl-like growth structures that have been compared to the open petals of a flower.	Folds and convolutions greatly increases its surface area which can result in increased exposure to mechanical damage.	*Fungiida* (Lettuce coral)
Columnar Coral	Digit-like, columns	When exposed to storm conditions is much more susceptible to breakage.	*Meandrinidae* (Pillar corals)
Table Coral	Broad, horizontal surfaces. Pattern of growth increases the exposed surface area of the coral to the water column	Increases surface area can result in increased. exposure to mechanical damage	*Fungiida* (Sheet coral, Saucer coral)
Branching Coral (Thin)	Branches that also have secondary branches	When exposed to storm conditions, are much more susceptible to breakage	*Acroporidae* (Staghorn)
Branching (Fine, hydrocorals)	Colonies form multiple, branched structures in all directions, will encrust and take on shape of other coral	When exposed to natural conditions (water motion) are most sensitive to breakage.	*Millepornina* (Hydrocorals, lace corals)

Note. Morphology of coral species, listed from least to most sensitive. Coral descriptions are from the National Ocean Service (2016).

Hawkins and Roberts (1992) studied the fore-reef slope communities around Sharm-el-Sheikh on the coast of the Egyptian Red Sea. In the heavily dived area they found more broken hard corals, abraded colonies, live loose coral fragments, reattached fragments, and partly dead colonies than in the non-dived areas. Prior et al. (1995) also compared types of coral damage between dive and non-dive sites at Sharm-el-Sheikh. The dive sites had more broken, crushed, and knocked over coral than did non-dive sites.

To determine the effects that scuba diving has on coral reef species in the U.S. Virgin Islands, Chadwick-Furnam (1997) observed six different invertebrate species at 7 different locations and counted the number of damaged and undamaged corals at each site. Massive stony corals had low levels of damage, erect sponges and branching stony and soft corals had intermediate levels of damage, and sea fans and branching hydrocorals had the highest levels of damage. Chadwick-Furnam (1997) concluded that damage to branching and soft corals (those classified as the intermediate levels of damage) varies directly with the number of divers at the reefs.

At nine sites in the West Bay area of Grand Cayman Island, Tratalos and Austin (2001) classified diver use level based on a census of the island's major diver operators. The three sites most heavily used had significantly lower percentages of hard coral than low intensity and non-dive sites.

Krieger and Chadwick (2013) assessed coral damage on reefs near Key Largo dive sites in the Florida Keys National Marine Sanctuary. Six patch reefs were selected ranging from low to high visitation rates estimated by the number of mooring buoys at each dive site. Almost all live stony corals exhibited tissue mortality at the reefs with the most moorings.

In Bonaire, Lyons et al. (2015) tested for differences in the benthic assemblages between heavily visited dive sites and those that receive few divers and found 10% less structure complexity in the heavily dived sites. The benthic environment also varied between sites. Massive corals, such as *Orbicella annularis*, were 31% less abundant at the heavily diver visited sites than the less visited sites.

4.5 Adaptive Actions that Mitigate Exposure

Adaptive capacities are the skills, experiences, strategies, and resources that are needed to implement actions that can reduce vulnerability (Smit & Wandel, 2006) These "adaptive actions" can reduce exposure, change sensitivity, or alter the human-natural system. Such measures can protect reefs in priority areas while still promoting tourist activity. Decision makers who take adaptive actions that shape the vulnerability of coral reef ecosystems in Puerto Rico include: The Department of Natural Resources, The Puerto Rico Tourism Company, tour operators (including owners, captains, and staff), and the visitors, specifically divers, themselves.

4.6 Modifying Recreationalists' Behavior

4.6.1 Dive Tour Operators

In La Cordillera Nature Reserve, there are two major dive operations that leave from Fajardo daily, during the high season, bringing scuba divers to several possible reefs that are designated scuba diving areas within the reserve and include dive locations around Palominos Island, Diablos, and Lobos (Figure 4.4). The decision of where to go is largely left to the captain and crew and is "key" to understanding the exposure of reefs to divers and, therefore, understanding the vulnerabilities of these systems.

The crew of these vessels also shape the exposure of the reef to visitor contacts. They orient divers to the reef, provide "Discover Scuba" lessons, give instructions for how to experience the reef, encourage or discourage types of behavior, and provide oversight and correction.

4.6.2 Tour Operator Briefings

Medio et al. (1997) examined effects of a verbal intervention on divers at Ras Mohammed National Park in Egypt. This within-subjects study evaluated tourists who purchased a 5-day,10-dive package. Mean rates of contact with coral for the first 3 dives were 0.2/min. Before the 4th dive, tourists received a 45-minute presentation explaining coral reef biology, diving behaviors that damaged reefs, and the purposes for creating marine protected areas. This was followed by an in-water demonstration of how to identify live reef cover and non-living substrate. Mean rates of contact were significantly reduced to 0.05/min for dives post treatment. Barker (2003) tested the effect of a one-sentence inclusion in a regular pre-dive briefing given by tour operators at St. Lucia. The intervention had no effect on diver behavior. Camp and Fraser (2012) found that when dive leaders provided a more in-depth conservation education dive briefing, there was a significant reduction in the number of impacts divers made with the reef. Divers who received a conservation focused briefing contacted the reef less (0.16 touches per minute compared to 0.37 touches per minute).

Krieger and Chadwick (2013) compared divers affiliated with Blue Star dive shops to divers not affiliated with a Blue Star shop. The Blue Star program was established in the Florida Keys National Marine Sanctuary to recognize charter boat dive operators who promote responsible and sustainable diving in the Florida Keys. Blue Star operators promote reef conservation awareness and diving and snorkeling etiquette through various strategies including on-line information, coral identification cards, and informative pamphlets. Blue Star dive shops administer short dive briefings prior to each dive explaining that divers were in a protected area and should not touch or take any corals since they are living organisms and vital to the health of the reef. They found dive contacts from Blue Star operations were significantly lower (0.23/min) than non-Blue Star operations (0.37/min; p<0.001). Coral tissue abrasion and sediment deposition was also significantly lower for Blue Star divers than non-Blue Star divers (p <0.001).

4.6.3 Diver Interventions

In two subtropical rocky reef marine protected areas, Hammerton and Bucher (2015) tested two levels of interventions to determine if these strategies reduced the number of diver contacts with the coral reefs. The first was a targeted briefing with specific references to minimize benthic contact and the second included the targeted briefing as well as a direct underwater reinforcement at the time of the contact (an underwater slate was shown to a diver contacting the reef with the message “please keep off the reef.”). Hammerton and Bucher (2015) found that the targeted briefing had a significant effect over the usual briefing, but in-water reinforcements had a significantly greater effect than just the targeted briefing alone. Dive interventions are defined as an action taken by a dive guide to correct a behavior that may be harmful to the reef or marine life. A dive guide can intervene by signaling or demonstrating a correct behavior in order to prevent, correct, and reduce the number of contacts divers make with the reef or harmful interactions with marine life.

Barker and Roberts (2004) found that an in-water intervention by a dive leader was an effective strategy for reducing contacts with the reef. Roche et al. (2016) examined the role of dive supervision by recording dive guide interventions underwater, and observed a total of 81 interventions. 80% of these interventions were a buoyancy correction or a correction to prevent a contact with the reef before it occurred.

4.6.4 Scuba Divers

Scuba divers participating in excursions include residents of Puerto Rico and tourists. At the reef, divers make decisions that shape the exposure of the reef to harmful actions. They decide how to manage their movements in the water (divers may intentionally touch the reef to take a photo or wear gloves so they can touch organisms) or collect pieces of coral or shells at the reef. A diver's view on the conditions of the reef (water visibility, diversity of marine life, health of the reef) have also been useful for management strategies (Klint et al., 2012; Lucrezi et al., 2013; Musa, 2002). More experienced divers may exhibit recreation specialization which can also influence their behavior. The overall group behavior of scuba divers is also guided by social norms.

4.6.5 Recreation Specialization

Recreation specialization is defined as a temporal linear progression in an activity performed by outdoor recreationists (campers, anglers, divers) in which participants move from general interest and low involvement to specialized interest and high involvement. Each level of specialization involves distinctive behaviors and skills and includes other factors such as equipment preference, type of experiences sought, desired setting for the activity, attitudes toward resource management, preferred social context, and vacation patterns (Loomis et al., 2008). There have been a few studies on the theory of recreation specialization related to the attitudes of divers. Todd (2000) surveyed scuba divers to examine their level of development in relationship to their motivation to dive and found that commitment, skill, experience, participation, professional development, and knowledge increased as a diver moved up the specialization scale. Interestingly, these factors decreased when divers stopped participating in the activity.

Thapa et al. (2006) collected data from 370 divers to see if there was a connection between recreation specialization and marine based environmental behavior. They looked at factors related to three major categories of environmental behavior. The first category was contact behavior and included questions about frequency of participation in scuba diving and contact with marine life. The survey included questions about experience, participation, touching marine organisms, standing on coral, and collecting marine artifacts. The second category focused on general diving behaviors and included questions about wearing gloves, streamlining equipment, skill level, and buoyancy in the water column. The final category focused on education and knowledge and the centrality of scuba diving to one's lifestyle. Survey questions were designed to ask where specific knowledge about marine life was acquired and how often those surveyed participated in marine related events.

Thapa et al. (2006) found that the frequency of diving participation was high with 39% reporting having completed over 159 dives and 21% reporting they had completed over 100 dives in the area where the research was conducted. Almost 18% of those surveyed had been diving for more than 20 years. There was a strong correlation between increased levels of experience and ability and decreased participation in environmentally insensitive behaviors. They also found that as a diver increased his or her involvement in diving, centrality to lifestyle also increased as did one's knowledge about the marine environment. Efforts to practice environmentally responsible behaviors underwater were also reported as a priority. These findings suggest that there is a positive association with specialization and pro-environmental behavior.

Loomis et al. (2008) also studied the role that recreation specialization has in fostering environmentally responsible behaviors of divers and snorkelers in the Florida Keys. In this study, the researchers utilized eight testable propositions developed by Ditton et al. (1992) to further study Bryan's theory of recreation specialization. Ditton et al. (1992) re-conceptualized the topic of recreation specialization in terms of social sub-worlds (Loomis et al., 2008). Social sub-worlds are defined as “internally recognizable constellations of actors, organizations, events, and practices which have coalesced into a perceived sphere of interest and involvement for participants” (Unruh, 1979).

In order to link Bryan’s work with these social sub-worlds, Ditton et al. (1992) developed eight propositions. The first proposition states that people participating in a given recreation activity are likely to become more specialized in that activity over time. The second claims that as the level of specialization in a given recreation activity increases, the value of side bets (financial and emotional investments) will likely increase. Next, as the level of specialization in a given recreation activity increases, the centrality of that activity in a person’s life will likely increase. The fourth states that as levels of specialization in a given recreation activity increase, acceptance and support for the rules, norms, and procedures associated with the activity will likely increase. The fifth proposition posits that as the level of specialization in a given recreation activity increases, the importance attached to equipment and the skillful use of that equipment will likely increase. Proposition six claims that as the level of specialization in a given recreation activity increases, dependency on a specific resource will likely increase. The seventh proposition states that as the level of specialization in a given recreation activity increases, the level of mediated interaction relative to that activity will likely increase. The final proposition states that as the level of specialization in a given recreation activity increases, the importance of activity specific elements of the experience will decrease relative to non-activity specific elements of the experience. Loomis et al. (2008), surveyed both resident and non-resident divers in the Florida Keys, and found that 98% of resident divers and 97% of non-resident divers were classified as having a moderate or high level of specialization. Higher concentrations of less specialized resident and non-resident divers were found in the lower keys compared to the upper keys. The survey results supported several of these propositions. For example, proposition number four, specialized divers have a greater acceptance and support for the rules, norms, and procedures associated with an activity, was found to be significant. This is an important finding for outreach and management strategies. Local Action Strategies can design different kinds of strategies for these two geographical regions based on where specialized divers and non-specialized divers recreate. Since specialized divers have a greater acceptance of the norms, rules, and procedures for protecting coral reefs, strategies can target low or moderately specialized divers to practice reef etiquette behaviors while participating in recreation activities. This also applies to "resort divers" who are not certified.

Loomis et al. (2008) also found that divers with higher levels of recreation specialization were more likely to seek out information compared to those at the lower end of the specialization scale, which supports proposition number six. They also found that specialized divers have a greater financial and emotional investment in the activity which correlates with proposition number two. In addition, they found that less specialized divers depend on other divers or dive operators for the necessary information needed about diving at specific locations. These divers did not depend on any other informational sources. This is an important finding for Local Action Strategies since it supports a key role for those in the dive industry. Dive operators, instructors, and masters can ultimately play a vital role in the delivery of messages that promote environmentally responsible behaviors and coral reef etiquette. Local Action Strategies should include these concepts.

4.7 Methodology

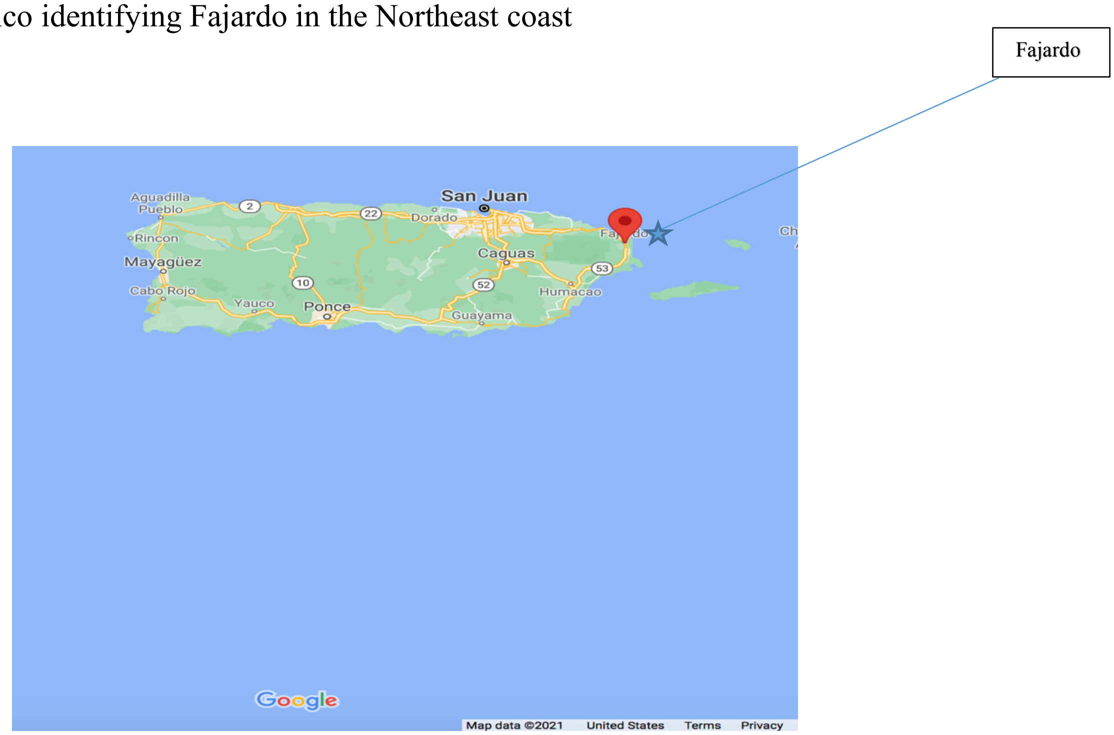
My research included designing a methodology to measure the exposure and sensitivity of a coral reef ecosystem in La Cordillera Nature Reserve, Puerto Rico to divers, as well as to understand the adaptive actions of captains and crew who make key decisions of which reefs to visit and how to prepare divers for the experience in order to reduce exposure. I then applied and evaluated this approach to select reefs within La Cordillera Nature Reserve.

4.7.1 Study Site

Fajardo, a small city located in the east region of the island, is a popular destination for marine recreational activities (Figure 4.2). The development of the El Conquistador Hotel in the 1960's launched the tourism industry in Fajardo which now is home to five large marinas, including Marina Puerto del Ray, the largest in the Caribbean. A majority of the registered vessels in Puerto Rico (greater than 65,000) are located in this area. While the tourism industry continues to grow rapidly, the effect of tourism and recreational misuse upon coral reef systems on the island of Puerto Rico is not well understood (Garcia-Sais et al., 2008). Tourism benefits are often measured as economic achievements and not ecological ones. Concerns about ecological degradation are often seen as impeding tourism benefits. In Fajardo, sewage discharge, vessel groundings, anchoring, oil pollution, illegal dumping of garbage, recreational overfishing, and collecting of coral as souvenirs have all contributed to localized coral reef degradation and mortality at the reefs in the waters at La Cordillera Nature Reserve (Figure 4.3), located off the coast of Fajardo (Hernandez-Delgado, 2005).

Figure 4.2

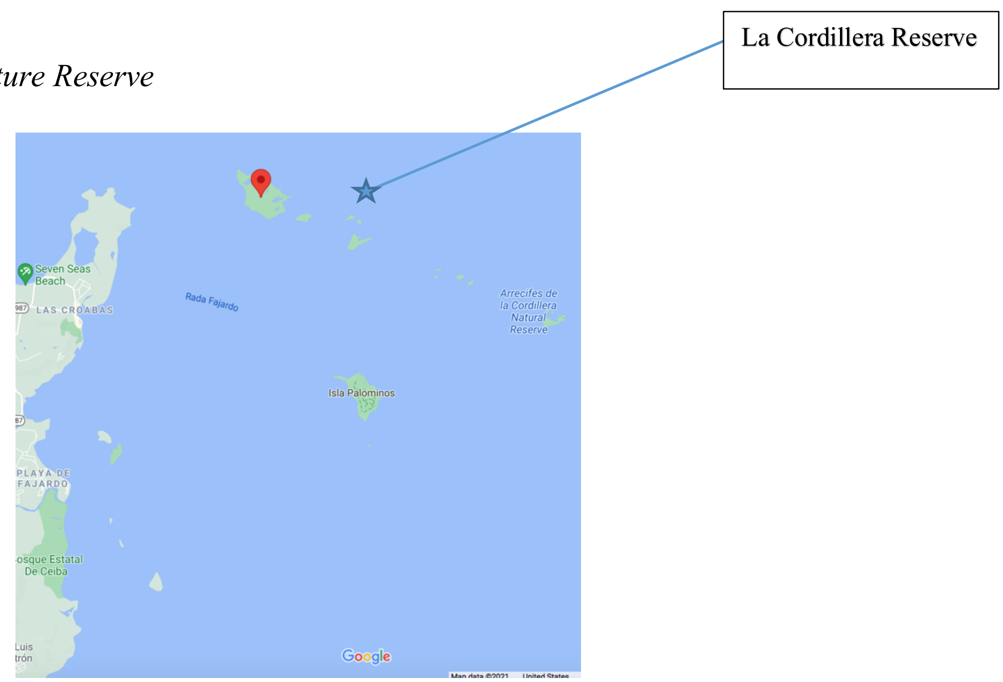
Map of Puerto Rico identifying Fajardo in the Northeast coast



Note. Maps Data: Google ©2021

Figure 4.3

Map of La Cordillera Nature Reserve

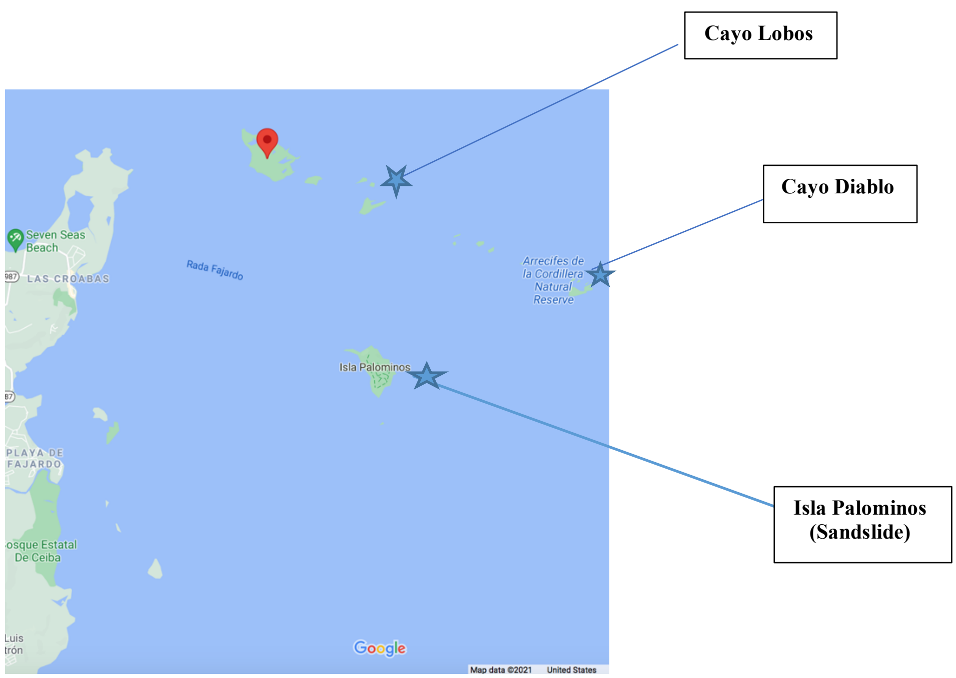


Note. Maps Data: Google ©2021

La Cordillera Nature Reserve, (Cayos de la Cordillera Nature Reserve), is a chain of ten small islands and keys with coral reefs, mangroves, lagoons, and sandy beach ecosystems. These ecosystems are critical habitat for several marine species including sea birds, sea turtles, and the West Indian Manatee (National Oceanic Atmospheric Administration [NOAA], 2009). The reserve is managed by the Department of Natural Resources. The islands are uninhabited, quiet and secluded. Opportunities for snorkeling, diving, swimming, and sailing are available because the waters are generally calm and clear. There are two scuba diving companies that leave from Fajardo daily, year round bringing hundreds of scuba divers to the different islands including Cayo Lobos, Cayo Diablo, and reefs around Isla Palominos (Figures 4.4).

Figure 4.4

Map of the popular reefs visited by diver operators (Cayo Lobos, Cayo Diablo, Isla Palominos)



Note. Maps Data: Google ©2021

4.7.2 Design and Application for Divers

The variables of exposure, sensitivity, and adaptive actions were measured as part of my design and application for a vulnerability assessment of divers recreating around coral reef ecosystems in La Cordillera Nature Reserve, Puerto Rico. Exposure included: the types and frequency of contacts by divers, the number of divers over the reef, and the duration of time individuals spent diving over the reef. The variables measured for sensitivity included the morphology and topography of the reef. The adaptive actions characterized included crew decisions about dive trips, their attitudes, and beliefs about coral reefs, and their interactions with divers before entering the water as well as during the dive. Divers' perceptions as well as their attitudes and beliefs about coral reefs and conservation were also factored into this assessment. Table 4.4 lists the variables designed and measured to complete a vulnerability assessment for divers.

Table 4.4

Variables measured as part of a vulnerability assessment for scuba divers

Vulnerability Assessment	Variable	Measured
Exposure	Number of divers at the reef for the entire time	Review captains' logs to determine the number of trips each operator makes per year and the number of divers on the vessel and the reefs visited during the 2011 and 2012 season
Exposure	Type and number of contacts/per minute/ per diver	Random in-water observation of 100 divers for a five-minute period to record the number, type, and severity of contacts with the reef.

Table 4.4 (continued).

Sensitivity	Reef topography	Video transects along fairly well established scuba routes used by dive operators to characterize reef as either plateau, slanting, varied, or wall.
Sensitivity	Reef morphology	Video transects along fairly well established scuba routes used by dive operators.
Adaptive Action	Staff Decisions	Interview key informants (vessel owners, captains, crew, dive instructors, dive masters).
Adaptive Action	Operators Briefings	Pre-dive briefings and interventions given to divers by vessel crew.
Adaptive Action	Diver knowledge, perceptions, and beliefs	Survey completed by divers after vessel is docked back at marina.

4.7.3 Collaboration with Tour Operators

There are only two major Scuba diving tour operators that are Fajardo-based and organize trips on a regular basis to La Cordillera Nature Reserve. I approached both owners, explained my research and requested permission to attend dive trips free of charge. I explained that I would observe divers in the water without their consent or knowledge. I also asked permission to distribute surveys to divers post trip back at the dock. Both owners were strongly supportive and allowed me to attend trips as long as there was space available on the vessel.

4.7.4 Diver Observation Protocol

In developing the in-water observation protocol, I drew on previous work of researchers who have made in-water observations of divers. Dr. Thomas Webler was instrumental in developing and guiding this process. The two tour operators make up to three daily trips to La Cordillera

Nature Reserve (Figures 4.3 & 4.4). Operators follow a similar schedule offering a two-tank morning dive at two different reefs within the Reserve and a one tank afternoon dive visiting only one reef. There are nine dive sites that dive operators can select from, but not all were visited during the time period when I collected my data. Dive reefs visited around Palominos Island include: (1) Sandslide, and (2) Trench, and other reef dive sites include (3) Diablos and (4) Lobos (a different part of the reef from where snorkeler operators visit). Other sites that dive operators list as potential reefs to visit within La Cordillera Nature Reserve include (5) The Wall, (6) Spurs, (7) Spurs and Grooves, (8) Big Rock/Little Rock, and (9) Sebation.

4.7.5 Observing Diver Behavior (Types and Frequency of Contacts/per Minute)

On the days I observed divers, I checked in at the dive shop at 7:30 am, received and prepared my equipment, and boarded the vessel for a 9:00 am departure to the first dive location within La Cordillera Nature Reserve. Onboard I kept my purpose and intent private to avoid influencing divers. To prevent the staff from changing their behavior with guests or to alter their briefings, I kept the details of my research limited even with the crew. Data about the dive trip was recorded (Table 4.5). If a diver asked about my clipboard and data recording sheets, I stated that I was a graduate student collecting data on coral reefs and the fish in Puerto Rico.

Upon departure, the crew gives an in-depth vessel safety briefing and dive safety reminders. Once at the first dive site, dive instructors give another onboard in-depth briefing, but this briefing focuses specifically on our dive plan while the instructors have the attention of everyone onboard the vessel. All dives are led by a dive instructor or dive master. The maximum number of certified divers per instructor/dive master was approximately eight. After the briefing divers buddy up, check and don their gear, and complete a safety check with their buddy. With the assistance of vessel crew, each certified diver disembarks (one at a time) using a technique called a giant stride entry. Divers wait at the surface until the entire group is in the water and descend together per the instructions of the dive instructor. Once the entire group has descended, divers will stay with their buddy and follow the dive instructor who is leading the excursion. Dive operators do not allow descents to take place directly over the reef.

The following protocol was utilized to select and observe certified divers and the types of behaviors (contacts) observed at the reef. Onboard, paired dive buddies were placed into small groups and assigned an instructor/dive master who led the excursion. Non- certified divers were grouped together with an instructor to review basic skills. During the dive, I stayed towards the back of the group and was able to observe each diver at least once during a 45-minute dive (average dive time). Once at the reef, the first diver in my immediate line of view was observed. I started a timer and followed 1.5 – 2 meters behind the diver. Using an underwater slate and waterproof, data sheets, I counted and recorded the different types of behaviors observed. I also recorded identifying information (design on wet suit, fin color, hair color, facial hair, tattoo, or other identifying features) as well as gender so that the individual could be approached to fill out a survey afterwards (Table 4.6). Observations of the individual ended when five minutes passed. At the end of each observation period, I would turn right and immediately begin observing a new diver who came into my view over the reef. I was able to observe each diver once. If there was time left during the dive, I would start with the initial diver and make a second observation. These data collection and experimental protocols were approved by a Human Subjects Review Committee at Antioch University New England.

The unit of analysis was a diver’s behavior for 5 minutes during a one tank dive. The dependent variables were: frequency, type, and severity of contact with coral or living organisms and intentionality of contact. Contact behaviors examined included eight behaviors that expose reefs to harm: kicking coral with fins, touching coral or other living things with hands, standing on coral, equipment contacts, brushing up against the reef, kicking up sediment near coral, picking up living or dead coral, shells or other organisms, breaking coral, and collecting.

Behaviors observed were written in code and slashes were made in each coded box for specific behaviors. Identifying information was recorded as well as several independent variables which included gender, the use of a camera, and glove use. Dispersed in between observations were written the names of fish encountered and corals observed to further disguise my work.

Table 4.5

Data recorded for each scuba dive trip

Scuba diver trip data
Date
Time of trip
Tour operator
Weather conditions
Briefing (Yes/No)

Table 4.6

Data collected for each scuba diver observation

Scuba diver observation data
Gender (Male/Female)
Use of camera (Yes/No)
Use of gloves (Yes/No)
Distinguishing characteristic(s) for follow-up survey
Number of minutes observed
Types of contacts observed/number of times
Silting
Fin kicks
Standing, sitting, kneeling
Touching coral
Brushing up against coral
Equipment contacts
Touching other organisms
Picking up organisms, rocks, shells, dead coral
Collecting

4.7.6 Measuring the Number of Dives, Divers and Time Individuals Spend Diving at a Reef

To collect data on the number of trips made during the high and low season, the number of divers participating in trips, the length of time spent diving at each reef, and the reefs visited, I utilized the captains' log books. A captain's log book contains a record of pertinent information about the dive trip which includes how many divers participated and which reefs were visited for each dive made. I utilized data from the 2011 and 2012 seasons which corresponds with my diver observation data. It is not necessary to count the number of scuba divers over the reef for each trip since I can assume that on most trips, every diver onboard the vessel participated in the dive. There are times when a diver may not get in the water (trouble equalizing, sea sickness, etc.) but these instances are not common. Most captains make notes in their log if a diver did not participate. To determine the length of time a diver spends at a reef, I recorded and averaged the dive times for each of the dives I participated in.

4.7.7 Design for Measuring the Characteristics of the Reef (for Exposure and Sensitivity) where Operators Bring Divers

I collected data on the topography, morphology, and dive depths at the two most frequently visited dive sites within La Cordillera Nature Reserve, Sandslide (Palominos Island reef) and Cayo Diablo. In developing this methodology, I drew on previous researchers who have collected data on the characteristics of a reef at dive and snorkel locations (Allison, 1996; Plathong et al., 2000, Rouphael & Inglis, 1997).

The morphology of benthic biota at each of the dive sites was described using video. Random transects were not necessary, since all divers follow a dive instructor/dive master who leads the group along a fairly well-established route around the reef. For these reasons, I was able to film the reef assemblages along the entire dive route using an underwater video camera. Swimming slowly, video recordings were made over and at times parallel to the corals. I filmed the entire dive at each location and then examined the recordings later to characterize topography and morphology. Depth was recorded on a slate every 5 minutes using scuba depth gauge.

Morphology of coral was characterized using the classification system of Chadwick-Furnam (1997), Plathong et al. (2000), Rouphael & Inglis (1995), and the National Ocean Service's (2016) coral morphology classification system. Corals were classified as one of the following ten categories: massive, branching (thick, stubby, thin, hydrocorals), columnar, encrusting, foliose, table, and soft. Video was also analyzed to characterize reef topography (plateau, fringing, rocky outcrops, varied, or wall). When validation on identification was needed, I consulted with a coral reef scientist (W.H. Schreiner, personal communication, June 2016).

4.7.8 Collecting Data on Adaptive Capacity

4.7.9 Survey Divers Using a Survey Instrument to Gather Data on Visitors' Attitudes, Perceptions, and Experiences

Since visitor satisfaction and skill level were anticipated to be a key factor in the decision-making by captains and staff, my target population to survey was scuba divers. I utilized a survey developed by Dr. Thomas Webler. The survey instrument can be found in Appendix D. Survey data were collected by asking each diver who participated in a dive if they would complete a survey (with prior permission of the company owner and the captain). Divers usually spend time filling out log books and organizing gear upon the return to port. I approached these divers and asked if they would be willing to share that day's diving experiences at La Cordillera Reserve. I stated that this information would be utilized for the management of the coral reefs within the Reserve. A written survey was then distributed to each diver. The survey questions were a mixture of open-ended and closed questions. The closed questions were answered with a Likert scale and were based on satisfaction with the dive(s), as well as perceptions, attitudes, and knowledge about coral reef ecosystems. Individuals were also asked to self-report on the number of contacts they made with the reef that day, skill level, and experience.

4.7.10 Tour Operators, Captains, and Crew who Make Key Decisions of Which Reefs to Visit and How They Prepare Visitors for the Experience of Diving

The crew of dive vessels (captain, dive instructors, dive masters) play an important role in the exposure of the reef to diver contacts. They lead the dive excursion (everyone stays together), give detailed briefings to orient visitors to the reef, encourage or discourage types of behavior, and provide oversight and correction. Ten face-to-face semi-structured interviews of key informants were conducted and included captains, dive instructors, dive masters, senior crew members, and operation managers if I could interview them. I selected these individuals based on their level of involvement in the decision making process. Interview questions are included in Appendix B. Interviews took place on the mainland after a dive trip. I obtained a signed, informed consent form from each interviewee which is included in Appendix C. Interviews were voice recorded, transcribed, coded, and analyzed for similar concepts. All personal information was kept confidential.

4.7.11 Diver Briefings

For each trip I attended, I recorded the briefing delivered by a crew member, so I could compare the similarities and differences between briefings. I also listened and took notes during the briefing and observed the diver behaviors during the briefings. Briefings were transcribed, coded, and compared.

4.7.12 Limitations

Since this is a sample study I only collected data from the two major dive operations in Fajardo, Puerto Rico that bring divers to La Nature Cordillera Reserve in Puerto Rico. While both companies based out of Fajardo led similar trips, trips offered by operators in other regions around the island may be different. There are several operators located in San Juan that bring divers into La Cordillera Nature Reserve, but these trips were not frequent enough that I could attend one.

I was able to validate that my observations were only of divers affiliated with the two operators based out of Fajardo since divers stayed together with the instructor and no other boats were present at the dive site during our time diving. I did not observe divers at reef locations outside of La Cordillera Nature Reserve. Even on tour excursions, not every diver was always observed, although all were asked to complete a survey.

Every attempt was made to make sure that the sampling protocol was representative of the overall population of divers in Puerto Rico. To do this I divided the number of days that I observed divers between the peak tourism and low tourism season. A majority of the divers during both the peak season (November through April) and the low season (May through October) were non-residents. Very few divers interviewed were residents of Puerto Rico.

4.7.13 Problems Encountered During this Research

I was only able to obtain the number of individuals and days spent diving within the Reserve from one of the two dive operators in Fajardo. The other dive operator based out of Fajardo was changing ownership and I was unable to get permission to review previous captain logs after several repeated efforts even though I participated in several dive trips with the previous owner and crew. I also reached out to the Department of Natural and Environmental Resources for these numbers (diver operators are required to report the number of individuals they bring to La Cordillera Nature Reserve each month) but even after several attempts had no success.

4.8 Results

4.8.1 Number of Divers at the Reef

Dive companies operate year-round but divide the year into two seasons. Peak season (November – April) and non-peak season (May – October). September and October (hurricane season) are considered the slowest months and companies often take days off during this time period for vessel maintenance. Both dive companies based out of Fajardo follow a similar schedule offering a two-tank morning dive, one tank per reef and a one tank afternoon excursion visiting just one reef within the reserve. Night dives are scheduled by appointment. Dive operator data analyzed found the average number of trips during both the peak and non-peak season was the same,107 trips. The average number of divers per trip was nine. The dives lasted from 35 – 51 minutes with a mean of 45 minutes at an average depth of 50 feet.

4.8.2 Diver Characteristics and Behaviors Underwater

102 observations of divers near coral in La Cordillera Nature Reserve, for a total of 497 minutes, were made with each observation lasting for a total of 5 minutes. Males comprised 70% of the observations while 30% of those observed were female (Figure 4.5). A majority of divers, 94% did not wear gloves (Figure 4.6). Of those observed, 20% carried or used a camera while diving (Figure 4.7).

Figure 4.5

Percentages of male and female divers observed

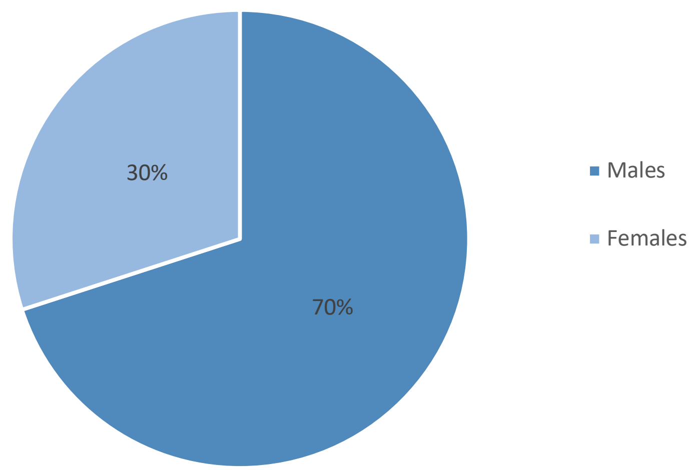


Figure 4.6

Percentages of divers observed wearing and not wearing gloves

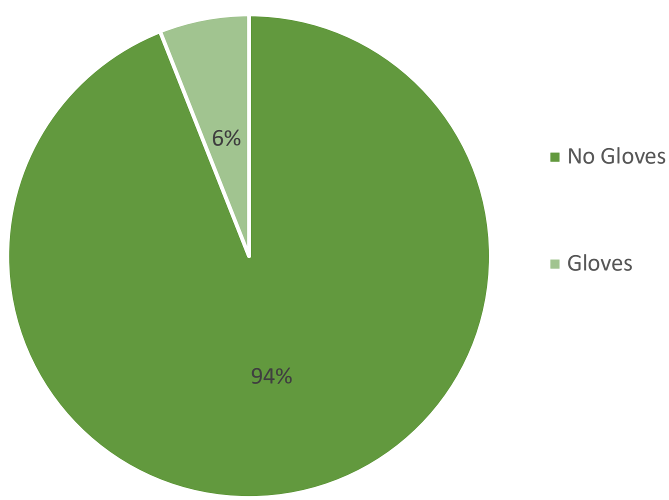
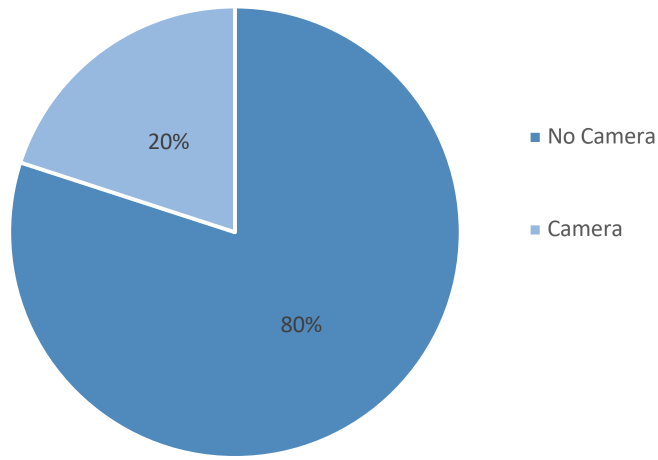


Figure 4.7

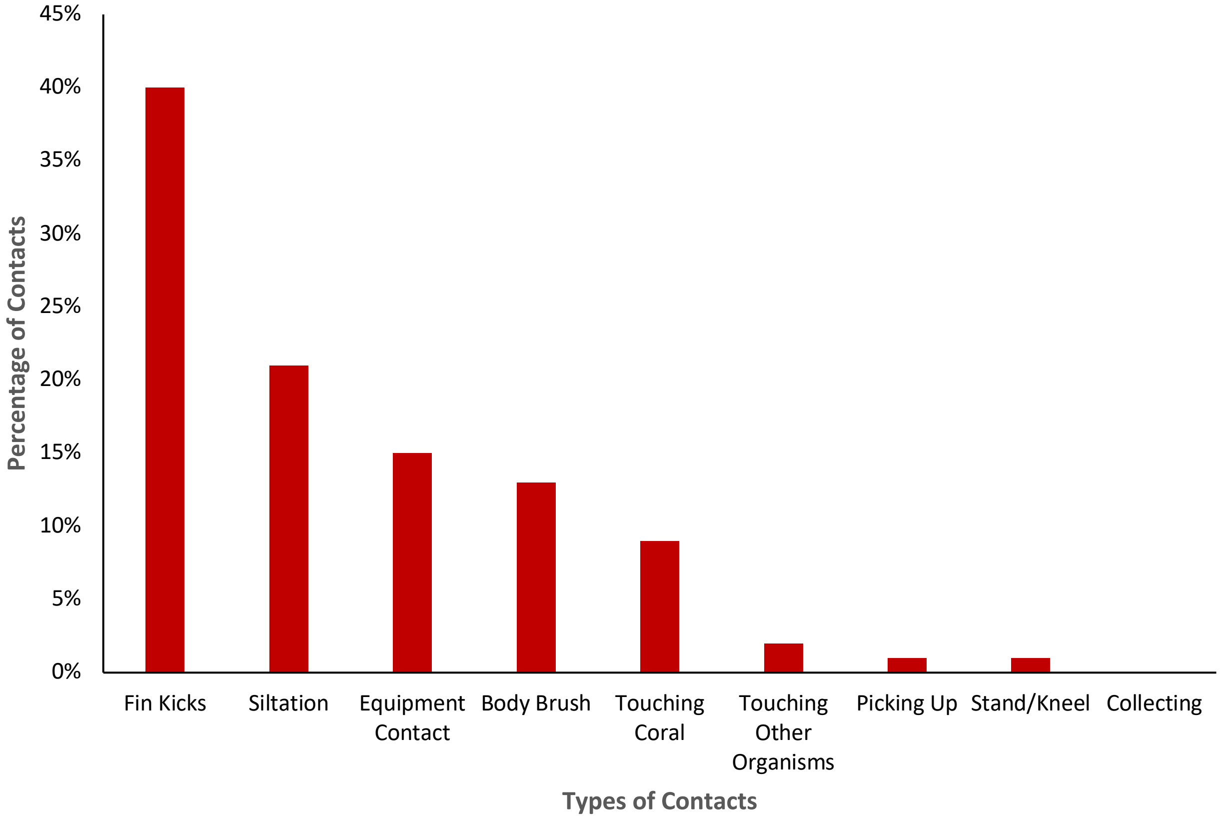
Percentages of divers observed using a camera or not using a camera while diving



A total of 260 contact behaviors were observed around the corals within the reserve. A majority of the contacts were the result of fin kicks (40%) (N =104), siltation (20%) (N = 52), equipment contacts (14%) (N= 36), body brushing against the reef (13%) (N = 34), intentionally touching the reef (9%) (N = 23), intentionally touching other things (2%) (N=5), picking up marine life (1%) (N = 3), and sitting, standing or kneeling (1%) (N = 3) (Figure 4.8). No divers were observed collecting anything at the reefs during the observation period. Although one diver was observed holding a shell back on the dive vessel and another told me he collected a shell. One diver was observed placing a wine bottle at Cayo Diablo. The tour operators do not allow divers to feed fish or other organisms while at the reefs.

Figure 4.8

The types and percentages of diver contacts observed



Overall, 44 of the 102 divers observed (43%) made no contact with the reef. 15% (N = 15) percent of the divers had one contact with the reef, 9 % (N = 9), had two contacts, 7% (N = 7) had three contacts, 4% (N = 4) had four contacts, 5% (N = 5) had 5 contacts, 4% (N = 4) had 6 contacts, 2% (N = 2) had 7 contacts, 4% (N = 4) had eight contacts, 4% (N = 4) had 9 contacts, and 2% (N = 2) had ten contacts (Figure 4.9). The highest number of contacts by one individual during a five-minute observation was twenty, followed by another individual who contacted the reef 19 times. The individual who made 19 contacts was a “Discover Scuba” diver who I observed on his first dive after taking an initial in-water course the same day. The individual who contacted the reef 20 times was a certified diver who was using a camera while diving. Figure 4.10 is an example of a photographer contacting the reef.

Figure 4.9

Number of diver contacts with a coral species at La Cordillera Nature Reserve

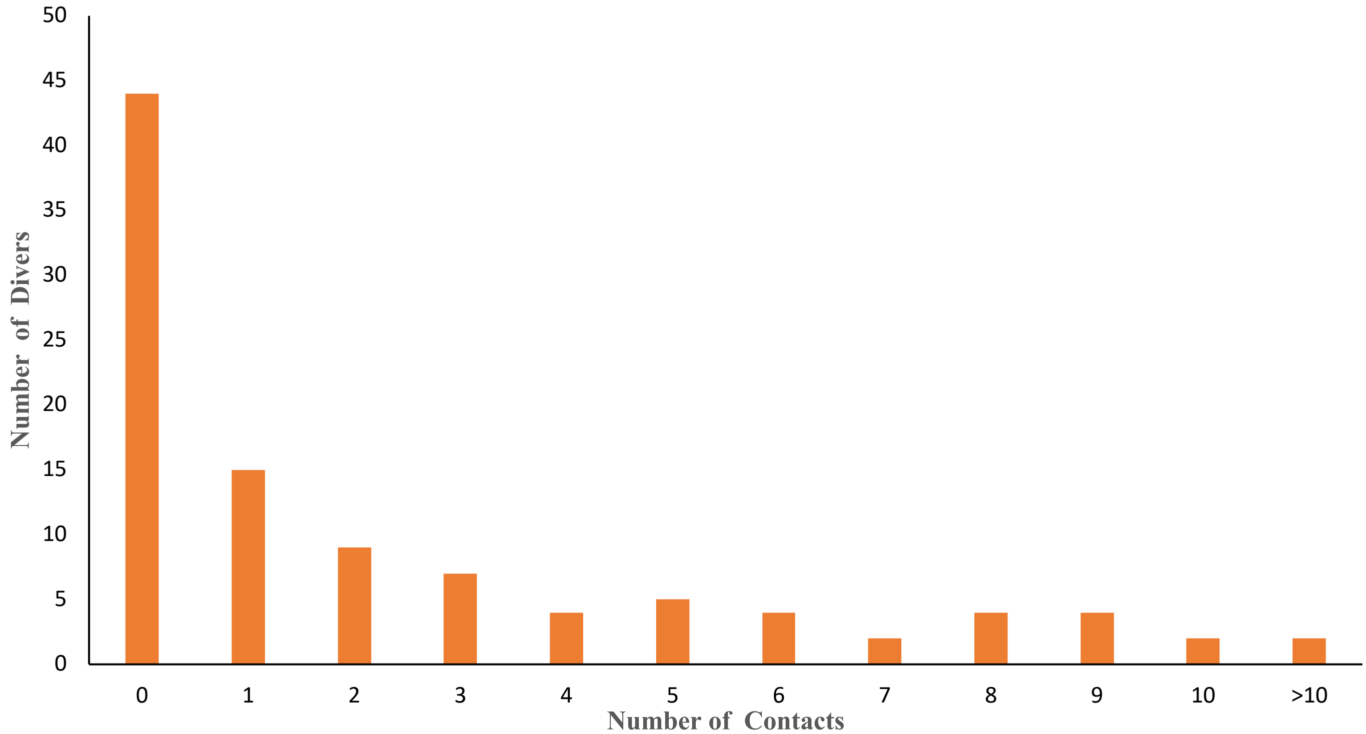


Figure 4.10

Diver kneeling on coral to take a photograph

Note. Photograph by K. Jakubowski (2012).

The frequency of potentially damaging contacts to living corals for divers in La Cordillera Nature Reserve was 0.5 contacts per diver per minute. Table 4.2 shows that the number of contacts by divers within La Cordillera Nature Reserve was higher than all but two other coral reef locations where research on number of contacts with reefs was conducted (Barker, 2003; Chung et al., 2013; Harriott et al., 1997; Krieger & Chadwick, 2013; Medio et al., 1997; Prior et al., 1995; Rouphael & Inglis, 2001 Talge, 1990; Zakai & Chadwick-Furnam, 2002). No statistically significant difference was observed when the frequency of contacts was compared with gender ($p>0.05$) or use of gloves ($p>0.05$). Analysis confirmed that divers who use cameras produced a statistically significant higher frequency of contacts than non-camera users ($p<0.05$).

4.8.3 Dive Sites

Dive sites are selected the morning of the dive by the captain and the crew. Sites are selected based on water visibility, prevailing wind, swells, and comfortable sea conditions. If there are “Discover Scuba” divers (first time divers who take an introductory course and are not being trained in a pool), the first reef visited within the Cordillera reef system is off of Isla Palominos and is called Sandslide. It is a good location for beginners to practice basic skills underwater in the sandy area adjacent to the reef. On the 12 trips in which I participated, the second reef site was either (2) Cayo Diablos (3) Hour Glass (4) Trench or (5) Lobos. All dive sites are reached within 30 to 50 minutes by motorized vessel. There is no beach access at any of the dive locations. These reefs have been found to have the highest live coral cover (> 30%) since they lie on a protected section of the shelf, up-current from large river discharges (Garcia-Sais et al., 2008).

The dive reef sites are ideal for diving and not always snorkeling, therefore the number of snorkelers onboard vessels is usually small. However, dive tour operators will take a small group of snorkelers on the vessel. These individuals are usually family members of the divers, who do not want to dive but prefer to snorkel around the vessel. The captain will keep an eye on these snorkelers who do not venture far from the vessel.

4.8.4 Reef Characteristics at Cayo Diablo

Cayo Diablo’s reef topography is considered one of the best examples of a developed fringing reef in Puerto Rico (Garcia-Sais et al., 2008). The reef is also known for geomorphological (“spurs and grooves”) coral formations (Figure 4.11). Formed by waves, the coral formations are shaped like a spur that has a high vertical structure with channel grooves in between the spurs. The grooves are located between the coral spurs and contain sediment like sand and coral rubble.

At Diablo, the distance between a spur and groove can be over 7 meters (Garcia-Sais et al., 2008).

Figure 4.11

Spur at Diablo Reef, La Cordillera Nature Reserve

Note. Photograph by K. Jakubowski (2012).

This topography could encourage divers to get into the grooves in order to take a close look at the coral and thus expose the coral to more diver contacts. However, dive leaders tend to keep divers along the outside of the reef for a majority of the dive (figure 4.12).

Figure 4.12

Divers parallel and along the perimeter of the reef

Note. Photograph by K. Jakubowski (2012).

On the return trip to the vessel, dive guides bring divers over the reef (figure 4.13). While they tend to keep divers above the coral, some divers will move closer to the reef to get a better look.

Figure 4.13

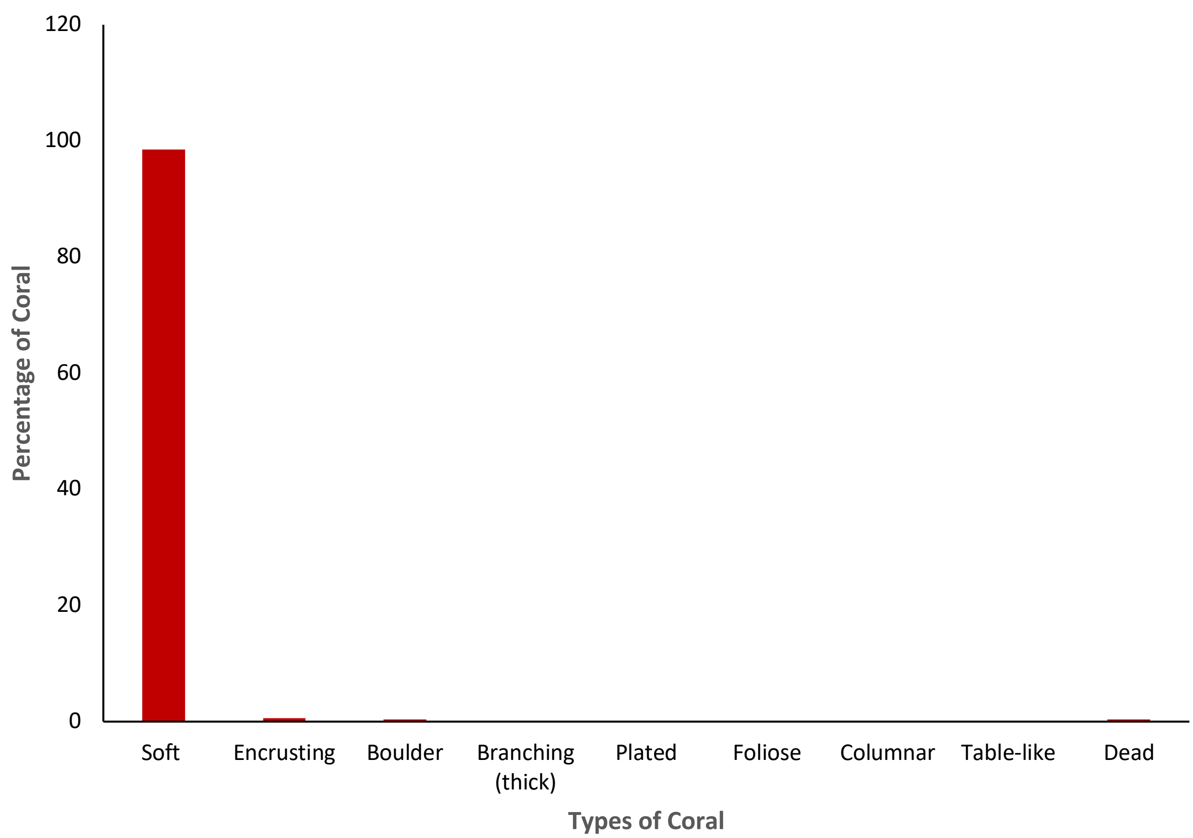
Diver observed over the reef with a green sea turtle (Chelonia mydas)

Note. Photograph by K. Jakubowski (2012).

The average depth at which divers descended at Diablo Reef was 40 feet. Soft corals (*Gorgonian* species) occupied the largest proportion (98%) (N=2940) of the substratum trail at Diablo Reef as represented in Figure 4.14. Soft branching coral are considered to have intermediate sensitivity to snorkeler and diver damage (Fox et al., 2003; Hall, 2001; Sheppard & Loughland, 2002; Stobart et al., 2005). Only a small percentage of hard corals were observed along the transect. 0.5% (N = 15) were mostly encrusting corals, (*Porites astreoides*), 0.4% (N=12) boulder coral, and 0.01% (N = .3) plated coral. Non-living boulder coral and coral rubble (mostly pieces of thick branching *Acropora palmate)* occupied 0.4 % (N = 12) of the transect. No other coral morphologies were observed.

Figure 4.14

Morphology of corals at Cayo Diablo, La Cordillera Nature Reserve

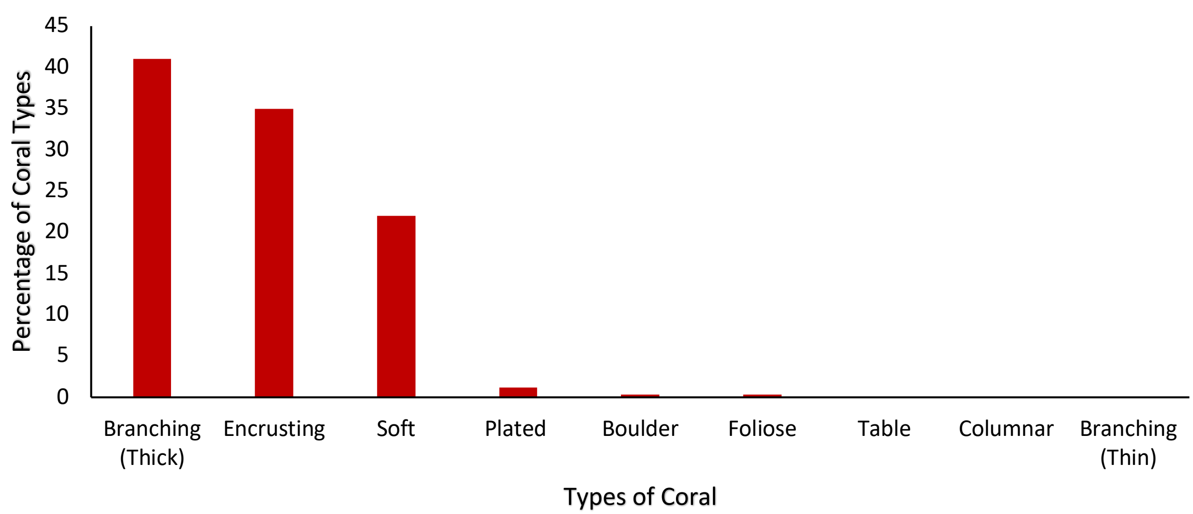


4.8.5 Reef Characteristics at Sandslide (Isla Palominos)

The topography of Sandslide, off the coast of Isla Palominos, is classified as a fringing reef. There is a large sloping, sandy area adjacent to the reef for which the dive site is named and serves as a good location to review skills with beginners. The average depth at which divers descended at Sandslide was 50 feet. Short, thick, stubby branching finger-like corals (*Porites porites*) occupied the largest proportion (41%) (N = 675) of the substratum trail as represented in Figure 4.15. Encrusting corals made up 35% (N = 525) of the transect species followed by soft corals at 22% (N = 300). Only a small percentage of plated (1.2%) (N = 18), boulder (0.3%) (N = 5), and foliose (0.3%) (N = 5) corals were observed. No table, columnar, or thin branching coral were observed along the transect. Numerous pieces of non-living coral rubble were observed all along the transect.

Figure 4.15

Morphology of corals at Sandslide (Isla Palominos), La Cordillera Nature Reserve



4.8.6 Diver Perceptions

92 divers completed a survey once back at the dock. 88% (N = 81) were not residents of Puerto Rico and were participating in the dive trip as part of their vacation (Figure 4.16). 56% of the divers who completed surveys were male and 44% were female (Figure 4.17).

Figure 4.16

Percentages of residents and nonresidents surveyed

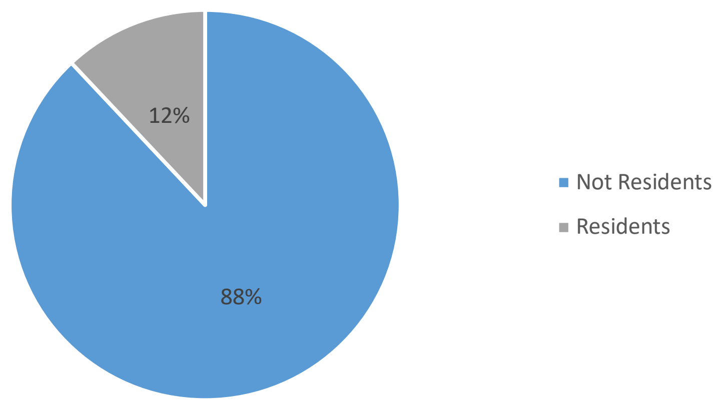
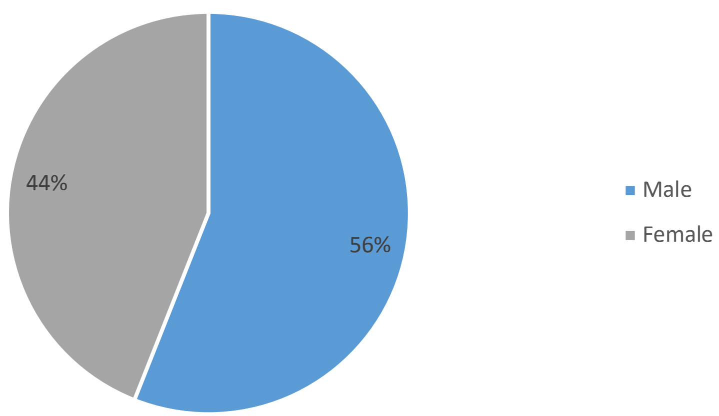


Figure 4.17

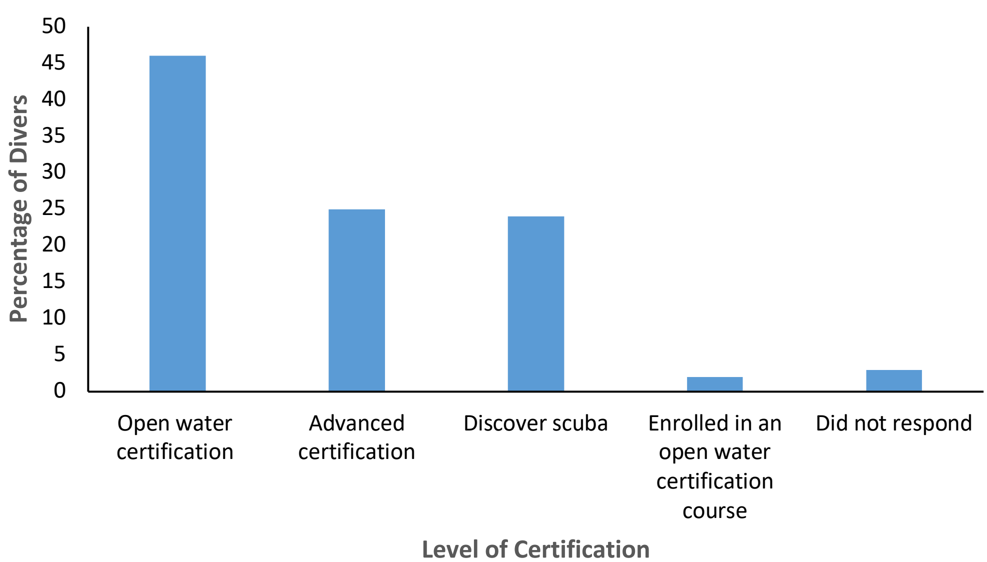
Percentages of individuals surveyed by gender



To measure skill and knowledge level, divers were asked to self-report on their experience level by recording their highest certification and total number of dives in their scuba history. Obtaining an open water scuba certification is the first step towards demonstrating proficiency, knowledge, and skills in both utilization of equipment and the act of diving. Certification acknowledges global recognition by dive operators and demonstrates a level of commitment to this recreational activity (PADI, 2018). As shown in figure 4.18, 71% (N = 65) of divers surveyed held a dive certification. 25% (N = 23) of these individuals held an advanced degree (advanced open water, rescue, master, instructor), and 46% (N = 42) held an open water dive certification (the basic course needed to dive independently). Of the 29% (N = 27) not certified, 24% (N = 22) stated they were participating in "Discover Scuba," 2% (N = 2) were enrolled in an open water dive certification course, and 3% (N = 3) did not respond.

Figure 4.18

Divers report their level of certification



The total number of dives completed by divers surveyed ranged from 1 – 300. Two outliers, one reporting 750 dives and another reporting 1000 dives were not included in the following analysis. Of those certified the mean number of dives was 31 and the median was 10.

To measure environmental awareness, questions in the survey addressed diver perceptions, knowledge about the health of the reef, diversity of marine life, and clarity of the water. My findings support the conclusion that divers who visited La Cordillera Nature Reserve enjoyed the dive areas. As shown in Table 4.7, 64% (N= 60) of divers were very or extremely satisifed with seeing a healthy reef. Table 4.8 indicates that approximately 58% (N = 58) percent of divers responded that they were very or extremely satisfied with the diversity of marine life at the reefs. As shown in Table 4.9, 48% (N = 45) of the divers surveyed were very or extremely satisfied with the water visibility while diving at the reefs within La Cordillera Nature Reserve. Analysis confirmed a statistically significant relationship between divers who reported they were knowledgeable about marine ecology and coral reefs and those who reported they were slightly or moderately satisfied with seeing a healthy reef ($p<0.05$).

Table 4.7

Diver satisfaction with the health of the coral reefs at La Cordillera Nature Reserve

Healthy Reef	**N**	**Mean Percentage**
Extremely Satisfied	30	32
Very Satisfied	30	32
Moderately Satisfied	28	30
Slightly Satisifed	2	3
Not at All Satisfied	0	0
Not Sure	2	3
Total	**92**	**100**

Note. Diver Surveys 2011-2015

Table 4.8

Diver satisfaction with the diversity of marine life at La Cordillera Nature Reserve

Diversity of Marine Life	N	Mean Percentage
Extremely Satisfied	28	30
Very Satisfied	30	32
Moderately Satisfied	26	28
Slightly Satisifed	6	7
Not at All Satisfied	0	0
Not Sure	2	2
Total	**92**	**100**

Note. Diver Surveys 2011-2015

Table 4.9

Diver satisfaction with water visibility at La Cordillera Nature Reserve

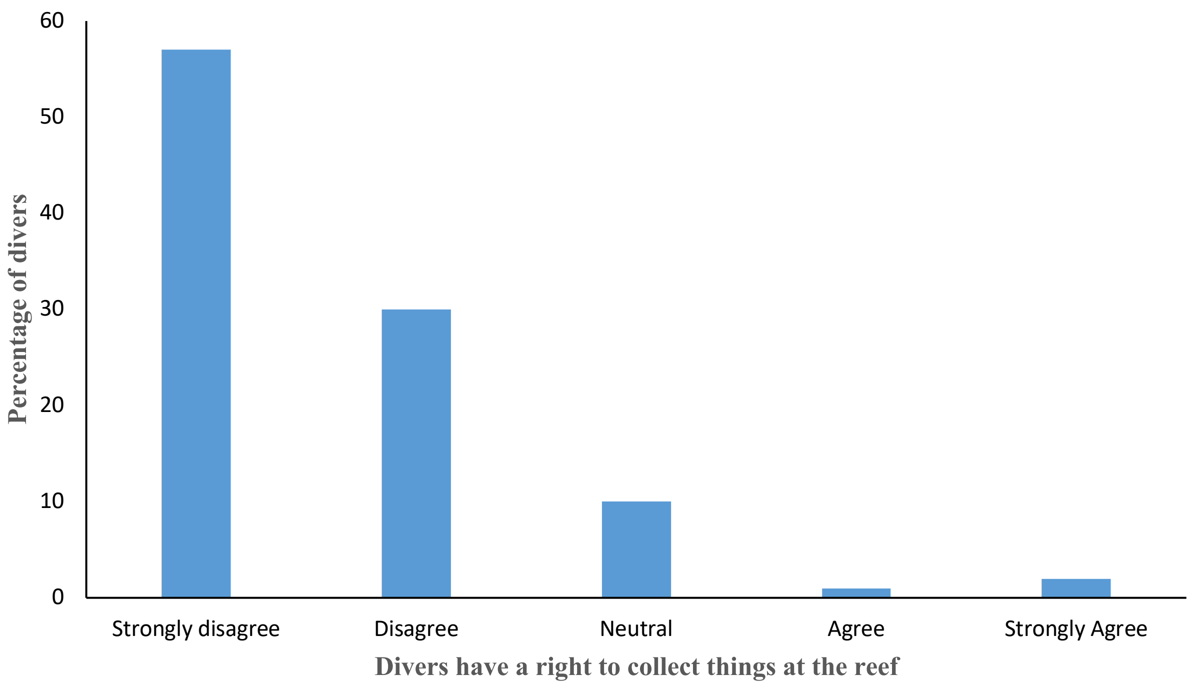
Water Visibility	N	Mean Percentage
Extremely Satisfied	19	21
Very Satisfied	26	28
Moderately Satisfied	34	37
Slightly Satisifed	11	12
Not at All Satisfied	0	0
Not Sure	2	2
Total	**92**	**100**

Note. Diver Surveys 2011-2015

Additional questions to measure conservation awareness and attitudes of divers towards coral reef ecosystem conservation and management were analyzed. As shown in figure 4.19, a majority of scuba divers (87%) (N = 80) disagreed that scuba divers and snorkelers have a right to collect things at the reef.

Figure 4.19

Diver perceptions about right to collect at the reef



88% (N = 81) of divers who responded to the survey felt that dive instructors and dive masters should correct divers whose behavior could be damaging the coral reef (Figure 4.20). 57% (N = 52) agreed that a coral reef crisis was a real concern and 51% (N = 47) agreed that humans are damaging coral reefs. Additional diver comments that reflect attitudes about the dive can be found in table 4.10.

Figure 4.20

Diver perceptions of instructors correcting harmful behaviors at the reef

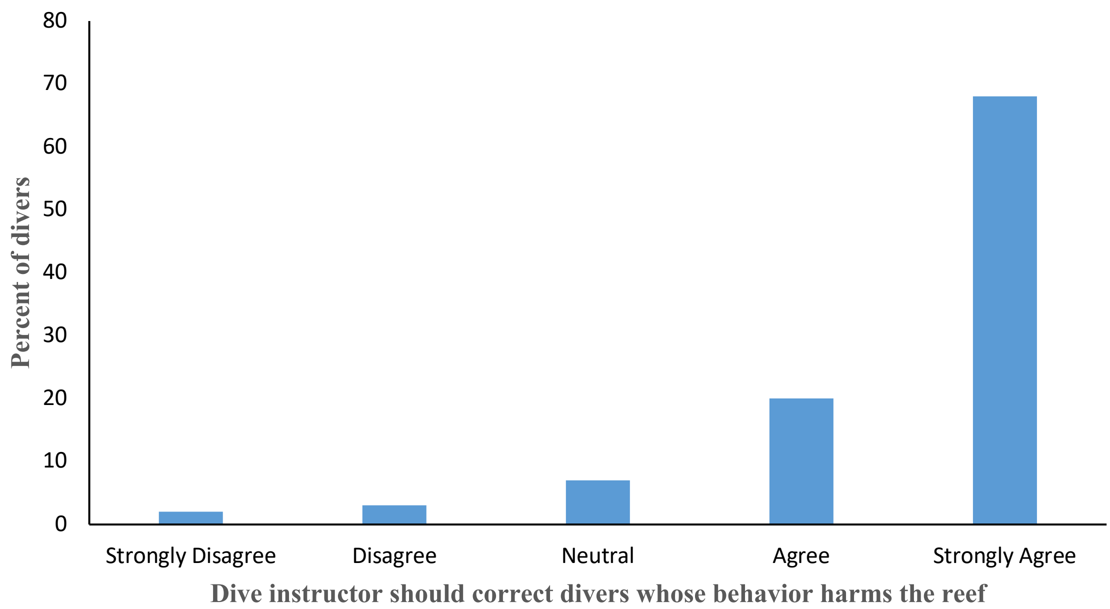


Table 4.10

Qualitative feedback from scuba divers who visited La Cordillera Nature Reserve

Reef was beautiful. I had an amazing time.
Divers in the group practice good buoyancy control.
The dive guides did a great job.
I took one small shell that didn't have an animal in it.
Only certified divers that have taken PADI courses should be allowed to dive. No resort divers.
Amazing reef.
Had fun!
Thank you for helping to keep the coral reefs in Puerto Rico healthy.
Dive briefings at start of trip are great.

4.8.7 Social Norms of Scuba Divers

The behavior of scuba divers is often guided by social norms. Social norms are a set of standards or rules shared by a larger group of individuals, which all individuals in the group are expected to observe (Schwartz,1977; Vaske et al., 1986). The atmosphere onboard a dive vessel is more serious than a snorkeler vessel. Scuba divers tend to arrive early for their trip so they have time to sign in, organize and check their gear, and keep a detailed dive log. There is no loud music, drinking, or smoking onboard. Conversations onboard dive vessels are dive related and include sharing past diving experiences, favorite dives, cool marine life previously observed, and new gear. Post dive conversations are about the diving experiences. Other norms observed are about safety and include never putting your mask on your forehead, having a snorkel attached to your mask, pairing up with a buddy, looking out for that buddy while underwater, and attaching to your buoyancy control device (BCD) a brightly colored, inflatable safety buoy in case those onboard need to spot you from a distance. I observed all of these social norms on each dive that I participated within La Cordillera Nature Reserve. At some coral reef dive sites, additional social norms are practiced and include not wearing gloves, never making contact with the bottom, not feeding fish, and a "look but don't touch policy."

4.8.8 Staff Briefings and Interventions

Of the 12 diving trips I attended, every trip included three briefings, a safety briefing at the beginning of the trip onboard the vessel but before the vessel left the dock and one dive/reef specific briefing at each dive location. Briefings were delivered by a dive instructor. I recorded and transcribed briefings from both tour companies bringing divers out to La Cordillera Nature Reserve from Fajardo. While briefings had slight variations between vessels, they were always in-depth, serious, and consistent in content and messages. Common themes contained in the briefings can be found in Table 4.11.

Briefings were not difficult to deliver. 100% of divers surveyed stated they were provided briefings onboard the vessel and several made a point to comment that they found the briefing useful. Scuba divers on board are attentive during the briefings. I did not observe divers donning equipment, taking pictures, or quietly chatting with their buddy during briefings. A majority appeared to be paying attention and questions were often asked.

Table 4.11

Dive briefing messages from tour operators

Message	Tour Company I	Tour Company II
Provided an in-depth orientation about our dive course	Yes	Yes
Included a dry-erase board to explain the dive route	Yes	No
Provided specific instructions for entering the water and controlled descent	Yes	Yes
Provided specific instructions about the dive route	Yes	Yes
Discussed no taking of any resources (coral, shells, rubble)	Yes	Yes
Informed divers not to touch coral	Yes	Yes
Stated no touching or disturbing marine life (specifically turtles)	Yes	Yes
Provided general information about La Cordillera Nature Reserve	Yes	Yes
Empowered divers - Divers have the ability to prevent harm (self-efficacy)	No	No

Table 4.11 (continued).

Provided scientific information about the reefs	No	No
Provided a conservation message about corals	No	No

Dive instructors all carried a rattle/shaker clipped to their BCD as a device to get the attention of the divers they were leading. On four occasions, I observed an instructor use the shaker to correct a behavior by providing a signal. Behaviors included touching the coral, getting too close to a sea turtle, holding on to the coral to observe a spiny lobster, and holding on to coral to take a picture. Each time the diver was informed of his/her mistake, he/she was quick to correct the behavior.

4.8.9 Dive Instructor Interviews

Ten key informant interviews were conducted with crew members from tour operations based out of Fajardo in order to gain a better understanding of how decisions are made regarding which reefs to visit, how crew promote dive etiquette behaviors, and perceptions of the reefs. I analyzed responses to key informants specific to the dive industry in order to understand reasons that factor into their decisions about which reefs to visit and how to prepare divers for their experience.

Dive operator key informants said dive sites are selected the morning of the dive by captain and crew. Priorities for dive site selection include best visibility and comfortable sea conditions. Storms involving lighting, strong winds, swells, current changes, and poor visibility were the main factors that determined which reefs to visit on a given day. If the operator had “Discover Scuba” guests or students working on their certification onboard then the first dive site was always Sandslide (Isla Palominos) which provides a large sandy area, is only about 15 feet in depth and a safe distance from the reef to practice scuba skills. Certified divers onboard would be led by an instructor to the reef for their dive. Other factors that play a role in reef selection include diver certifications and experience. Key informants stated that if a majority of divers are experienced, the operator will specifically go to Cayo Diablo Reef since it is a beautiful dive site with a diversity of marine life. The struggle to satisfy customers, especially when most tourists will read reviews on websites that either promote their operation or speak negatively, can affect job security.

The availability of mooring buoys was another point of contention mentioned by dive key informants. For example, a dive site named Trench only had one mooring buoy which was damaged by a vessel. Both dive operators no longer visit Trench because they prefer not to anchor in the sand or turtle grass (*Thalassia testudinum).* Anchoring in the turtle grass damages habitat and sand raises a safety issue for a large vessel since it can be dragged through the sediment. Vessels anchored in the sand can shift and move which then becomes a safety issue for divers. Anchors can also move and catch on the reef. Key informants felt that moorings at the reef sites need to be maintained. On several occasions the dive companies had repaired mooring buoys even though it is the DNER staff who is responsible for installing, replacing, and maintaining these structures.

All dive key informants felt that dive and snorkel operators should practice good reef etiquette and that providing a briefing before they got into the water and correcting behaviors in the water were the most important factor in protecting the coral reefs. While dive key informants felt education was the most effective method to reduce contacts with the reef, they felt that a majority of divers listen to briefings and follow instructions regarding not taking anything from the reef or intentionally touching organisms. The ratio of divers to an instructor is no more than 8:1 (but usually less since the average number of divers onboard was 9 individuals): key informants felt they could supervise activities under water and correct intentional behaviors when dive groups are small. Instead of more education for divers, dive key informants felt that more local education was needed especially for boat owners visiting the reefs and residents recreating in the area. Key informants also felt that the DNER should work with both dive and snorkel tour operators and offer best practices workshops. They raised concern that snorkelers consume alcohol on board snorkel vessels and then enter the water without a supervised guide; they also indicated that snorkel-specific guides should be in the water monitoring practices.

Every key informant expressed their passion and appreciation for the marine life in Puerto Rico. They shared stories about being exposed to the marine environments of Puerto Rico at an early age. A family member (father, mother, cousin, older sibling, close family friend) was usually given credit for this childhood exposure to the marine environment. Key informants credited these individuals and experiences as one of the main reasons for their involvement in the marine profession and fondness of the coral reef environment. All dive instructors interviewed expressed their concerns over the changes they have observed to the reefs and a decrease in diversity of marine life. While key informants stated that diving and snorkeling does contribute to degradation, they believed a combination of factors are affecting the marine life in Puerto Rico. Stressors specifically mentioned by operators included pollution, anchoring, warmer waters, climate change, oil discharge, algae blooms, and invasive species.

Dive-operator key informants also expressed their concern over the lack of communication with government officials responsible for managing La Cordillera Nature Reserve. Those interviewed stated they felt they were not aware of all of the policies and regulations for the La Cordillera Nature Reserve. They also felt that there is little collaboration between operators and government managers. Dive operators were willing to work with government officials to assist with maintaining moorings and had previously reached out to government managers who did not respond. Operators felt this lack of communication was not helpful for conservation or management.

4.9 Discussion

While tourism affiliated with coral reef ecosystems continues to increase, corals continue to degrade and decline from a variety of stressors associated with the negative impacts of tourism. In Puerto Rico, diving is an activity that can threaten the corals and marine life that visitors enjoy and tour operators depend on for economic security and well-being. In order to demonstrate the vulnerability of coral reefs in Puerto Rico to scuba diving, a method to characterize vulnerability was developed and applied to select reefs along the northeast coast within La Cordillera Nature Reserve. Inductive indicators were utilized in this vulnerability assessment since sufficient data were available to indicate variables and the potential harm. My findings support the conclusion that some reefs within La Cordillera Nature Reserve, Puerto Rico are vulnerable to diving activities but adaptive actions can be implemented to reduce exposure. A component of exposure, the frequency of potentially damaging contacts from divers in La Cordillera Nature Reserve, was 5 times higher than all but two other coral reef locations where research on number of contacts with reefs was conducted. The greatest number of potentially damaging contacts made by divers were the result of fin kicks (40%) which is consistent with other research conducted on diver contacts with reefs (Barker, 2003; Harriott & Davis, 1997; Krieger & Chadwick, 2013; Medio et al., 1997; Prior et al., 1995; Roche et al., 2016; Rouphael & Inglis, 2001; Talge, 1990). Fins extend the length of a diver’s legs, bringing the diver closer to the reef. Most of the fin contacts I observed appeared unintentional and were most likely caused by lack of skill, poor buoyancy, distraction, incorrect weight system for buoyancy or lack of knowledge.

In addition, Cayo Diablo has a high percentage of soft corals (98%). These corals move with water currents. This unpredictable movement can make it difficult for a diver to avoid a contact and may be a contributing factor to why the contact rate per minute is higher for divers in Puerto Rico.

The most common types of coral at both Sandslide and Diablo are classified as less sensitive species. At Sandslide, 45% of the corals observed were thick, stubby branching coral, specifically *Porites*, which is classified as a rapid colonizer (Hernandez-Delgado, 2005). Encrusting (35%), and soft corals (22%) were the remaining majority. Corals classified in these three groups are considered less sensitive since they can withstand higher wave activity. Coral reef biologists state that physical damage from hurricanes is the greatest threats to the reefs at La Cordillera Nature Reserve followed by disturbances created by anthropogenic physical damage. Impacts from divers may be contributing to changes in the reef community structure. This has been reported at the island of Bonaire in the Caribbean, where impacts from heavily dived areas are thought to have caused the loss of massive corals at the expense of faster growing corals (Hawkins et al.,1999).

Similar to other research, divers who use cameras while diving had significantly more contacts with the reef than non-camera users (Barker, 2003; Medio et al., 1997; Prior et al., 1995; Rouphael & Inglis, 2001). Certified divers know not to stand, sit, or kneel on the reef. Only 1% of the contact behaviors fell in this category. However, a diver was observed kneeling on a soft coral to take a photograph. This diver was also responsible for the greatest number of contacts observed.

While the frequency of contacts within La Cordillera Nature Reserve is high, especially when multiplied by the number of visitor-minutes spent at the reef on a yearly basis, the scale of the problem can appear to be a significant factor increasing coral vulnerability. However, it is important to note that at the time this research was completed, there were only two commercial operators that were bringing divers to La Cordillera Nature Reserve on a regular basis. If both tour operators average 9 divers per trip, 214 trips per year, that brings the number of divers visiting the reef to 3800 a year which is less than the carrying capacities set for Bonaire National Park, Red Sea Ras Mohammed National Park, Sipadan, Malaysia, and the US Virgin Islands (Dixon et al., 1993; Hawkins & Roberts, 1997; Musa, 2002; Zakai & Chadwick-Furman, 2002).

With less than 4,000 divers going out to La Cordillera Nature Reserve per year, the focus should be on adaptive actions that reduce contacts and prepare these divers to practice environmentally responsible behaviors at the reef. Tour operator crew recognize the need for coral reef conservation and expressed a strong desire about taking measures to protect the reefs from damage by divers, vessels, and pollution. Capacity of individuals to adapt to change is determined by availability and access to those resources. Tour operator crew are willing to collaborate and increase interactions with government officials including DNER reserve managers and those working with the department of tourism as these agencies can provide the resources. For example, both tour operators refuse to visit the reef known as Trench since the mooring at this site is damaged and they do not want to anchor in the sand and risk drifting into the reef. However, they need the assistance of the DNER to repair and maintain infrastructure. Tour operators also indicated their concerns about not exposing the reef to harmful behaviors as well as their willingness to work with other stakeholders to protect the reefs within the reserve. Other adaptive measures they felt were needed include increased policing within the Reserve (especially during peak season and holidays), enforcing of the Reserve rules, and sharing of

Reserve rules and regulations with all stakeholders including private boat owners, fishers, and other tourism-related operators utilizing these resources.

The guides bringing guests to the Reserve can shape the exposure of the reef to diver contacts. They orient visitors to the reef, provide lessons, certify divers, give instructions for how to experience the reef, encourage or discourage types of behavior, and provide oversight and correction. Barker (2003) found that the highest contact rate occurred in the first ten minutes of the dive since divers were still acclimating to the underwater world. Barker (2003), DiFranco et al. (2009), and Rouphael & Inglis (2001) found that contact rates decreased as the dive progressed. DiFranco et al. (2009) recommend that all dives should start in less vulnerable habitats for this reason. Dive guides based out of Fajardo do a thorough job making sure the divers in their group descend away from the reef and establish buoyancy before the group begins the dive. During the initial dive, guides kept the group parallel to the reef and not over it. These are good examples of active management and support the role that dive leaders can play in reducing the exposure of coral reefs to physical contacts.

Studies examining the effects of pre-dive briefings to prepare divers and promote environmentally responsible behavior have had mixed results. Medio et al. (1997), Camp and Fraser (2012), Hammerton & Bucher (2015), and Roche et al. (2016) found that in-depth pre-dive briefings reduced diver's contact rates in the Florida Keys. Barker (2003) found a pre-dive briefing, that included a one sentence conservation message, had no effect on contact rates. However, Camp and Fraser (2012), Barker (2003) and Medio et al. (1997) all acknowledge the role that operators can play in promoting responsible behaviors by divers around the reefs. Every diver surveyed for this research stated they heard the dive briefing. Several commented on the survey that the briefings were strong, helpful, and contained important information. I observed divers paying attention and asking questions to dive guides during the briefings. In addition, the number of divers (average 9 individuals) also helped keep the setting for the briefings small and focused.

For all of these reasons, persuasion communication, specifically the central route to persuasion, is a promising mechanism for managing the behaviors of divers. The central route to persuasion involves a great deal of effort by the receiver to process the information in a message in order to determine its merit. The recipient of the message pays a great deal of attention to the content of the message, pondering its meaning, thinking critically about its content, and integrating it into his existing belief system (Petty & Wegener, 1999). The elaboration goes beyond the message and involves additional relevant thoughts generated by the receiver. If the arguments within the message are perceived as strong, a greater persuasion should occur. If this occurs, the attitude change can be expected to last into the future since it will be internalized (Roggenbuck, 1992). For these reasons, the content of the message is extremely important. The success of this method also depends on other variables including the recipient's prior knowledge, skills, experience, interest, motivation and personal relevance to the situation.

It is fair to say that in order for the central route of persuasion to be effective, the recipient must have high motivation to pay attention to the message content, be capable of processing and understanding the message, accept the content of the message, and have the skills to carry out the behaviors. Attitudes formed through this process are considered strong since they are more resistant to counter persuasion and, therefore, can be used to predict future behavior. Questions to gauge divers' attitudes indicate positive attitudes towards supporting actions to reduce stress on coral reef ecosystems. 57% of the divers surveyed in Puerto Rico felt that the coral reef crisis was real and 51% agreed that humans do damage coral reefs. These responses indicate that if the content of the message is effective and divers are capable of processing, understanding, and accepting the message, environmentally responsible behaviors may increase.

Persuasion communication states that the message must be perceived as strong in order for a greater persuasion to occur. The current briefings delivered by tour operators in Puerto Rico should be revised to focus less on discouraging negative behaviors and more on encouraging positive behaviors. Webler and Jakubowski (2011) designed successful video briefings to modify visitor behaviors at reefs in Puerto Rico by utilizing the social science theories of behavior and behavior change, in particular a strong theory of behavioral change, the Value Beliefs Norm (VBN) theory. VBN theory explains that the drive for individual behavior originates in a commitment to fundamental values but is then modified by information/knowledge, expectations about incentives and punishments, and social expectations or peer pressure. Examples of pro-environmental messages include self-efficacy (divers can avoid doing harm), awareness of consequences (corals build a strong skeleton but their "skin" is fragile), and prescriptive norms (some corals burn, keep your distance). These messages asserted positive environmental attitudes (you came to the reef to experience how remarkable it is), and appeal to benevolence (divers would never deliberately do anything to hurt marine life) (Webler & Jakubowski, 2016).

Giglio et al. (2018) also assessed education video briefing within the Arraial do Cabo Marine Extractive Reserve in Brazil. The video briefing provided information on low-impact diving techniques and environmental information about coral reefs. Divers who watched the video had significantly lower contact rates with the reef compared to divers who did not watch. These findings suggest that video messages can be an effective form of persuasion communication.

Camp and Fraser (2012) found that in-depth conservation education messages provided in the dive briefing did reduce the number of contacts divers made with the reef. They recommended local conservation education for tourists since their knowledge may be broader and they may not be aware of the biological life and conservation concerns at a specific dive site. For example, dive instructors taking visitors to La Cordillera Nature Reserve could include in their briefings information about the high percentage of soft corals at Cayo Diabo and their random movements based on the water currents. As a result of this unpredictable movement, divers should extend their distance from the reef in order to prevent accidental contacts.

Loomis et al. (2008) also studied the role that recreation specialization has in fostering environmentally responsible behaviors of divers in the Florida Keys. As previously discussed, the researchers utilized 8 testable propositions developed by Ditton et al. (1992) to further study Bryan's theory of recreation specialization. Proposition number four, specialized divers have a greater acceptance and support for the rules, norms, and procedures associated with an activity, is relevant to my research especially for managing first time divers with no experience. Discover Scuba is popular within La Cordillera Nature Reserve. It serves an important purpose by exposing people to the underwater world, raising awareness, and encouraging individuals to continue on with their scuba certification. While "Discover Scuba" divers do not go near the reef on their first dive since they are learning and practicing basic dive skills with an instructor, (usually at Sandslide away from the reef on a sandy bottom or at a resort pool), they will complete an instructor led dive at a reef within the Reserve. The only two Discover Scuba divers I observed were responsible for a high number of contacts during an observation period of 5 minutes at the reef (19 and 10 contacts). While Barker (2003), Harriott et al. (1997), and DiFranco et al. (2009) found no significant difference between total number of contacts and dive experience, Barker did find that cruise ship passengers were significantly more likely to contact the reef than non-cruise ship passengers. These passengers are often "non-specialists" diving for the experience and not as their main vacation activity. For these reasons, Barker felt they may not be taking it as seriously and be less skilled. I observed one “Discover Scuba” training while in Puerto Rico and found that the focus of the training is understandably dive safety skills not conservation messages. It is also understandable that when first time divers visit the reef, they may be anxious, nervous, and a bit compulsive. I recommend basic conservation messages should be added to the Discover Scuba lessons since they are an important part of the training, (raise awareness of the importance of coral reef ecosystems, corals are fragile organisms, divers can avoid contact), I also recommend that individuals who have not taken an official certification course should not be brought to reefs that have a higher percentage of sensitive coral species.

Finally, research findings suggest that scuba divers who visited La Cordillera Nature Reserve were satisfied with their experience. 64% of divers were satisfied with seeing a healthy reef and 58% of divers surveyed felt they saw a diversity of marine life. These findings are similar to Barker (2003) who found that as long as the reef was not visibly damaged and had high quantities of fish, it was enough to adequately satisfy visitors. This knowledge can be utilized by dive operators for dive site selection based on their divers’ skills, experiences, and perceptions.

Divers are supportive of learning, being corrected, and following the rules for both safety reasons and conservation reasons. Tour operators have an important role in these experiences, including promoting pro-environmental behaviors at the reefs. Teaching moments are easy, tangible, and inexpensive measures that can contribute to the management of human impacts on coral reefs and reduce the vulnerability of the system to such activities.

A final research recommendation to reduce the vulnerability of reefs in La Cordillera Nature Reserve is the need for improvement in the relationship between tour operators and government officials in charge of managing the activities that take place within the Reserve. Dive operators believe they are not getting the support they need from the government and their voices are not being heard when it comes to actions that would help the tourism industry while protecting the quality of the coral reefs. Those interviewed stated they felt they were not aware of all of the policies and regulations for the Reserve. They also felt there is little collaboration between operators and government managers. For example, mooring buoys need to be maintained. Both dive operators based out of Fajardo refuse to visit reefs without moorings. This puts more visitor strain on the only reefs they can visit and can affect carrying capacities at frequently visited dive sites. Dive key informants also expressed their concern over the lack of communication with government officials responsible for managing the La Cordillera Nature Reserve.

4.10 Conclusion

The corals of La Cordillera Nature Reserve are protected and guidelines for management have been outlined in a coral reef management plan. However, in developing a methodology to test the vulnerability of coral reefs to diving, I conclude that diving activities within La Cordillera Nature Reserve, Puerto Rico, specifically at Sandslide (Isla Palominos) and Cayo Diablo reef, contribute to increasing the vulnerability of the reef ecosystems in the Reserve. The federal Coral Reef Task Force Strategy prioritizes the study of recreational use at reefs as one of its top priority goals (National Oceanic Atmospheric Administration United States Coral Reef Task Force [NOAA], 2016). This includes the development of strategies to reduce impacts from recreational use, protect the health of coral reefs, and enhance coral reef resilience.

Increasing adaptive capacity and implementing management actions to reduce vulnerability, specifically actions that decrease exposure, is a tangible possibility. Reducing contacts is one such measure. Gardner et al., (2003) stated that if human behaviors could be managed correctly, corals would be capable of handling natural stresses more effectively. Actions to encourage pro-environmental behaviors at the reef include revised briefings that reinforce etiquette at the reef and social norms that can empower certified divers to make a greater effort to not contact the reef.

Non-certified divers should be restricted to reefs with coral species that are less sensitive to diver contact. For example, a majority of the corals observed at Cayo Diablo Reef were soft corals. The unpredictable movement of these corals can increase diver contacts. A first-time diver may not have the ability to maneuver around these organisms increasing the frequency of contacts.

Improved communication with managers and government officials involved in tourism at the reef is another necessary component to reduce vulnerability. Tour operators can collaborate with coral reef managers as part of the Coral Reef Management Plan. Management options that could reduce contacts include the installation of additional mooring buoys and stronger management of all tourist activities at the reef. These strategies are all tangible actions for managing dive tourism in order to reduce the vulnerability of the reef. Strategies can be evaluated and adapted as necessary. Without such actions, corals at La Cordillera Nature Reserve in Puerto Rico will most likely continue to be exposed to stressors that can escalate the degree of degradation to reef ecosystems.

4.11 References

Adger, W. (2006). Vulnerability. *Global Environmental Change*, *16*(3), 268-281. https://doi.org/10.1016/j.gloenvcha.2006.02.006

Allison, W.R. (1996). Snorkeler damage to reef corals in the Maldive Islands. *Coral Reefs*, *15*(4), 215-218. https://doi.org/10.1007/BF01787454

Alwang, J., Siegel, P.B., & Jørgensen, S.L. (2001). *Vulnerability: A view from different disciplines*. Social Protection Discussion Paper Series No. 0115. Social Protection Unit, Human Development Network. The World Bank.

Antonius, A. (1985). Coral reef pathology: A review. *Proceedings 4th International Coral Reef Symposium, Manila,2*:3-6. https://agris.fao.org/agris-search/search.do?recordID=XB8310992

Appeldoorn, R., Beets, J., Bohnsack, J., Bolden, S., Matos, D., Meyers, S., Rosario, A., Sadovy, Y., & Tobias, W. (1992). Shallow water reef fish stock assessment for the U.S. Caribbean. *NOAA Tech. Mem.* NMFS-SEFSC-304.

Appeldoorn, R., Yoshioka, P., Ballantine, D. (2009). Coral reef ecosystem studies: Integrating science and management in the Caribbean. *Caribbean Journal of Science, 45*(2-3), 134-137. https://doi.org/10.18475/cjos.v45i2.a2

Barker, N.H.L. (2003). *Ecological and socio-economic impacts of dive and snorkel tourism in St. Lucia, West Indies* (Doctoral dissertation, University of York). ProQuest Dissertations and Theses Global.

Barker, N.H.L. & Roberts, C.M. (2004). Scuba diver behavior and the management of diving impacts on coral reefs. *Biological Conservation,120*, (4), 481-489. https://doi.org/10.1016/j.biocon.2004.03.021

Burgett, J. (1990). Diving deeper into Hanauma: Identifying conceptual barriers to effective management. In M. Miller and J. Auyong (Eds.), *Proceedings of the 1990 Congress on Coastal and Marine Tourism*. (Vol 1., pp. 100-105). National Coastal Resources Research Institute.

Camp, E. & Fraser, D. (2012). Influence of conservation education dive briefings as a management tool on the timing and nature of recreational SCUBA diving impacts on coral reefs. *Ocean and Coastal Management,61*, 30-37. http://doi.org/10.1016/j.ocecoaman.2012.02.002

Carpenter, S., Walker, B., Anderies, J.M., & Abel, N. (2001). From metaphor to measurement: Resilience of what to what? *Ecosystems, 4*(8), 765-781. https://doi.org/10.1007/s10021-001-0045-9

Chadwick-Furman, N.E. (1997). Effects of SCUBA diving on coral reef invertebrates in the U.S. Virgin Islands: Implications for the management of diving tourism. In den Hartog, J.C. (Ed.), *Proceedings of the Sixth International Conference on Coelenterate Biology* (91-100). National Naturhistorisch Museum.

Chadwick-Furman, N. & Loya, Y. (1990). Regeneration after experimental breakage in the solitary reef coral *Fungia granulosa* Kluzinger,1879. *Journal of Experimental Marine Biology and Ecology*, *142*(3), 221 – 234. https://doi.org/10.1016/0022-0981(90)90093-R

Chung, S.S., Au, A., & Qiu, J.W. (2013). Understanding the underwater behavior of scuba divers in Hong Kong. *Environmental Management 51*:824–837. http://doi.org/10.1007/s00267-013-0023-y

Davis, D. & Tisdell, C. (1995). Recreational scuba-diving and carrying capacity in marine protected areas. *Ocean and Coastal Management*, *26*(1),19-40. https://doi.org/10.1016/0964-5691(95)00004-L

Dearden, P., Bennett, M., & Rollins, R. (2006). Implications for coral reef conservation of diver specialization. *Environmental Conservation,33*(4), 353-363. https://doi/10.1017/S0376892906003419

DiFranco, A., Milazzo, M., Baiata, P., & Tomasello, A. (2009). Scuba diver behavior and its effects on the biota of a Mediterranean marine protected area. *Environmental Conservation, 36*(1), 32 - 40. http://doi.org/10.1017/S0376892909005426

Dimmock, K. (2009). Finding comfort in adventure: experiences of recreational SCUBA divers. *Leisure Studies,28*(3), 279-295. https://doi.org/10.1080/02614360902951674

Ditton, R.B., Loomis, D.K., & Choi, S. (1992). Recreation specialization: Re-conceptualization from a social world's perspective. *Journal of Leisure Research, 24*(1), 33-51. https://doi.org. 10.1080/00222216.1992.11969870

Dixon, J.A., Fallon Scura, L.,& Van't Hof, T. (1993). Meeting ecological and economic goals: Marine parks in the Caribbean. *Ambio*, *22*, 117-125.

Dodge, R.E.; Aller, R.C.; Thompson, J. (1974). Coral growth related to resuspension of bottom sediments. *Nature, 247*, 574-577. https://doi.org/10.1038/247574a0

Federal Emergency Management Agency. (2018). *Scientists working to restore Puerto Rico's coral reefs battered by 2017 hurricanes.* https://www.fema.gov/press-release/20210318/scientists-working-restore-puerto-ricos-coral-reefs-battered-2017-hurricanes

Fox, H.E., Pet, J.S., Dahuri, R. & Caldwell, R.L. (2003). Recovery in rubble fields: Long-term impacts of blast fishing. *Marine Pollution Bulletin, 46*(8):1024-1031. https://doi.org/10.1016/S0025-326X(03)00246-7

Gallopín, G.C., (2006). Linkages between vulnerability, resilience, and adaptive capacity. *Global Environmental Change 16*(3), 293-303. https://doi.org/10.1016/j.gloenvcha.2006.02.004

Garcia-Sais, J., Appeldoorn, R., Battista, T., Bauer, L., Bruckner, A., Caldow, C., Carrubba, L., Corredor, J., Diaz, E., Lilyestrom, C., Garcia-Moliner, G., Hernandez-Delgado, E., Menza, C., Morell, J., Pait, A., Sabater, J., Weil, E., Williams, E., & Williams, S. (2008). The State of Coral Reef Ecosystems of Puerto Rico. In J.E. Waddell & A.M. Clarke (Eds.), *The State of Coral Reef Ecosystems of the United States and Pacific Freely Associated States: 2008* (pp. 75 – 116). NOAA Technical Memorandum NOS NCCOS 73. NOAA/NCCOS Center for Coastal Monitoring and Assessment's Biogeography Team.

Gardner, T.A., Côté, I.M., Gill, J.A., Grant, A., & Watkinson, A. R. (2003). Long-term region-wide declines in Caribbean corals. *Science*, *301*(5635*)*, 958-960. https://doi.org/10.1126/science.1086050

Garrod, B. (2009). Market segments and tourism typologies for diving tourism. In B. Garrod & S. Grossling (Eds.), *New frontiers in marine tourism: Diving experiences, sustainability, management* (pp. 31- 39). Elsevier.

Giglio, V., Luiz, O., Chadwick, N., & Ferreira, C. (2018). Using an educational video-briefing to mitigate the ecological impacts of scuba diving. *Journal of Sustainable Tourism, 26*(5), 782- 797. https://doi.org/10.1080/09669582.2017.1408636

Hall, V. R. (2001). The response of *Acropora hyacinthus* and *Montipora tuberculosa* to three different types of colony damage: Scraping injury, tissue mortality and breakage. *Journal of Experimental Marine Biology and Ecology*, *264*(2), 209-223. https://doi.org/10.1016/S0022-0981(01)00318-5

Hammerton, Z. & Bucher, D. (2015). Levels of intervention – Reducing SCUBA-diver impact within subtropical marine protected areas. *Journal of Ecotourism, 14*(1), 3 – 20. https://doi.org/ 10.1080/14724049.2015.1073738

Harriott, V.J., Davis, D., & Banks, S.A. (1997). Recreational diving and its impact in marine protected areas in eastern Australia, *Ambio,26*, (3),173-179.

Hawkins, J.P. & Roberts, C.M. (1992). Effects of recreational SCUBA diving on fore-reef slope communities of coral reefs. *Biological Conservation*, *62*(3), 171-178. https://doi.org/10.1016/0006-3207(92)91045-T

Hawkins, J. P. & Roberts, C.M. (1996). The growth of coastal tourism in the Red Sea: Present and future effects on coral reefs. *Ambio, 23*(8), 503-508.

Hawkins, J.P. & Roberts, C.M. (1997). Estimating the carrying capacity of coral reefs for scuba diving. In H.A. Lessios, I.G. Macintyre, & M. McGee (Eds.), *Proceedings of the Eighth International Coral Reef Symposium volume two* (pp. 1923-1926). Smithsonian Tropical Research Institute.

Hawkins, J.P., Roberts, C., V'ant Hof, T., De Meyer, K., Tratalos, J., & Aldam, C. (1999). Effects of recreational scuba diving on Caribbean coral and fish communities. *Conservation Biology, 13*(4), 888-897. https://doi.org/10.1046/j.1523-1739.1999.97447.x

Hernández-Delgado, E.A. (2005). *Natural history, characterization, distribution and current status of Puerto Rico coral reefs. Puerto Rico biodiversity:Terrestrial vertebrates and ecosystems.* Natural History Series. San Juan, Puerto Rico: Editorial Instituto de Cultura Puertorriqueña, 281-356.

Hernández-Delgado, E.A., Ramos-Scharrón, C.E., Guerrero, C., Lucking, M.A., Laureano, R., Méndez-Lázaro, P.A., & Meléndez-Díaz, J.O. (2012). Long-term impacts of tourism and urban development in tropical coastal habitats in a changing climate: Lessons learned from Puerto Rico. In M. Kasimoglu (Ed.)., *Visions from global tourism industry-creating and sustaining competitive strategies* (357-398). InTech Publications.

Inskeep, E. (1991). *Tourism planning*. Van Nostrand Reinhold.

Jameson, S.C., Ammar, M.S.A., Saadalla, E., Mostafa, H., & Riegl, B. (1999). A coral damage index and its application to diving sites in the Egyptian Red Sea. *Coral Reefs*, *18*(4), 333- 339. https://doi.org/10.1007/s003380050208

Jenner, P., & Smith, C. (1992). *The tourism industry and the environment*. Economist Intelligence Unit.

Kay, A.M., & Liddle, M.J. (1989). Impact of human trampling in different zones of a coral reef flat. *Environmental Management*, *13*(4), 509-520. https://doi.org/10.1007/BF01867685

Klint, L.M., Jiang, M., Law, A., Delacy, T., Filep, S. Calgaro, E., Dominey-Howes, D., & Harrison, D. (2012). Dive tourism in Luganville, Vanuatu: Shock stressors and vulnerability to climate change. *Tourism in Marine Environments, 8*(1-2), 91-109. https://doi.org/10.3727/154427312X13262430524225

Krieger, J.R. & Chadwick, N.E. (2013). Recreational diving impacts and the use of pre- dive briefings as a management strategy on Florida coral reefs. *Journal of Coast Conservation*, *17*(1), 179-189. https://doi.org/ 10.1007/s11852-012-0229-9

Lessios, H.A., Robertson, D.R., & Cobit, J.D. (1984). Spread of *Diadema* mass mortality through the Caribbean. *Science, 226*, 335-338. http://doi.org/10.1126/science.226.4672.335

Liddle, M.J. (1991). Recreation ecology: Effects of trampling on plants and corals. *Trends in Ecology and Evolution*, *6* (1), 13-17. https://doi.org/ 10.1016/0169-5347(91)90141-J

Liddle, M.J. & Kay, A.M. (1987). Resistance, survival and recovery of trampled corals on the Great Barrier Reef. *Biological Conservation*, *42*(1), 1-18. https://doi.org/10.1016/0006-3207(87)90049-8

Loomis, D., Anderson, L., Hawkins, C., Paterson, S. (2008). *Understanding coral reef use: Scuba diving in the Florida Keys by residents and non-residents.* The Florida Reef Resilience Program. The Nature Conservancy Florida Keys Program, 1 – 141. https://frrp.org/FRRP%20documents/frrp_diving.pdf

Lucrezi, S., Saayman, M., & van der Merwe, P. (2013). Managing diving impacts on reef ecosystems: Analysis of putative influences of motivations, marine life preferences, and experience on divers' environmental perceptions. *Ocean and Coastal Management, 76*, 52 – 63. https://doi.org/10.1016/j.ocecoaman.2013.02.020

Lyons, P.J., Arboleda, E., Benkwitt, C.E., Davis, B., Gleason, M., Howe, C., Mathe, J., Middleton, J., Sikowitz, N., Untersteggaber, L., & Villalobos, S. (2015). The effect of recreational SCUBA divers on the structural complexity and benthic assemblage of a Caribbean coral reef. *Biodiversity and Conservation, 24*(14), 3491-3504. http://doi.org/10.1007/s10531-015-1009-2

Medio, D., Ormond, R. & Pearson, M. (1997). Effect of briefings on rates of damage to coral by SCUBA divers. *Biological Conservation*,*79*(1)*,* 91-95. https://doi.org/10.1016/S0006-3207(96)00074-2

Mundet, L. & Ribera, L. (2001). Characteristics of divers at a Spanish resort. *Tourism Management, 22*(5), 501-510. https://doi.org/ 10.1016/S0261-5177(01)00016-4

Musa, G. (2002). Sipadan: A SCUBA-diving paradise: An analysis of tourism impact, diver satisfaction and tourism management. *Tourism Geographies, 4*(2),195-209. https://doi.org/10.1080/14616680210124927

National Oceanic and Atmospheric Administration (NOAA). (2009). *Coral Reef Habitat Assessment for U.S. Marine Protected Areas: Commonwealth of Puerto Rico*. https://www.coris.noaa.gov/activities/habitat_assessment/puerto_rico.pdf

National Oceanic and Atmospheric Administration (NOAA). (2016). *U.S. Coral Reef Task Force Strategy FY 2016-2021*. https://data.nodc.noaa.gov/coris/library/NOAA/CRCP/other/USCRTF/uscrtf_strategy_2016_2021.pdf

National Ocean Service (NOS). (2016). https://oceanservice.noaa.gov/education/tutorial_corals/media/supp_coral03d.html

Neil, D. (1990). Potential for coral stress due to sediment re-suspension and deposition by reef walkers. *Biological Conservation*, *52*(3), 221-227. https://doi.org/10.1016/0006-3207(90)90127-B

Nemeth, R. S. & Nowlis, J.S. (2001). Monitoring the effects of land development on the near-shore reef environment of St. Thomas, USVI. *Bulletin of Marine Science*, *69*(2), 759-775.

Nowlis, J.S., Roberts, C. M., Smith, A. H. and Siirila, E. (1997). Human-enhanced impacts of a tropical storm on nearshore reefs. *AMBIO, 26*(8), 515-521.

Orams, M. (1999). *Marine tourism: Development, impacts, and management*. Routledge.

Parker, S. (2001). Marine tourism and environmental management on the Great Barrier Reef. In V.L. Smith & M. Brent (Eds*), Hosts and guest revisited: Tourism issues of the 21st Century* (pp.232-241). Cognizant Communication Cooperation.

Petty, R. & Wegener, D. (1999). The elaboration likelihood model: Current status and controversies. In S. Chaiken & Y. Trope (Eds.), *Dual process theories in social psychology* (pp.41-72). Guilford Press.

Pigram, J.J. & Jenkins, J.M. (1999). *Outdoor Recreation Management.* Routledge.

Plathong, S., Inglis, G. J. & Huber, M. E. (2000). Effects of self-guided snorkeling trails on corals in a tropical marine park. *Conservation Biology, 14*(6), 1821-1830. https://doi.org/10.1111/j.1523-1739.2000.99301.x

Prior, M., Ormond, R., Hitchen, R., & Wormald, C. (1995). The impact of natural resources of activity tourism: A case study of diving in Egypt. *International Journal of Environmental Studies, 48*(3-4), 201-209. https://doi.org/10.1080/00207239508710990

Professional Association of Dive Instructors [PADI]. (2017). Statistics. https://www.padi.com/sites/default/files/documents/2017%20PADI%20WW%20Statistics.pdf

Professional Association of Dive Instructors [PADI]. (2018). https://www.padi.com

Richmond, R.H. (1996). Reproduction and recruitment in corals: Critical links in the persistence of reefs. In: C.E. Birkeland, (Ed.), *Life and Death of Coral Reefs.* (pp.175-197). Chapman & Hall.

Riegl, B. & Velimirov, B. (1991). How many damaged corals in Red Sea reef systems? A quantitative survey. *Hydrobiologia, 216-217*(1), 249-256. https://doi.org/10.1007/BF00026471

Roche, R.C., Harvey, C.V., Harvey, J.J., Kavanagh, A.P., McDonald, M., Stein-Rostaing, V.R., & Turner, J.R. (2016). Recreational diving impacts on coral reefs and the adoption of environmentally responsible practices with the SCUBA diving industry. *Environmental Management, 58*(1), 107-116. https://doi.org/10.1007/s00267-016-0696-0

Rogers, C.S. (1990). Responses of coral reefs and reef organisms to sedimentation. *Marine Ecology Progress Series*, *62,* 185-202. https://doi.org/ 10.3354/meps062185

Roggenbuck, J. (1992). Use of persuasion to reduce resource impacts and visitor conflicts. In M. Manfredo (Ed.), *Influencing Human Behavior*, pp. 149-248. Sagamore Publishing.

Rouphael, A.B. & Inglis, G.J. (1997). Impacts of recreational SCUBA diving at sites with different reef topographies. *Biological Conservation*, *82*(3), 329-336. https://doi.org/10.1016/S0006-3207(97)00047-5

Rouphael, A.B. & Inglis, G.J (2001). "Take only photographs and leave only footprints"?: An experimental study of the impacts of underwater photographers on coral reef dive sites. *Biological Conservation*, *100*(3), 281–287. https://doi/org/10.1016/S0006-3207(01)00032-5

Rouphael, T., & Inglis, G. (1995). The effects of qualified recreational SCUBA divers on coral reefs. *CRC Reef Research Centre. Technical Report No. 4*, Townsville, Australia, 1-39.

Rygel, L., O'Sullivan, D., & Yarnal, B. (2006). A method for constructing a social vulnerability index: An application to hurricane storm surges in a developed country. *Mitigation and Adaptation Strategies for Global Change, 11*, 741-764. https://doi.org/10.1007/s11027-006-0265-6

Salm, R.V. (1986). Coral reefs and tourist carrying capacity: The Indian Ocean experience. *Industry and Environment*, *9*(1), 11-15.

Schwartz, S.H. (1977). Normative influences on altruism. *Advances in Experimental Social Psychology,10*, 221-279. https://doi.org/10.1016/S0065-2601(08)60358-5

Sheppard, C. & Loughland, R. (2002). Coral mortality and recovery in response to increasing temperature in the southern Arabian Gulf. *Aquatic Ecosystem Health Management, 5*(4), 395-402. https://doi.org/10.1080/14634980290002020

Smit, B. & Wandel, J. (2006). Adaptation, adaptive capacity and vulnerability. *Global Environmental Change,16*(3), 282-292. https://doi.org/10.1016/j.gloenvcha.2006.03.008

Spalding, M., Burke, L., Wood, S., Ashpole, J., Hutchison, J., & zu Ermgasssen, P. (2017). Mapping the global value and distribution of coral reef tourism. *Marine Policy, 82*,104-113. https://doi.org/10.1016/j.marpol.2017.05.014

Spurgeon, J. (1992). The economic valuation of coral reefs. *Marine Pollution Bulletin, 24*(11), 529-536. https://doi.org/10.1016/0025-326X(92)90704-A

Stobart, B., Teleki, K., Buckley, R., Downing, N., Callow, M. (2005). Coral recovery at Aldabra Atoll Seychelles: Five years after the 1998 bleaching event. *Philosophical Transactions of the Royal Society,363*(1826), 251-255. https://doi.org/10.1098/rsta.2004.1490

Talge, H. (1990). Impact of recreational divers on coral reefs in the Florida Keys. In W.C. Jaap (Ed.), *Advances in Underwater Science. Proceedings of the American Academy of Underwater Science 10th Annual Scientific Diving Symposium* (pp. 364-374).

Talge, H. (1993). Impact of recreational divers on scleractinian corals at Looe Key, Florida. In R.H. Richmond (Ed.), *Proceedings of the 7th International Coral Reef Symposium, Volume 2, pp.1077-1082.*, University of Guam Press.

Thapa, B., Graefe, A., & Meyer, L. (2006). Specialization and marine based environmental behaviors among SCUBA divers. *Journal of Leisure Research*, *38(4),*601- 615. https://doi.org/10.1080/00222216.2006.11950094

Tilmant, J.T. (1987). Impacts of recreational activities on coral reefs. In B. Salvat, (Ed.), *Human impacts on coral reefs: Facts and recommendation (pp. 195 – 214).* Antenne Museum E.P.H.E.

Todd, S. (2000). Scuba diving in New York's Great Lakes: From novice to professional. *New York Sea Grant Institute Completion Report*. SUNY, Department of Recreation and Leisure Studies.

Tratalos, J. & Austin, T. (2001). Impacts of recreational SCUBA diving on coral communities of the Caribbean island of Grand Cayman. *Biological Conservation*, *102*(1), 67-75. https://doi.org/10.1016/S0006-3207(01)00085-4

Unruh, D.R. (1979). Characteristics and types of participation in social worlds. *Symbolic Interaction, 2,* 115- 130. https://doi.org/10.1525/si.1979.2.2.115

Uyarra, M.C., Watkinson, A., and Côté, I. (2009). Managing dive tourism for sustainable use of coral reefs: Validating diver perceptions of attractive site features. *Environmental Management*, *43*(1), 1-16. http://doi.org/10.1007/s00267-008-9198-z

Vaske, J., Shelby, B., Graefe, A.R., & Heberlein, T.A. (1986). Backcountry encounter norms: Theory, method, and empirical evidence. *Journal of Leisure Research*, *18*(3), 137–153. http://doi.org/ 10.1080/00222216.1986.11969653

Walker, D.I. & Ormond, R.F.G. (1982). Coral death from sewage and phosphate pollution at Aqaba, Red Sea. *Marine Pollution Bulletin*,*13*(1), 21-25. https://doi.org/10.1016/0025-326X(82)90492-1

Webler, T., & Jakubowski, K. (2011). *Characterizing harmful behaviors of snorkelers and SCUBA divers to coral reefs in Puerto Rico: Interim Project Report.* Social and Environmental Research Institute: Greenfield MA, 15pp.

Webler, T. & Jakubowski, K. (2016). Mitigating damaging behaviors of snorkelers to coral reefs in Puerto Rico through a pre-trip media-based intervention. *Biological Conservation, 197*, 223-228. https://doi.org/10.1016/j.biocon.2016.03.012

Zabala, M. (1999). Recreation in Mediterranean marine parks: Limits and perspective. In F. Briand (Ed.), *Scientific Design and Monitoring of Mediterranean Marine Protected Areas* (pp. 51–52). CIESM Workshop Series.

Zakai, D. & Chadwick-Furman, N.E. (2002). Impacts of intensive recreational diving on reef corals at Eilat, northern Red Sea. *Biological Conservation, 105*(2), 179-187. https://doi.org/10.1016/S0006-3207(01)00181-1

Chapter 5
Coral Reef Management Strategies for Reducing Vulnerability to Dive and Snorkel Recreational Activities

5.1 Introduction

Coral reefs have been defined as one of Earth's "essential life support systems" (International Union for Conservation of Nature /United Nations Environment Programme/World Wildlife Fund [IUCN/UNEP/WWF],1980). This title has been earned because of the rich biological diversity and productivity found at coral reefs as well as the significant role coral reefs play in other tropical, coastal, ecosystems. Coral reef ecosystems also provide important goods and services to humans. They serve as a source of food security, coastal protection, medicine, and income. Most island communities with coral reefs depend on both the beauty and diversity of life found within these ecosystems since they serve as income from fisheries and popular recreation destinations for local residents and tourists alike. It has been estimated that 70 million tourist trips have occurred globally as a result of the presence of coral reefs. Considering that indirect benefits are not factored into this total, the number should be considered much higher (Spalding et al., 2017). Over 100 jurisdictions depend on coral reefs world-wide as a source of income. In the Maldives, tourism is the largest industry, accounting for 41.5% of the gross domestic product, with scuba diving an important activity that generates significant revenue (Van't Hof, 1988; World Travel & Tourism Council [WTTC], 2014,). It is estimated that 30 million people are completely dependent upon coral reef ecosystems for their livelihoods (Wilkinson, 2008).

Coral reefs add value to existing tourism destinations by providing an outing opportunity and, thereby, supporting a local service industry for snorkeling, diving, swimming, recreational fishing, and boating. Local lodging, retail, dining, and marinas also benefit. Reef related tourism provides income generation and employment. Nature-based tourist activities are also known to raise environmental awareness and influence attitudes and knowledge as well as promote stewardship behaviors towards the environment (Ardoin et al., 2015). These benefits also come with risks. In the Caribbean, economic development, increasing populations, and lack of effective policies to conserve these resources can result in degraded coastal marine and terrestrial ecosystems (Valdéz-Pizzini et al. 2012).

Tourism can also alter the perceptions of local communities and the government's view on how these marine ecosystems and resources are utilized (Hernandez-Delgado et al., 2012). For example, before the tourism boom in Belize, most coastal communities were dependent on fishing and farming for their subsistence. Today, these communities have a higher dependency on using the reefs for tourism gains and a shift in how reefs are valued has occurred. Instead of focusing on coral reefs for subsistence, the focus has changed to the immediate revenue generated from tourism activities (Diedrich, 2006).

The decline of reefs globally is in part due to the increasing and expanding use of their goods and services (Burke et al., 2011; Gardner et al., 2003; Glynn,1994; Hoegh-Guldberg et al., 2007; Hughes et al., 2003). Approximately 75% of reefs worldwide have been rated as threatened (Burke et al., 2011). A combination of anthropogenic stressors is responsible for the severity of the coral reef crisis and includes coastal development, land-based sedimentation overload, sewage discharge, inorganic debris, overfishing, habitat degradation, pollution, and climate change impacts (Burke et al., 2011; Doney, 2006). Impacts of climate change have resulted in the loss of mangrove forests, seagrass beds, and coral bleaching, as well as changes in ocean chemistry, which impacts the shell formation of organisms including corals, forams, crustaceans, and mollusks (Burke et al., 2011, Doney, 2006; Rhein et al., 2013).

The unique ecology and diverse biology of coral reef ecosystems makes them more vulnerable to both local and global stressors, more so than other systems. Scientists classify reefs as heterogeneous, fragile, and globally stressed ecosystems affected by both positive and negative feedback mechanisms (Mumby & Steneck, 2008). While coral species have some resilience to natural disturbances, they are sensitive to minor changes in water temperature, salinity, turbidity, and the overall chemistry of the water they inhabit. In addition, the biological process of building and repairing the coral reef structure takes a significant amount of time. Scientists and coral reef managers no longer support the concept that reefs are stable on the scale of millennia (Mumby & Steneck, 2008). If we do not take measures to mitigate coral reef stressors, scientists project that within decades a majority of coral reef ecosystems globally will be eradicated (Frieler et al., 2013). Of the approximately 1000 species of reef building corals that exist, NOAA (2014) listed 20 species of corals as threatened and two species as endangered under the Federal Endangered Species Act.

In the Caribbean, coral reefs have been declining for at least the last forty years (Appeldoorn et al., 1992). Today, 75% of the coral reef ecosystems in this region are under medium to highly threatened status (Appeldoorn et al., 2009; Burke et al., 2011). Puerto Rico's coastline includes over 5,000 km^2 of coral reef ecosystems that are accessible to the public (Garcia-Sais et al., 2008). As previously described, these reefs have been affected by a variety of both global and local stressors. Specific local stressors include land-based pollution and runoff, coastal development, overfishing, population increases along the coast, vessel groundings, recreational overuse impacts, coral diseases, bleaching due to increasing sea temperatures, and invasive species. More than 50 percent of living coral in Puerto Rico has been lost and the rate of loss continues to increase (Morelock, et al., 2001). These changes impact other species dependent on the reef including significant decreases in catch per unit of effort for coral reef fish in the recreational fishing industry (Lilyestrom & Hoffmaster, 2002).

Scientists have documented early warning signs since the 1970s with the loss of elkhorn coral (*Acropora palmata*) and the loss of the long-spined black sea urchin (*Diadema antillarum*) in the 1980s, both from epizootics (Lessios et al.,1984). In the 1990's severe declines in several reef fishery catches were documented and served as more evidence (Appeldoorn et al.,1992). The 2005 coral bleaching event and post bleaching coral mass mortality during 2006, caused by warm sea surface temperatures and 14 accumulated degree heating weeks, resulted in 82 species of coral affected. A NOAA Biological Review Team (BRT) determined that, due to the decreased abundance of elkhorn and staghorn corals (genus *acropora*), it is likely that the ecosystem functions related to growth of coral reefs and provision of habitat have been greatly compromised (Boulon et al., 2005). Disease, coral bleaching, and physical damage from hurricanes were considered the greatest threats followed by human caused physical damage such as groundings, anchoring, diving, and snorkeling.

Snorkeling and scuba diving, both tourist recreational activities in the marine environment, were once thought of as low-impact options for coral reef use. However, these recreational activities can significantly degrade coral reefs when visitors act inappropriately. Specific damaging behaviors include fins kicking coral, brushing up against the reef, holding on to coral, standing or kneeling on the reef, and walking on coral polyps (Barker, 2003; Medio et al., 1997; Prior et al., 1995; Rouphael & Inglis, 2001; Webler & Jakubowski, 2016). Even minor human contacts can damage the protective layer of tissue that covers the corals leaving them susceptible to algae colonization, which then collects sediment and ultimately smothers the coral (Hall, 2001; Liddle & Kay, 1987; Walker & Ormond, 1982). Coral diseases caused by physical tissue damage can kill corals and eventually lead to shifts in the type, diversity, and percentage of corals that occupy reef ecosystems (Hawkins & Roberts,1997). Alevizon (2002) suggests that diving and snorkeling activities should be considered to have the same impact as consumptive activities in terms of the effects they have on coral reef systems.

For all of these reasons, reef management would be more effective with knowledge of the acceptable level of recreational impacts and the critical thresholds that must be avoided. To date, no research has been done on tourism activities, even though Puerto Rico's Coral Reef Management Plan, developed by coral reef experts from Puerto Rico, includes Local Action Strategies (LAS) for coral reef conservation (2011-2015), and does prioritize the management of recreational use of marine and coastal areas to reduce the impacts to coral reefs as one of its top priority goals. Recommendations include the development of strategies to improve water quality, protect coral reef fisheries, reduce human impacts including those from recreational use, and manage for climate change (Ortiz Sotomayor, 2015).

It is difficult to estimate how many tourists and their activities a reef can support. It can be assumed the ecosystem is resilient to stresses below some threshold and above this threshold the reef rapidly degrades (Davis & Tisdell, 1995). The tourism industry wants the resource protected; however, without strong scientific numbers, precautionary management activities often lose out to short-term economic gains (Ragster & Geoghegan,1992). Implementing strategies to reduce local stressors can alleviate some of the factors that make coral reefs more vulnerable. In this chapter, I address the research question: *What management actions will be effective at reducing the vulnerability of coral reefs caused by the behaviors of divers and snorkelers at coral reefs in Puerto Rico?* To address this question, I will discuss the adaptive strategies that are currently being utilized at coral reef ecosystems globally to reduce exposure and sensitivity associated with dive and snorkel tourism, including their strengths and limitations. After each strategy, I discuss if and how these adaptive actions have been implemented to reduce impacts within La Cordillera Nature Reserve, Puerto Rico, as well as provide recommendations for additional measures based on my research.

5.2 Managing Coral Reef Resources

Effective management of coral reef resources must be based upon a sound understanding of the relationship between natural and anthropogenic interactions (White et al.,1994). Ecological variables, and human variables which include reciprocal relationships and feedback loops, need to be measured (Liu et al., 2007; Schultz et al., 2007). For all those involved in the management process, the challenge is that multiple human activities are difficult to disentangle from each other and ecosystems are unique in that they respond to stressors associated with each activity differently (Halpern et al., 2007). In addition, maintaining the balance between the satisfaction of stakeholders and the preservation of the intrinsic qualities of the ecosystem adds to the complexity (Kenchington, 1993). In order to manage the various activities that take place within coral reef ecosystems, resource management and conservation efforts need to move toward an integrated, multi-sector, coupled systems approach. This approach combines humans and environmental systems and no longer views each as separate and isolated systems (Carter et al., 2014; Virapongse et al., 2016; Werner & McNamara, 2007).

Such integration involves both horizontal and vertical elements. Horizontal integration, described as joined-up decision making, includes examining a variety of factors, both terrestrial and marine, that cause degradation. Land based activities include deforestation, non-point source pollution, and urbanization projects that change the landscape and result in increased run-off. Ocean based activities include fisheries, tourist activities, and marine transportation. Vertical integration includes collaborative decision making by all levels of government and other stakeholders who influence, affect, or manage marine resources (Brown et al., 2002). For managing tourism at the reef, vertical integration includes coral reef managers, scientists, policy makers, government officials, crew working onboard vessels, local community members, fishers, recreationists, and tourists.

Horizontal and vertical integration are essential since they require acquiring public compliance and support for new regulations to protect coral resources as well as addressing all stressors fairly. For instance, it is difficult to justify new land management practices that limit sedimentation or overfishing when tourism impacts go unattended. Policies that focus disproportionately on one stakeholder group will not be considered as legitimate as policies that deal fairly with all threats. Addressing all stressors in an even and coordinated manner communicates a sense of fairness to stakeholders. Decisions that are perceived to be fair are more widely accepted by community members and may result in increased compliance for rules and regulations. The ultimate goal is to find effective ways to minimize the loss of coral reef ecosystems by reducing their vulnerability and assisting in their recovery (Hughes et al., 2003).

5.3 Managing Tourism in Puerto Rico

Tourism in Puerto Rico accelerated in the 1950s and 1960s when investors were allowed to come to the island, invest in and purchase extensive coastal land to build hotel complexes along the north and east coasts of the island, which includes San Juan and Fajardo. Fajardo, a small city located in the east region of the island, is a popular destination for boating, diving, and snorkeling. The development of the El Conquistador Hotel in the 1960's launched the tourism industry in a city which now claims five large marinas, including Marina Puerto del Ray, the largest in the Caribbean. A majority of the registered vessels in Puerto Rico (greater than 65,000 vessels) are located in this area. While the industry continued to grow rapidly across the island, the effect of tourism and recreational misuse upon coral reef systems on the island of Puerto Rico was not well understood. This holds true, even today (Garcia-Sais et al., 2008). Tourism benefits are often measured as economic achievements rather than ecological ones. In fact, concerns about ecological degradation are often seen as impeding tourism benefits. Several reasons have been suggested for why the development of the tourism sector in Puerto Rico may be non-sustainable. This includes a top down approach to managing the industry which has led to marginalization of local communities, development near ecologically sensitive habitats, relaxed environmental regulations, conflicts of interest and corruption, and rapid construction without much planning and concern for the environment and its people (Hernandez-Delgado et al., 2012).

5.4 Management of Puerto Rico's Coral Reef Ecosystems

Tropical coastlines are high in biodiversity and contain some of the richest, most productive, and fragile ecosystems on Earth (Cenacchi, 2010). This high biodiversity, along with access to the resources along these coastlines has made coastal environments vulnerable to human pressures (Hernandez-Delgado et al., 2012). In Puerto Rico, about 70% of the island's population lives in municipalities that are within close proximity to these coastal marine environment (United States Census Bureau, 2012). These same areas are also developed for tourism and are the most visited by nonresidents.

The Department of Natural and Environmental Resources of Puerto Rico (DNER) is the agency with jurisdiction over coral reef resources up to nine nautical miles from the high tide line and includes all shallow reef ecosystems (National Oceanic and Atmospheric Administration [NOAA], 2009). Puerto Rico Law 147, established in 1999, provides protection, conservation, and management of the coral reefs around the island. The secretary of the Department of Natural and Environmental Resources is responsible for allocating funding, penalizing negative actions to the resource, and for providing alternative solutions to protect coral reefs for future generations. The law also emphasizes the need to educate the general public on the importance of coral reefs, their maintenance, and the ways citizens can participate in protecting these ecosystems (Puerto Rico House of Representatives Bill 1466, 1999). The Department of Natural and Environmental Resources receives its funding for coral reef management solely from the National Oceanic and Atmospheric Administration (NOAA, 2009*)*.

5.4.1 The United States Coral Reef Task Force

Beginning in the1980s, Caribbean coral reefs experienced a significant reduction in coral cover due to massive coral bleaching and coral disease (Aronson & Precht, 2006). These stressors were the catalyst for establishing a group of experts tasked with taking measures to make coral reef ecosystems sustainable (United States Coral Reef Task Force [USCRTF], 2016). In 1998, the USCRTF was established by Presidential Executive Order 13089 “to preserve and protect the biodiversity, health, heritage, social and economic value of U.S. coral reef ecosystems and the marine environment” (USCRTF, 2016). The main goal of the USCRTF is to preserve and protect coral reef ecosystems by helping build partnerships, strategies, and support for on-the-ground action to conserve coral reefs. The USCRTF consists of leaders from 12 federal agencies and seven U.S. states, territories, and commonwealths, and three freely associated states (USCRTF, 2016). Six major threats have been identified as areas to focus immediate local action. These include overfishing, land-based sources of pollution, recreational overuse and misuse, lack of public awareness, climate change and coral bleaching, and disease. Adaptive actions recommended by USCRTF includes the creation of coral reef management plans for each

United States territory as well as education, monitoring, research, restoration, enforcement, and mitigation (USCRTF, 2016).

5.4.2 Puerto Rico's Coral Reef Management Plan

While climate change, land-based sources of pollution, and unsustainable fishing are listed as major concerns, Puerto Rico's Coral Reef Management Priorities (2011-2015) document also lists recreational uses within marine and coastal areas associated with coral reefs as a major issue that requires local action and includes goals and objectives geared towards reducing the impacts necessary in order to protect the health of coral reefs and enhance coral reef resilience (NOAA, 2009; Ortiz Sotomayor, 2015).

Specifically, Goal C1:

> *Manage the recreational and maritime uses of maritime and coastal areas to reduce the impacts on coral reefs.*

Objectives to meet this goal include:

Objective C 1.1: Reduce the impact of vessel anchoring and boat grounding on seagrass beds and coral reefs and enable efficient enforcement.

Objective C1.2: Identify specific areas for recreational use. Should focus on already impacted reefs and artificial reef sites so as to preserve and limit activities on higher quality reef ecosystems.

Objective C1.3: Develop outreach programs for recreational operators to encourage compliance with coral reef regulations and to use best management practices for recreational use in their operations.

- *For the North East Reserves this includes developing outreach programs for recreational operators, as well as commercial and maritime operators, to encourage compliance with coral reef regulations and to use best management practices for recreational use in their operations.*

Experts serving on the task force identified and ranked priority sites in Puerto Rico for coral reef conservation based on biological value, high degree of risk and threat, absence of risk or threat, and viability. These stakeholders agreed that the top four sites should receive initial attention.

The North East Reserve (which includes La Cordillera Nature Reserve) was ranked second in importance for coral reef conservation in Puerto Rico.

To meet these objectives, the United States Coral Reef Task Force (USCRTF) called for Local Action Strategies (LAS) to be developed in each of its member territories. These place-based strategies are defined as locally driven, short-term roadmaps for collaborative and cooperative efforts among federal, state, territorial, and nongovernmental partners (USCRTF, 2016).

Local Action Strategies are designed to identify targeted goals and objectives and implement specific projects that reduce key threats to valuable coral reef ecosystems. Plans include strategies to influence humans to adopt and practice environmentally responsible behaviors (USCRTF, 2016). This is especially applicable to local action strategies addressing problems associated with recreational users including tour operator, diver, and snorkeler activities and behaviors around coral reefs. For example, Puerto Rico's Local Action Strategies have included educational pamphlets developed for local businesses and tourist information centers which provide recreational users with actions that should be taken to prevent the misuse and overuse of coral reefs. Other public service campaigns, include billboards and posters encouraging pro-environmental behavior around reefs. These media campaigns can be found at airports along the east coast of the United States and in the Caribbean. Both Florida and Puerto Rico have also utilized English and Spanish public service announcements in print, audio, and video formats.

5.5 Adaptive Capacity and Actions for Coral Reef Ecosystems

Adaptive capacity enables management actions that can reduce vulnerability (Smit & Wandel, 2006). Vulnerability is defined as the state of susceptibility of harm from exposure to stresses associated with environmental and social change (Adger, 2006). Vulnerability research consists of three main components - exposure, sensitivity and adaptive capacity (Adger, 2006; Gallopín, 2006). Gallopín (2006) defines exposure as the "degree, duration and/or extent in which the system is in contact with, or subject to, the perturbation." Sensitivity is, "the degree to which the system is modified or affected by an internal or external disturbance or set of disturbances." Adaptive capacity is "the system's ability to adjust to a disturbance, moderate potential damage, take advantage of the opportunities, and cope with the consequences of a transformation that occurs" (295 – 296). Adaptive actions can reduce exposure, change sensitivity, restore the system, and reduce harmful consequences. For instance, an adaptive management action that reduces exposure from vessel anchors includes the installation of mooring buoys at popular dive and snorkel reefs. Mooring buoys reduce exposure by reducing mechanical damage to corals caused by vessel anchors and regulate where dive and snorkel operators can bring visitors to the reef. However, buoys require the capacity to act on this management action. This includes government approval, funding to site, purchase, install, monitor, enforce use, and repair. Another example of an adaptive action that can reduce the exposure of coral reefs to snorkeler or diver contacts includes tour company crew deciding how to instruct divers and snorkelers about coral reef etiquette as well as prepare them for their experience at the reef.

5.6 Marine Protected Areas

Setting aside natural areas for protection is a necessary component of conserving biodiversity and managing the natural resources we rely on for ecosystem services (Daily et al., 1997). A marine protected area (MPA) is a "clearly defined geographic space, recognized, dedicated and managed, through legal or other effective means, to achieve the long-term conservation of nature with associated ecosystem services and cultural values" (IUCN, 2008). This management tool was created to enhance the resilience of linked social-ecological systems with the goal of protecting biodiversity while utilizing the ecosystem services sustainably (Horta e Costa, 2016). MPAs can regulate harvesting and extraction while managing the sustainable use of resources and the recovery of habitats (Aguilar-Perera, 2006).

The success of a marine protected area is dependent on two key factors - the environmental conditions in and around the protected area and the support of local communities (Camp & Frazer, 2012). Designating an area as protected is a complex process since it involves social and historical factors, existing conditions, possible restoration, plans for sustainable uses, future scenarios, and human values. MPAs are considered effective for tourism and recreation since these activities can be revenue generating and can be used for other management actions within the protected area (Weaver, 2008).

Protected areas include marine sanctuaries, estuarine research reserves, ocean parks, and marine wildlife refuges. Once established, these areas are managed by all levels of government. Marine protected areas are created for a variety of reasons including protection of certain types of habitats, preservation of cultural resources and archaeological sites, and/or the protection of fisheries production and wildlife species (NOAA, 2017).

For coral reef ecosystems, the benefits gained from creating marine protected areas are well known. Benefits include increases in number and types of fish species (especially in areas where fishing is not allowed), increases in coral cover, and improvements in the structural complexity of the reef (McClanahan & Shafir, 1990). Research has shown that reserves increase populations of herbivorous fish which helps keep algal cover on coral down (Hughes et al., 2007). This relationship has increased the resilience of coral populations as well as coral recruitment (Mumby et al., 2007). For these reasons, marine protected areas are excellent locations for divers, snorkelers, and tour operators who use these benefits as selling points.

A management plan is usually developed and implemented for a marine protected area (MPA). It is a site-specific document created to state the visions, goals, objectives, and priorities for the management of ecosystems and natural resources within the MPA. Marine protected areas are a popular strategy for managing human activities in and around coral reefs in the wider Caribbean. Once the MPA is designated, certain activities within the location may be allowed while others are limited or prohibited in order to protect natural, cultural, and historic resources (National Marine Sanctuaries, 2008). Within a marine protected area, multiple strategies for addressing natural and anthropogenic impacts to the reef can be implemented. The plan can establish rules and regulations that focus specifically on reducing reef exposure by managing dive and snorkel operations at the reefs. Reducing exposure to negative behaviors may decrease vulnerability.

5.6.1 Strengths

For coral reef ecosystems, the intended and added benefits gained from creating marine protected areas are well known. Benefits include protecting several different ecosystems and habitats within the protected area which allows for a more integrated conservation plan (Wilhelm et al., 2014). These protected ecosystems can have added benefits which include increases in the number and types of fish and invertebrate species (especially in areas where harvesting is not allowed), increases in coral cover, and improvements in the structural complexity of the reef (McClanahan & Shafir, 1990). This combination of factors can make marine protected areas excellent locations for divers, snorkelers, and tourist operators who use these benefits as a selling point. Another advantage is protected areas in the Caribbean have resulted in tourism becoming a primary livelihood (Dixon, 1993). Research has shown that protected areas that are managed properly earn a significant revenue for the local economies (Kenchington et al., 2003).

Once an area has been given the legal status of being protected, other strategies to reduce vulnerability to dive and snorkel recreation can be implemented within the MPA including managing the number of divers/snorkelers, designating the locations where these activities can occur, and restricting certain types of equipment.

5.6.2 Limitations

Marine protected areas alone are not effective if broader regulations and management strategies are not established for the area protected as well as for the areas outside of the marine protected area. This includes implementing "coral-friendly" fisheries policies that limit the harvesting of herbivorous fish species (Mumby et. al, 2008). Other management strategies needed include the mitigation of land-based sources of pollution and sedimentation that occur outside the reserve.

Marine protected areas require surveillance, monitoring, and enforcement of the regulations established. This capacity can be expensive. Marine protected areas have also been criticized as having the potential to only serve as "paper parks." The term paper park is defined as "a legally established protected area where experts believe current protection activities are insufficient to halt degradation" (Pomeroy et al., 2007). They look effective on paper but following through with the application has been ineffective. Marine protected areas must also take into account not only the biological goals but also the social, cultural, and economic needs of the communities in which they are established. In addition, marine protected areas can't be considered successful if they only result in biological successes since the system has many complex socio-ecological relationships (Pomeroy et al., 2007).

5.7 Zones Within Marine Protected Areas

Multiple-use marine protected areas can be divided into zones where certain activities are allowed or prohibited. Establishing set boundaries for activities that pose different types of threats with different impacts can be a beneficial resource management tool to reduce vulnerability and build resilience (Great Barrier Reef Marine Park Authority, 2017). Marine use zones can be used to address many issues including: protecting natural resources from overuse, protecting specific organisms, habitats, and more sensitive species of coral, managing recreational activities to reduce exposure, and separating conflicting user groups to name just a few. They can be designed across a range from general use to restrictive use. This includes no take zones, anchorage zones, habitat protection zones, diving or snorkeling zones, multi-use zones, all-purpose recreational zones (diving, snorkeling, swimming, fishing), wilderness zones, and special use zones. For example, based on the multitude of anthropogenic stresses that coral reef ecosystems are exposed to, scientists may suggest that a percentage of a marine protected area be established as a no-take zone. While fish and other species may not be harvested from this zone, activities like diving and snorkeling would be allowed. Such closures are not new. Traditional marine resource management practices often included closing areas to fishing. For example, Hawaiians have long used 'kapus' or fishery closures to maintain fish populations (Gulko et al., 2002).

5.7.1 Strengths

As mentioned, zoning areas within a marine protected area can increase the number and types of fish species, increase coral cover, and improve the structural complexity of the reef. Zones can also manage the social, cultural, and economic needs of the communities in which they are established. For example, zones can be established specifically for recreational activities that take place within a marine protected area. Zones can also prevent conflict between different user groups.

5.7.2 Limitations

Scientists and managers struggle with determining the size that different zones should be in order to make them effective. Establishing a zoned area depends on many factors and there is still an insufficient amount of information available to ensure a sustainable system. For example, marine fishery scientists state that protecting 20% of the total potential fishing area should be the minimum when establishing a "no-take" marine protected zone (Murray et al., 1999). Other limitations to marine zoning have been identified. For example, once zones are established, a classification system with appropriate information must be available and disseminated to all user groups so that they are aware of the boundaries for a zoned area (Horta e Costa, 2016; Laffoley et al., 2018). If there are no clear boundaries, confusion can occur because of the variety of zones and different levels of protection. In some cases, users are almost totally unaware of the boundaries or regulations for zones. Even if appropriate information is provided, users may not comply with the regulations set for established boundaries.

5.8 Regulations

Most coral reef protected areas have regulations that establish the rules and restrictions for human activities within the protected area and zones. The primary purpose of these regulations is to protect, preserve, and manage the marine protected area's ecological, recreational, educational, historical, and aesthetic resources. Regulations specific to recreational programs address where activities can take place, how often these activities can take place, who can participate, what modes of transportation can be utilized, and what behaviors are allowed.

Several of the management strategies identified and described in this paper (carrying capacity, zoning, mooring use, user fees) are most likely implemented through regulations as well.

Regulations specific to divers and snorkelers include not being allowed to remove, take, harvest, damage, disturb, touch, break, cut, or otherwise injure, or possess any living or dead coral, or coral formations. Regulations can also apply to equipment use or diver skill level. For example, in some locations, divers are not allowed to wear gloves or feed fish. Also, in order to dive in a specific location within the protected area, divers may be required to have a higher level of certification and skill. Such regulations can reduce exposure to harmful behaviors that make coral reefs more vulnerable.

Regulations also include permits and licenses distributed by a government agency in order to allow tour operators to bring individuals into protected areas. Permits may not be given out until environmental impact assessments are completed. Each permit contains specific conditions designed to ensure that the tourist program is consistent with the management plan and that the operation is environmentally sustainable.

5.8.1 Strengths

Regulations provide a guideline for how user groups within the marine protected area can behave. When effectively applied, regulations can protect and preserve the natural resources within a marine ecosystem. Regulations can also minimize conflicts that can occur between resource users.

5.8.2 Limitations

Regulations must reach targeted user groups in a format in which the required laws are clear and easy to understand. If users do not support the rules, it can be more difficult to gain compliance. Often, regulations require an enforcement plan in order to achieve compliance. Thus, if regulations are not carried out, they have no purpose.

5.9 Marine Protected Area Case Study - La Cordillera Nature Reserve, Puerto Rico

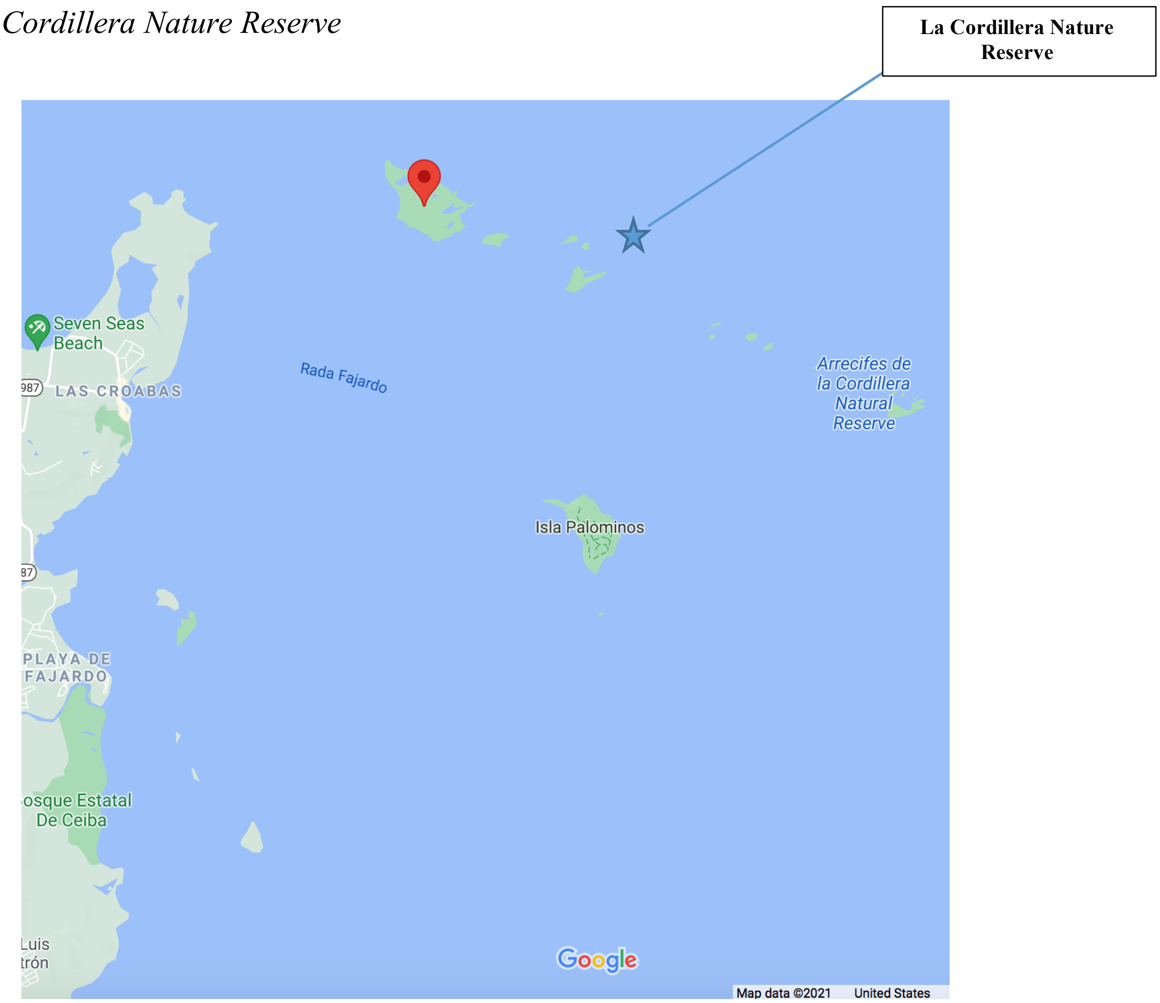
The Free-Associated State of Puerto Rico contains one of the largest contiguous coral reefs and mangrove ecosystems in the United States Caribbean (García-Sais et al., 2005). Establishing a marine protected area around coral reefs in Puerto Rico is complicated because it involves both the government of Puerto Rico and also the federal government; laws established at the territorial and federal level need to be considered.

La Cordillera Nature Reserve, located on the northeast side of Puerto Rico, east of the city of Fajardo and identified in Figure 5.1, was classified as a marine protected area in 1980. It is one of 32 marine protected areas in Puerto Rico, designated as a natural reserve for the conservation, preservation, and restoration of the physical, ecological, geographic, social, and environmental value of the natural resources found in this geographic area (NOAA, 2009).

The 101.37 km^2 area consists of a chain of ten small islands and includes coral reefs, mangroves, sea grass and algal beds, wetlands, fish spawning areas, commercial and recreational finfish habitat, and habitat for invertebrates such as lobsters, conch, and vertebrates including sea turtles, marine mammals, and birds. It has both ecological and economic importance which includes habitats for endangered species, nesting grounds for sea turtles, ecological connectivity to the main island and the island of Culebra, cultural importance, and recreational and tourist activity (Ramos, 2014). It is managed by the DNER through the division of reserves and refuges and has one full-time manager and several enforcement rangers. La Cordillera Nature Reserve is classified as a uniform, multiple use area receiving year round protection. Fishing is prohibited in zones designated as swimming areas. Primary local stressors to the reserve include recreational boat users, vessel groundings, irresponsible anchoring, land based pollution from sewage and agriculture, overfishing, and tourism activities (Ramos, 2014).

Figure 5.1

Map of La Cordillera Nature Reserve



Note. Maps Data: Google ©2021

5.9.1 La Cordillera Nature Reserve Management Plan

A formal management plan has not been developed for La Cordillera Nature Reserve although management plans, local action strategies, and a management board have been established. Outlined in the draft plan, includes 3% of the Reserve designated as a no-take marine reserve, applicable to both commercial and recreational fishing. This includes the reefs around Cayo Diablo and Cayo Lobos which are visited by dive and snorkel operators. Navigational buoys that identify vessel use zones are also recommended. While researchers in Puerto Rico agree that establishing marine protected areas with specific zones is a first step towards conservation, reserves bring only a minor degree of protection to coral reefs without effective management plans, established zones, regulations, education and outreach, enforcement of laws regulating fishing and recreation activities within these zones and stakeholder compliance. (Garcia-Sais et al., 2008).

Regulations in Puerto Rico are established by both the DNER as well as the United States federal government. Often times local community members are not aware of these regulations or which level of government is responsible. A recommendation for Puerto Rico's coral reef management plan includes aligning the state and federal agencies' laws and regulations for consistency, effectiveness, and less confusion for stakeholders.

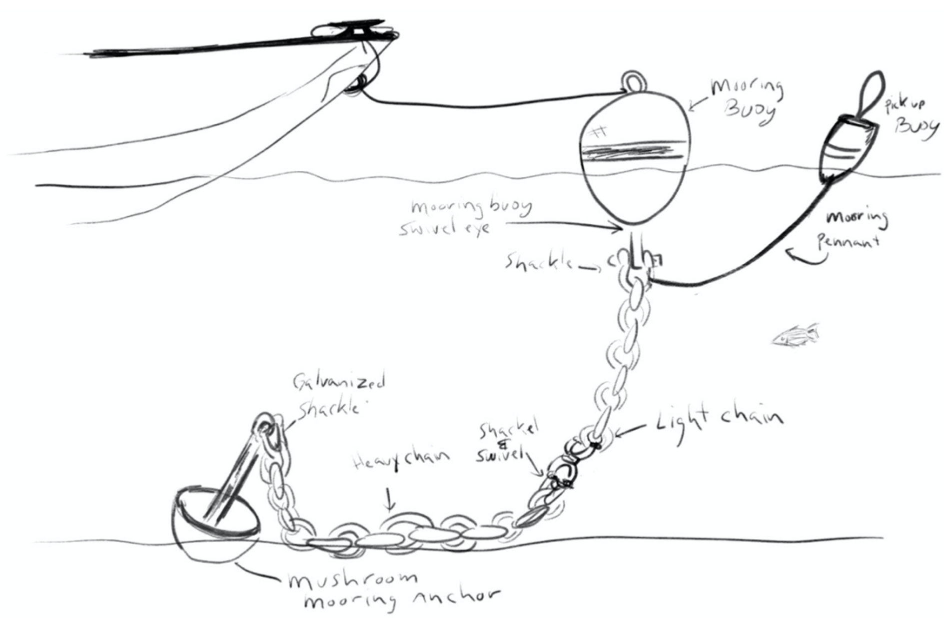
Concession licenses and permits are currently required by tour operators working within La Cordillera Nature Reserve. Hernandez-Delgado et al. (2012) found that the concessionaires, comprised of dive and snorkel operators, catamaran and other large vessel operators, and fishing and other mixed-trip charters, have a high dependency on the Reserve's coastal and marine resources for their livelihoods and are aware that the reef ecosystem and its resources are declining. Over 70% of the concessionaires interviewed by Hernandez-Delgado et al. (2012) were in favor of a no-take MPA within the reserve. They favored no commercial and recreational fishing but felt non-consumptive uses (diving, snorkeling, and cruising) should be allowed.

Specific areas they felt should be no-take marine protected areas included the heavily visited locations, Icacos Island and Cayo Lobos and less popular Cayo Diablo and Cayo Isla Palominos.

5.10 Moorings

A mooring buoy is a small round float attached to a pickup line with a floating buoy to which vessels can tie up instead of dropping an anchor (BoatersLand, 2017). This pick-up line is attached to a through-line that connects to a down-line or chain which is attached to a heavy weight that sits on the ocean floor (Figure 5.2). The weight acts like an anchor, holding the buoy afloat on the water's surface. Depending on the type of mooring, one or more vessels can tie off to the mooring without having to use their own anchor system (BoatersLand, 2017).

Figure 5.2
Sketch of a mooring buoy



Note. Werner Schreiner, 2019. Reprinted with Permission

5.10.1 Strengths

Mooring buoys are often placed in areas with sensitive marine environments, such as coral reefs and sea grasses. At dive and snorkel sites, they are placed on the sandy bottom, far enough away from the coral reef. The intended benefit of using mooring buoys is to reduce mechanical damage to coral reef ecosystems by reducing their exposure to anchors. This includes preventing anchor chains from breaking corals or gouging out large pieces of tissues and skeleton.

If divers and snorkelers are overusing the reef, mooring buoys can be relocated to give the reef time to recover. This can allow different parts of the reef to recover. Moorings can also be used to zone areas for particular activities. Zoning can help prevent conflicts between user groups, for example, between tour operators and recreational boaters. Finally, fees can be charged for using a mooring. Revenue generated is an added benefit and can be used to support the placement of additional moorings, and other management strategies such as enforcement, education, or monitoring.

5.10.2 Limitations

Economic costs associated with moorings include the cost of siting, installing, monitoring, and maintaining the moorings as well as enforcement of their use. Coral reef managers must also recognize that there is the possibility that damage to the benthic environment can occur during the installation or removal of a mooring buoy. While mooring buoys are fixed in the marine environment, they have to be maintained. Even then, they usually only last for several seasons because of the effects of salt water (BoatersLand, 2017).

There must also be enough mooring buoys at each site to accommodate the number of tour vessels who regularly use the site. If a mooring buoy is not available, some vessel operators may drop anchor wherever they decide (Barker 2003). However, more moorings can increase exposure since they do not control for carrying capacity. In areas where mooring buoys have been placed, researchers found more damage than locations without, due to the steady flow of visitors on a regular basis (Harriott, 2002). Additionally, a vessel can use the mooring briefly to drop off a group of divers or snorkelers at the mooring site and come back for them at a specified time. Nonetheless, despite these limitations, coral reef scientists observed that anchor damage still far outweighs the damage done by divers (Harriott, 2002). Finally, boaters and tour operators may not always be aware of new installations or removal of moorings. Outreach materials to inform all stakeholders are needed.

5.10.3 Moorings within La Cordillera Nature Reserve

To protect fragile ecosystems like coral reefs and seagrass beds from anchor damage, the DNER developed a Marine Buoy Program in 1990. DNER's Marine Resources Division is responsible for siting, installing, and maintaining approximately 270 mooring buoys off the coast of Puerto Rico (Zabinski et al., 2009).

In 2009, Zabinski et al., (2009) completed an assessment of the DNER mooring buoy program in Puerto Rico by documenting the locations of moorings, analyzing their condition, and making recommendations for additional moorings. Within La Cordillera Nature Reserve, the researchers documented only one mooring buoy located off the island of Icacos, one of the most popular locations for vessels to recreate and individuals to snorkel. The other two DNER buoys were missing. Non-DNER mooring buoys were present in the area, probably placed by tour operators that want to keep the surrounding ecosystems intact while still being able to moor on a regular basis.

As previously mentioned, objective C1.1 of the LAS plan for Puerto Rico is to reduce the impact of vessel anchoring and boat grounding on seagrass beds and coral reefs and enable efficient enforcement. Coral reef management plans specific to dive and tour operations include establishing vessel use zones, installing navigation and mooring buoys that note the different use zones, establishing no-anchor zones, and developing outreach programs for recreational, commercial, and maritime operators to encourage compliance and to use best management practices (Ortiz Sotomayor, 2015).

Mooring buoys within the reserve can successfully help reefs be less vulnerable by reducing the exposure of reefs to anchor damage, especially around Icacos Island, where boating, commercial, and private recreational use are popular as there is access to the sandy beach. There are at minimum eight large catamarans that leave from Fajardo daily during the high season, bringing hundreds of snorkelers to reefs like Icacos, Lobos, and Tortugas and two scuba diving operators that run several boats to reefs at Diablos and reefs off of Palominos Island. Fajardo claims five large marinas with greater than 65,000 vessels registered in this region. On weekends and holidays, there can be hundreds of recreation vessels anchored and rafted together at Icacos Island.

When mooring buoys were first installed in Puerto Rico, anchor damage had initially been reduced. However, the buoys are not continually monitored; therefore, their condition and how they are utilized is not known. (Garcia-Sais et al., 2008). My research findings support this knowledge. Key informants interviewed responded that they were dissatisfied with the DNER for not providing enough mooring buoys within the reserve and for not maintaining the buoys presently installed. In addition, key informants responded that crowding was another major factor. The availability of a mooring buoy on a crowded day at snorkeling locations was a point of contention. As of 2016, key informants interviewed stated there were only four mooring buoys at Tortugas Reef (off Icacos Island) even though there are at least eight licensed catamarans that have DNER permits to go to the Reserve. The mooring buoys have the word "diving" written on them. However, if a small private vessel has a mask on board, they are allowed to use the mooring without penalty. Tour operator captains are then forced to anchor their large vessels in the sand or turtle grass (*Thalassia testudinum).* I observed snorkel captains and crew trying to find an alternative spot around the reef to anchor on numerous occasions. Captains interviewed stated they preferred not to anchor in the sand. *L*arge catamarans anchored in the sand can shift, move, and can even be dragged by currents which then becomes a safety issue for snorkelers who are regularly using ladders to get on and off the vessel. Ecologically, anchoring in the sand can damage sea grass beds especially if using anchors from the stern of the boat, in shallow waters. When the vessel is turned on, propeller wash can damage vegetation (Otero & Carubba, 2007).

One key informant from a dive operation stated they no longer go to the reef around Palominito Island called, Trench, because the mooring buoy is no longer there and they do not want to use an anchor in the sand or turtle grass (*Thalassia testudinum).* Key informants felt that moorings at the reef sites are not maintained. Informants stated they have worked with crew from other operations to buy and install equipment and repair damaged moorings at dive locations within the Reserve, technically the responsibility of DNER.

As discussed, commercial moorings are often utilized by private recreational vessels visiting the Reserve. Key informants felt that in addition to needing more moorings at the reef, moorings should demarcate commercial use only. There should also be increased enforcement by DNER rangers regarding commercial use only.

5.11 Carrying capacity

Research in many parts of the world has identified a correlation between the number of visitors a reef ecosystem can support and the degradation of corals, supporting the claim that scuba diving and snorkeling can be a serious threat to coral reefs (Allison, 1996; Hawkins & Roberts, 1992; Kay & Liddle, 1989; Krieger & Chadwick, 2013; Liddle, 1991; Liddle & Kay, 1987; Plathong et al., 2000; Prior et al., 1995; Riegl & Velimirov, 1991; Tratalos & Austin, 2001). Up to a certain level of activity, snorkeler and diver-induced impacts appear to be minor, but beyond some "critical level" those impacts quickly become significant (Burgett, 1990; Davis & Tisdell, 1995). The carrying capacity of an ecosystem refers to the maximum level of recreational use (in terms of numbers of people and activities that can be accommodated by an area) before an unacceptable or irreversible decline in ecological values occurs (Inskeep, 1991; Jameson et al., 1999; Pigram & Jenkins, 1999).

Limiting the number of people that can visit a reef is a proposed management strategy. Such measures can reduce crowding and environmental degradation. Carrying capacity can be estimated by comparing the relationship between the number of divers or snorkelers to the amount of coral reef degradation to determine the appropriate number of users that a reef can handle without causing "unacceptable impacts" to this ecosystem (Barker, 2003; Medio et al.,1997; Uyarra & Cote, 2009). A process to determine the limits of acceptable change (LAC) was developed by Stankey et al. (1985). The process initially determines what the desired conditions at a recreation setting should be. This includes natural, social, and managerial conditions that need to be maintained or restored. Next, the levels of change that are acceptable in different recreational settings are determined. The carrying capacity of a coral reef ecosystem will depend strongly on the behavior of people participating in snorkeling activities. For example, Hol Chan Marine Reserve in Brazil receives approximately 50,000 visitors per year. Researchers conducted a study to determine the factors leading to unacceptable tourism impacts within the Reserve. Methods included following groups and recording behavior and impacts as well as asking visitors to complete a questionnaire to find out what information they are learning from guides and how they report their group's behavior. The study revealed that limiting numbers would be difficult and not the most effective solution. It also revealed that behavior modification and education were the most important factors in decreasing the impacts of tourism (Green Reef Environmental Institute et al., 2002).

Table 5.1 lists the current estimates for divers at coral reef locations studied and is on average between 4000-7000 divers per site/per year (Dixon et al., 1993; Harriott et al., 1997; Hawkins & Roberts, 1997; Mundet & Ribera, 2001; Musa, 2002; Prior et al., 1995; Riegl &Velimirov, 1991; Zakai & Chadwick-Funnan, 2002). Barker (2003) found that the most popular sites in St. Lucia and elsewhere received upwards of 10,000 divers or more (well above the recommended carrying capacity threshold at other locations). There is little research on carrying capacities for snorkelers at coral reefs. Researchers recommended Hawaii's Hanauma Bay's carrying capacity be set at 1,000 snorkelers per day.

Table 5.1
Suggested carrying capacities for dive and snorkel activities

Dive Location	Carrying Capacity	Study
Bonaire National Park	4000 – 6000 divers per site/year	Dixon et al., 1993
Hanauma Bay, Hawaii	1,000 snorkelers a day*	Burgett, 1990
Medes Island	450 divers/per year	Mundet & Ribera, 2001
Red Sea Ras Mohammed		
National Park	5000 – 6000 divers per site/year	Hawkins & Roberts, 1997
Sipadan, Malaysia	100 divers per day	Musa, 2002
US Virgin Islands	500 divers per site/per year	Zakai & Chadwick-Furman, 2002

Note. * Indicates snorkelers

5.11.1 Strengths

Specifically, establishing a carrying capacity for a coral reef ecosystem can play an important role in regulating the number and types of behaviors that the reef is exposed to by divers and snorkelers (Garcia-Sais et al., 2008). In areas where tourism and development are being planned, diver and snorkeler carrying capacities can be used to effectively design the size and configuration of the zoned area where tourism will be allowed (Jameson et al., 1999). Effective diver and snorkeler outreach and education programs combined with other management strategies, for example mooring buoy compliance, may allow coral reef managers to increase carrying capacities.

5.11.2 Limitations

Defining a carrying capacity for a specific coral reef ecosystem is a controversial concept, since diver and snorkeler volume directly impacts local and regional tourist economies (Jameson et al., 1999). It is also a difficult challenge to identify critical levels and attempt to limit divers and snorkelers to a number below that threshold. A procedure to determine critical levels is needed, otherwise the term is subjective and implies a value judgment. However, it is a complicated management strategy since it is difficult to estimate how many tourists a reef can support. The concept is more than just the number of people at the reef but also includes the type of activities at the reef, how the reef is managed, knowledge and behaviors of visitors, tour operator decisions, the location of the reef, its morphology, topography, and depth, water conditions, and other environmental stressors (Barker & Roberts, 2004; Clark, 1991; Harriott et al., 1997; Salm, 1986; Schleyer & Tomalin, 2000; Zakai & Chadwick-Furna, 2002). Furthermore, some researchers have suggested that it is problematic to determine the actual carrying capacity for a specific reef due to the need to manage these resources over long time periods while the rate of growth of recreational demand is extremely rapid (Prior et al., 1995).

For marine environments that have established carrying capacities, enforcing such laws is not always easy. Mechanisms to enforce carrying capacities include the addition of more conservation officers as well as relying on tour operators to play an active role in monitoring compliance. Penalties for non-compliance could range from a fine for each violation to the loss of operating licenses for tour operators who are consistently not following the regulation.

5.11. 3 Carrying Capacities Within La Cordillera Nature Reserve

There is not a dive or snorkel carrying capacity established for each reef within La Cordillera Nature Reserve, Puerto Rico. Local Action strategy B1.3 objective 6:

> *Determine a carrying capacity/limits of acceptable change for heavily used areas like Cayo Icacos, a popular commercial operator snorkeling site and recreational site for private boat owners* (Ortiz-Sotomayor, 2015).

Scientists and managers are not certain what the limit should be to prevent the cumulative impacts from recreational fishing, boating, anchoring, snorkeling, diving, and swimming around the reefs (Garcia-Sais et al., 2008). Based on findings and recommendations, scientists and managers in Puerto Rico believe that guidelines for recreational use of coral reefs within reserves should be widely developed, disseminated, and adhered to. A work plan outlining a charge to complete an inventory that assesses the number of vessels, people on the beach, divers, snorkelers, swimmers, and all other users and circumstances has been tasked for La Cordillera Nature Reserve, specifically the heavily used areas like Cayo Icacos.

The highest average number of snorkelers I observed in the water at Icacos Reef, during a 5-minute time interval was 21 individuals. At Tortugas reef, the highest average number of individuals during a 5-minute time interval was 35 snorkelers. The number of snorkelers after these peaks, steadily declined. Several crew members stated that regardless of how many snorkelers are at the reef, most spend approximately 15 - 20 minutes snorkeling at the reefs around Icacos Island and slightly more time at Tortugas Reef. This is consistent with my findings. If snorkelers were brought to the reef every day, this averages to about 10,000 snorkelers around the reefs each year. I also observed snorkelers swimming, relaxing on the catamaran, and sitting on the beach. While there may be a high volume of people at the Reserve, snorkeling is not the only activity. With regard to divers, the average number of divers at the reefs within La Cordillera Nature Reserve was 9. This averages to slightly more than 3,200 divers per year which is below all the other recommended carrying capacities in other coral reef locations globally (Table 5.1).

Scientists and managers working in Puerto Rico also think there is a need to establish a maximum number of boats allowed at each reef or within the entire reserve. On one snorkeling weekend excursion I participated in, I counted 175 small vessels at the reef at Icacos Island.

Captains said that large numbers of private vessels are common at Icacos Island on weekends during the months of June, July, and August as well as on holidays year round. Similar concerns about "weekenders" visiting La Cordillera Nature Reserve have been reported. A study on user perceptions of the management and conflicts over resources within the Reserve found stakeholders interviewed felt most of the pressures that affect natural resources come from "weekenders" and not necessarily from fishers or tourist concessionaires and that their impact was profound (Ramos, 2014).

Other Local Action Strategies to reduce carrying capacity include establishing no-anchor zones (C1.1) and identifying specific areas (C1.2) for recreational use, potentially already impacted reefs and artificial reef sites, so as to preserve and limit activities on higher quality reef ecosystems (Ortiz-Sotomayor, 2015). This would protect more sensitive reef species to exposure and reduce vulnerability by keeping large numbers of recreationists, especially beginner snorkelers and divers, in one sacrificial location.

5.12 Enforcement

Enforcement is a coral reef management strategy that reduces coral reef vulnerability by reinforcing compliance of established regulations. Enforcement may prevent the occurrence of future violations which can alleviate stress on the system. Enforcement programs assist and protect recreational visitors by providing rules and safety information for all stakeholders in the industry.

The USCRTF states that a successful enforcement program in a marine protected area requires a comprehensive set of regulations and an enforcement program for implementation of these regulations. In addition, other necessary requirements include a coordinated interagency effort, community involvement, and sufficient resources to ensure proper supervision and implementation. Enforcement includes patrol presence, inspections, patrol education, licenses, quick response to violations and emergencies, and citizen involvement to help with reporting violations and supporting compliance.

5.12.1 Strengths

The presence of enforcement officers can increase awareness of rules and regulations. In addition, there seems to be a relationship between the number of enforcement officers monitoring a protected area and the number of recreationists as well as other stakeholders who comply with regulations. Compliance with regulations can result in coral reefs that are less exposed to stressors and thus less vulnerable.

5.12.2 Limitations

Often, limited resources at the federal, territorial, state, and local level can make effective coordination and enforcement difficult. In order to reduce the number of illegal activities, a certain number of full- time staff need to be present at all times. This requires a financial commitment.

5.12.3 Enforcement Within La Cordillera Nature Reserve

The DNER has a Maritime Ranger Unit of approximately 200 rangers that enforce ecosystem regulations, navigation, and fisheries regulations throughout the entire island. Eight of the rangers are part of a Coral Reef Ranger Task Force and are responsible for enforcing regulations for all coral reefs on the island as well as monitoring and observing other issues such as ship groundings and special projects such as coral reef restoration work (Page et al., 2013). Scientists and managers responsible for developing the priority management strategies in Puerto Rico have expressed concern over the lack of financial commitment dedicated to enforcement capabilities within the reserves. Enforcement is difficult and at times scarce (Valdés-Pizzini et al., 2012).

A capacity assessment completed by a consulting firm in 2013 found that reform of the DNER Ranger Corps program was needed. Without effective enforcement, stakeholders within the reserves are less likely to comply with rule and regulations (Page et al., 2013). Key informants I interviewed felt their relationships with DNER rangers were weak. Lack of support, especially during the peak tourism season when there is a great deal of recreational activity at the reefs, was a main complaint. Another key informant explained that he felt the tour operator vessels are targeted while recreational vessels not complying with regulations are overlooked. Goal 5 (A3) of Puerto Rico's local action strategies aims to strengthen enforcement with a work plan that includes providing all law enforcement officials with opportunities to increase their knowledge and effectiveness at implementing management regulations. And while some key informants suggested more education for DNER rangers, judges and lawyers also need to be informed of these regulations since they are handling these non-compliance cases. Ramos' (2014) research suggests that the rangers do receive trainings and do know the rules but that they are selective when it comes to enforcement. Ramos (2014) also found that many stakeholders felt they were the target of DNER ranger enforcement. For example, both fishers and small boat owners interviewed, perceived they were the main target and tour vessel operators were not (Ramos, 2014). These perceptions were different from the views of the key informants I interviewed.

5.13 Reef assessment monitoring programs

Monitoring coral reef ecosystems provides early detection of change. These changes can help scientists better understand the threats to coral and potential responses for effective management. Monitoring of biological, physical, and chemical features associated with reefs and human behaviors around reefs can provide essential information for reducing vulnerability. Monitoring programs can trigger responsive actions when signs of change beyond normally anticipated levels are observed.

In general, coral reef ecosystems can be monitored to determine their geographic extent, the condition they are in, human induced and naturally caused changes, and the effectiveness of current management strategies. The monitoring of reefs can also play an important role in evaluating the effectiveness of specific objectives in coral reef management actions. Examples of monitoring programs include taking a census of the size, number, and types of reef fish, monitoring the use of mooring buoys, monitoring the number and types of behaviors exhibited by divers and snorkelers around coral reefs, monitoring the number of vessels at the reef and their activities, and monitoring the health of the coral reef ecosystem. The USCRTF suggests that considerable thought should be given to management objectives and desired information when designing and implementing a monitoring program.

5.13.1 Strengths

When utilized effectively, monitoring programs can provide early information on changes in and around coral reef ecosystems. This knowledge can guide the management plan to reduce vulnerability.

5.13.2 Limitations

Steady and consistent monitoring is necessary for effective management. This level of commitment requires staff, facilities, and funding. It also requires efficient decision making and the capacity to implement changes in the management plan when results suggest that the current management plan needs to be adapted.

5.13.3 Reef assessment monitoring programs in La Cordillera Nature Reserve

Most of the research and monitoring on reefs that has taken place in Puerto Rico over the last several decades has focused on community characterization, monitoring programs, coral diseases, and environmental impact assessments (Garcia et al., 2008). The Department of Natural and Environmental Research in Puerto Rico developed six Coral Reef Monitoring Programs in natural reserves, which includes La Cordillera Nature Reserve. Monitoring of environmental indicators includes coral reef coverage, fisheries abundance/diversity, water quality, and socioeconomic indicators such as public use of Reserve areas. Researchers from University of Puerto Rico campuses, DNER, and the Caribbean Coral Reef Institute (CCRI) work with NOAA to monitor these reefs. Within the northeast reserve, Local Action Strategies include monitoring water quality and setting standards for coral reef and marine habitat protection within the Reserve.

The number of visitors brought to La Cordillera Nature Reserve is also monitored. Tour companies operating within the Reserve stated they must provide monthly reports to the DNER on the number of individuals and reefs visited on a daily basis.

5.14 User Fees

Without appropriate funding, it is difficult for coral reef managers to implement strategies that work towards reducing the vulnerability of coral reefs to dive and snorkel tourism. Implementing user fees in marine protected areas can be an income generator. Terk and Knowlton (2010) describe user fees as “one method for funding protected areas, through the recovery of use values” (p. 78). The concept of charging user fees for outdoor recreation has proven to be a successful management strategy. The United States National Park system implemented a national user fee program at all parks in the early 1950s to help the parks sustain facility improvements, natural and cultural resource preservation, and interpretation of park resources. Fees also allow visitors to contribute to the stewardship of the natural resources that they value and respect.

There are several types of fees that can be utilized at marine protected areas and include entrance fees, concession fees, general user fees, conservation fees, activity fees, sales revenue, licenses and permits. Each type of fee can have a different effect on the management of marine resources (Terk & Knowlton, 2010).

For snorkel and dive tourism, user fees can be justified as revenue that supports the management and enforcement within protected areas and keeps reefs in the condition that tourists and recreationists prefer. In addition, coral reef management staff recognize that fees generated from snorkeling and scuba diving are self-financing (Arin &Kramer, 2002). For example, Peters and Hawkins (2009) conducted research on marine park fees and found there was a great deal of public approval to pay entry fees to marine parks. While this study focused on a general fee, Terk & Knowltonn (2010) posit that these results are most likely applicable to activity fees. They believe there is no reason to doubt that snorkelers and divers would be substantially less supportive of paying an activity fee than a general fee that supports the conservation and protection of the coral reef ecosystems they seek. Barker (2003) found that the value of St. Lucia’s reefs, located in marine protected areas, was validated by the fact that visitors were willing to pay to visit them and by the fact that close to half of the visitors surveyed said the presence of a marine protected area was a key factor in their decision to visit the island.

5.14.1 Strengths

A significant benefit from user fees is that they are a predictable income and a portion of this revenue can be used to support management, education, monitoring, conservation, and enforcement (Green & Donnelly, 2003). For example, user fees can support the siting and installations of new mooring buoys or establish a dive and snorkel monitoring program. These funds can also be used for tourist education and "best practices" workshops for commercial operations. Researchers have found that recreation users who have to pay a fee tend to have a greater level of respect for the marine reserve and staff (Green & Donnelly, 2003). Finally, revenue could also be utilized to compensate residents who are negatively impacted by regulations established for marine protected areas.

5.14.2 Limitations

One major impediment to the utilization of user fees is the reluctance by marine protected area managers and tourist operators to implement user fee systems. A concern is that user fees may negatively affect tourism if the fees are not acceptable to users (Hawkins 1998; Wielgus et al., 2010). While managers and operators recognize the benefit generated by user fees, the potential loss of customer income can outweigh the long-term benefits of additional fees. One way to address this would be to allow free access to areas where conservation and restoration projects are not occurring. Divers, snorkelers, and their tour operators would have a choice to visit a restored reef for an additional fee or an open-access sacrificial reef for no charge. There is a concern that staff time spent on collecting fees could take away from the time spent on monitoring and enforcement.

5.14.3 Conservation Fees in La Cordillera Nature Reserve

Concession licenses and permits are required by tour operators working within La Cordillera Nature Reserve. Key informants interviewed from diver and snorkeler operations stated that they were required to collect a small conservation fee (key informants stated the fee was between $2.00 and $3.00) from each person that boarded their vessels to visit La Cordillera Nature

Reserve in Puerto Rico. They were unsure how DNER utilized the conservation fees that were collected. However, tour companies stated that not everyone is compliant. For example, small vessel captains organize trips to the reef without the required permits and conservation fees. Such activities can be considered unfair to tour operators in compliance and counterproductive to conservation objectives (Ramos, 2014).

5.15 Education, Outreach, Stewardship

In order to gain support for coral reef conservation, the general public (which includes recreationists and tourists both residents and non-residents) need to have a basic knowledge about coral reefs, understand how human actions can harm or help corals, be aware of the rules and regulations established for coral reef conservation, support these efforts and comply. Only a clear understanding of this information will help alleviate some of the anthropogenic impacts affecting coral reef ecosystems. According to the United States Coral Reef Task Force (USCRTF, 2000), "an informed community creates better stewards for our coral reef protected areas" (p.30). Often tourists visiting coral reef ecosystems are unaware of the stressors coral reefs are exposed to and more importantly may not understand how their own actions can impact coral species and the organisms that depend on these ecosystems or why this matters. These individuals may also not be aware of the policies and management strategies in place to protect the ecosystems they enjoy or how they can contribute to the conservation of coral reef ecosystems. This is especially true for tourists visiting coral reef destinations which are a distance from home and removed from their everyday routines. Even skilled snorkelers and divers may not be familiar with the specific issues associated with a geographic region.

Most measures to protect coral reefs involve changing the behavior of humans (USCRTF, 2000). As mentioned previously, researchers conducting a study in Hol Chan Marine Reserve in

Brazil revealed that behavior modification and education were the most important factors in decreasing the impacts of tourism (Green Reef Environmental Institute et al., 2002). For all these reasons the USCRTF mandates that every management plan has a sound education and outreach component and a methodology to reach the local community, resident and non-resident recreationists, tourists, students, fishers, boaters, decision makers, and all other stakeholders utilizing the reef.

5.16 Knowledge Sharing

Knowledge about the environment is defined as being either environmental or behavioral. The former is considered abstract knowledge. A person with environmental knowledge has general knowledge about the state of the environment and environmental issues like coral bleaching, waste issues, and marine pollution. Behavioral knowledge is defined as concrete knowledge required for action. For example, a person who knows how, where, and what to do when snorkeling or diving around coral reefs has behavioral knowledge (Schahn & Holzer, 1990).

In order to reduce the vulnerability of a coral reef ecosystem, it is recommended that education and outreach include a variety of programs that provide both environmental and behavioral knowledge. It should be provided to tourists as well as residents of Puerto Rico. Examples of education and outreach programs include recreational user-oriented programs, local community programs that focus on overall reef values and economic benefits of healthy reefs, school programs that raise interest and awareness for local children, and active involvement programs that train the public to understand regulations and comply. For tourists, interpretive programs can include briefings, signage, videos, and in water trainings at the reef that provide specific information about the marine environment they are visiting and encourage responsible behavior.

The staff working for tour operators shape the exposure of the reef to visitor contacts. They orient visitors to the reef, provide snorkel, dive, or refresher lessons, certify divers, give instructions for how to experience the reef, encourage or discourage types of behavior, and provide oversight and correction. Studies examining the effects of pre-dive briefings to prepare divers and promote environmentally responsible behavior have had mixed results. Medio et al. (1997), Camp and Fraser (2012), Hammerton & Bucher (2015), and Roche et al. (2016) found that in-depth pre-dive briefings reduced diver contact rates. Barker (2003) found a pre-dive briefing, that included a one sentence conservation message, had no effect on contact rates. However, Camp and Fraser (2012), Barker (2003) and Medio et al. (1997) all acknowledge the role that operators can play in promoting responsible behaviors by divers around the reefs.

Education and outreach activities can have distinctly different messages, concepts, and strategies, and be widely applied for different audiences and circumstances. Webler and Jakubowski (2016) reviewed USCRTF Local Action Strategies for Puerto Rico and found several examples of messages that discourage behaviors. Negative messages such as “do not touch the coral” and “do not take anything from the reef” are inconsistent with social science theories of behavior and behavior change. Showing images associated with improper behavior (e.g. garbage on the reef, motor boats scarring the reef) also contradict descriptive social norms. Webler and Jakubowski (2016) designed and developed new coral reef etiquette video messages for snorkelers and divers to view before boarding a vessel. Messages were based on the Value-Beliefs-Norms (VBN) Theory of Environmental Behavior. Divers and snorkelers were also asked to sign a pledge to practice environmentally responsible behaviors at the reef.

Commitment techniques have been shown to be effective in promoting a diverse variety of behaviors (McKenzie-Mohr & Smith, 1999). In fact, written commitments have been found to be more effective then verbal commitments (Pardini & Katzev, 1983). Post video and pledge treatment in-water observations found an 87% reduction in the coral contact rate (Webler & Jakubowski, 2016). The research suggests the pre-trip messaging together with a written pledge can change behaviors, thus improving the ability of ecotourism operators to help sustain reefs.

Giglio et al. (2018) also assessed an education video briefing within the Arraial do Cabo Marine Extractive Reserve in Brazil. The video briefing provided information on low-impact diving techniques and environmental information about coral reefs. Divers who watched the video had significantly lower contact rates with the reef compared to divers who did not watch. These findings suggest that video messages can be an effective form of outreach.

Education also includes dive and snorkeler interventions. Interventions are defined as an action taken by a dive or snorkel guide to correct a behavior that may be harmful to the reef or marine life. This intervention could then be used as an opportunity to inform the visitor. A guide can intervene by signaling or demonstrating a correct behavior in order to prevent, correct, and reduce the number of contacts divers or snorkelers make with the reef and discourage harmful interactions with marine life. Barker and Roberts (2004) found that an in-water intervention by a dive leader was an effective strategy for reducing contacts with the reef. Roche et al. (2016) examined the role of dive supervision by recording dive guide interventions underwater, and observed a total of 81 interventions. 80% of these interventions were a buoyancy correction or a correction to prevent a contact with the reef before it occurred. Operators who followed environmentally responsible dive programs had divers with significantly lower reef contacts than those from dive operations who did not enforce these practices (Roche et al., 2016).

5.16.1 Strengths

Environmental education, especially when it involves on-site experiences, can be an effective strategy for reducing negative behaviors around coral reef ecosystems (Rajecki, 1982). While education combined with experience is considered to have the strongest influence on knowledge gain, other avenues can help with disseminating information including presentations, curricula, newspaper articles, public lectures, videos and exhibits.

Emphasis on the content of the outreach and education messages for divers and snorkelers is important and should be emphasized in the work plan for local action strategies. Divers and snorkelers are very different. Even within each group, there is heterogeneity. Despite, these differences, reef etiquette educational messages delivered right before a diver or snorkeler participates in a water excursion, have a high potential for reducing contacts to the reef caused by experienced, uniformed or unskilled individuals.

Often an unskilled recreationist wants to do the right thing but may lack the knowledge or skills to carry out the behavior (Roggenbuck, 1992). For example, a novice diver may not be aware that the components of his dive equipment are loose and brushing up against the coral reef. Educational programs that emphasize instruction, demonstration, and audience participation can help novice snorkelers gain knowledge and practice the necessary skills needed to reduce the exposure of corals to harmful behaviors.

Education programs can also address uninformed actions that result from the lack of knowledge regarding rules and required behaviors. Education messages delivered on-site may work to increase environmentally responsible behaviors and compliance when the behavior is caused by lack of awareness or knowledge. An example is the novice snorkeler who may think it is harmless to stand on the coral to communicate with a snorkeling friend. Often, education messages can result in altered opinions and behaviors just by specifying why rules are important, communicating what behaviors are environmentally responsible, and supporting snorkeler and dive efficacy by empowering individuals to want to do the right thing to help the coral reefs.

5.16.2 Limitations

Most coral reef management plans assume that more knowledge about the marine environment will linearly lead to changes in attitudes and ultimately improve behaviors towards the coral reef environment. There are no definitive findings that support the idea that knowledge alone automatically results in attitude changes that lead to an increase in pro-environmental behaviors. The process in which people gain knowledge is also different from one individual to the next. First, an individual needs to have been exposed to the new knowledge. Second, the individual must attend to the information presented. For example, if a person is handed a brochure or sees a billboard or poster, he has to be motivated to read it. For briefings, individuals need to pay attention. Reception, the ability of an individual to retain the information gained in one's long term memory, is another limitation (Rajecki, 1982). Also, an individual must feel that he/she possesses the abilities and skills needed to perform the behavior. The content of the message is also essential for reducing the exposure of the reefs to human contacts.

Finally, outreach and education may not be effective against certain activities. For example, illegal activities, which include willfully violating laws and rules established by authorities, may happen regardless of the fact that someone may know he should not do the activity. For example, divers or snorkelers who disobey the "no collecting" rule and take pieces of coral or shells from protected reserves even when they know they shouldn't. Other activities where outreach and education may not be effective include careless actions, which are those that are wrong and inconsiderate. While the visitor is aware that these actions are wrong, he/she still partakes in the activity without giving it much consideration. An example is a snorkeler who intentionally uses the coral as a resting place in order to talk with a fellow snorkeler or a diver who balances using the coral in order to take a picture. For careless behaviors, education messages are moderately effective since such messages may be able to prevent these behaviors in the short term but serve as no guarantee that the behavior may not happen again in the future.

5.17 Education and Outreach for La Cordillera Nature Reserve

Education and outreach strategies are a key component of the Local Action Strategy (LAS) initiatives in Puerto Rico. Education and outreach activities include targeting a variety of stakeholders, including those employed by the dive and snorkel industry. Dive and snorkel industry specific Local Action Strategy objectives include developing programs for recreational operators that provide basic education on coral reef biology, encourage regulation compliance, and discuss best management practices for recreational use around coral reefs. These measures may reduce vulnerability by reducing exposure.

5.17.1 Media Campaigns and Outreach

Projects to utilize media sources to raise public awareness and inform users about coral reef ecosystems, their protection, and pro-environmental behaviors are a recommended local action strategy for Puerto Rico. Such messages have been developed and delivered via radio, video, press, text, and signage at popular locations around the island. Targeted audiences include tourists, residents, and those working within the industry. Venues include airports terminals, marinas, hotels, in-flight, on cruise ships, onboard tour operator vessels, restaurants, and within coastal communities. Text messages can also be utilized as a way to educate snorkelers and divers who have signed up for a trip.

5.17.2 Best Practices Workshops/Continuing Education Training

Education workshops, designed and implemented to train those working in the industry on coral reef knowledge and best practices is a Local Action Strategy recommended for Puerto Rico. These workshops will be mandatory for those seeking or renewing navigational licenses and concessionaries. Mandatory continuing education classes were also recommended to provide stakeholders with current management and regulation revisions within the Reserve.

5.18 Recommendations for Education and Outreach within La Cordillera Nature Reserve

The following are recommended education and outreach measures that could be implemented at La Cordillera Nature Reserve in order to decrease vulnerability at the select reefs visited by dive and snorkel operators.

5.18.1 Video and Pledge for Both Divers and Snorkelers

A short video and pledge should be shown at check in, before snorkelers and divers board vessels. This should be followed by the on-board briefings that crew provide. While the vessel crew should continue to give briefings, the messages in the briefings should be revised to provide pro-environmental messages. This includes messages that promote self-efficacy (snorkelers and divers can avoid doing harm), awareness of consequences (corals build a strong skeleton but their “skin” is fragile and can be injured from human contact), and prescriptive norms (some corals burn, keep your distance). Messages can assert positive environmental attitudes (you came to the reef to experience how remarkable it is), and appeal to benevolence (snorkelers and divers would never deliberately do anything to hurt marine life). Webler & Jakubowski (2016) found that tourists did not find the five-minute video burdensome. To the contrary, most were grateful to be educated and were eager to minimize their impact on the reef. Implementing a well-designed, mandatory video message is one way to reduce tourist pressure on coral reefs.

For the on-board crew briefing, specific strategies to keep snorkelers engaged during the briefing are recommended. Snorkel crew members interviewed stated that briefings are difficult to deliver, especially when there are a lot of snorkelers onboard. Not every snorkeler pays attention. I observed snorkelers donning equipment, taking pictures, or quietly chatting within their group during briefings. Crew members stated that it often feels like you are giving instructions to a "brick wall" or to "empty faces." For these reasons, persuasion communication should be considered as a promising mechanism for revising briefings and managing the behaviors of snorkelers. Attitude change through the peripheral route to persuasion occurs from less thoughtful processing of the communication (Petty & Cacioppo, 1986). The targeted recreationists for this approach are those recipients who pay little or no attention to the content of a persuasive message, and spend no time processing or integrating any part of the message into their value system (Roggenbuck, 1992). For these message recipients, the delivery of the message has a greater impact on producing a behavior change in the recipient than does the actual message. In other words, "who said it" is more important that "what is said" (Roggenbuck, 1992). If the message needs to be delivered in an environment that is distracting, loud, or chaotic, this approach may be the best option (Roggenbuck, 1992). A large catamaran of snorkelers consuming food, drinking alcohol, listening to music and having fun is a good example of an environment in which the peripheral route to persuasion may be the best option.

5.18.2 In-Water Supervision for Snorkelers

More active involvement by snorkeling crew is necessary to reduce the number of contacts that snorkelers make with the reef. Research has found that in-water reinforcements had a significantly greater effect than just on-board briefings (Barker, 2003; Hammerton & Bucher, 2015; Medio et al., 1997; Roche et al., 2016). Interventions are defined as any action taken by a dive or snorkel guide to correct a behavior that may be harmful to the reef or marine life. A dive or snorkel guide can intervene by signaling or demonstrating a correct behavior in order to prevent, correct, and reduce the number of contacts divers or snorkelers make with the reef or harmful interactions with marine life. Barker and Roberts (2004) found that an in-water intervention by a dive leader was an effective strategy for reducing contacts with the reef. Roche et al. (2016) examined the role of dive supervision by recording dive guide interventions and observed underwater a total of 81 interventions. 80% of these interventions were a buoyancy correction or a correction to prevent a contact with the reef before it occurred. Operators who followed environmentally responsible dive programs had divers with significantly lower reef contacts than those from diver operations who did not enforce these practices.

At La Cordillera Nature Reserve, scuba dive guides are always in the water and do correct behaviors. However, as snorkeler crew remain on board vessels, I recommend snorkel crew should be present in situ to intervene when snorkeler contacts are made, especially intentional contacts such as standing or sitting on the reef. A majority of key informants said they corrected behaviors from the vessel, but having crew members in the water may be more effective.

I would also recommend that all beginner snorkelers be required to take a brief in-water snorkel lesson at Icacos Island. I expect the number of individuals who are classified as beginner is much higher in Puerto Rico since this information was self-reported. In-water lessons with small groups of individuals would also serve as an opportunity to provide education about coral reef etiquette and marine life. Environmental awareness questions about the health and diversity of life at the reefs indicated that more than half the snorkelers surveyed felt the reefs were healthy (55%) and diverse (54%). These perceptions do not correlate with the scientific data about the state of the coral reefs in Puerto Rico.

5.18.3 Diver Orientation to the Reef

My research suggests that scuba divers who visited La Cordillera Nature Reserve are supportive of learning, being corrected, and following the rules for both safety reasons and conservation reasons. Tour operators have an important role in these experiences, including promoting pro-environmental behaviors at the reefs. Teachable moments are easy, tangible, and inexpensive measures that can contribute to the management of human impacts on coral reefs.

In Bonaire National Marine Park (BNMP), all scuba divers must attend an orientation with their dive operator (defined as a dive shop from which air tanks are obtained) before diving in the BNMP. The orientation consists of a 'dry' part and a 'wet' part. The 'dry' part is a briefing on the Bonaire National Marine Park rules. The 'wet' part of the orientation is the check-out dive, which is always supervised by the dive operation providing air. This check-out dive allows for the dive operation to determine if the diver is competent and capable of maintaining buoyancy. Good buoyancy can prevent contact with the reef. Repeat divers are required to attend a dive orientation and perform a check out dive every time they are back on the Island of Bonaire. Dive shops in Puerto Rico can consider similar orientation programs for their divers to encourage pro-environmental behaviors at the reef.

5.18.4 Discover Scuba Program

In Puerto Rico, Discover Scuba, defined by the Professional Association of Dive Instructors (2018) as a quick and easy introduction to what it takes to explore the underwater world, visitors are taken to coral reefs within La Cordillera Nature Reserve with an instructor. Discover Scuba serves an important purpose. It exposes people to the underwater world, raises awareness, piques interest, and encourages individuals to continue on with their scuba certification. The only two Discover Scuba divers I observed were responsible for a high number of contacts during an observation period of 5 minutes at the reef (19 and 10 contacts). While Barker (2003) and Harriott et al. (1997) found no significant difference between total number of contacts and experience or dive experience, Barker did find that cruise ship passengers were significantly more likely to contact the reef than non-cruise ship passengers. These passengers are often "non-specialists" diving for the experience and not as their main vacation activity. For these reasons, Barker felt they may not be taking it as seriously and may be less skilled. I observed one "Discover Scuba" training and found that the focus of the training is understandably dive safety skills; first time divers visiting an underwater environment may feel anxious, nervous, and a bit compulsive. However, I believe conservation messages should be added to the Discover Scuba lessons since they are an important part of the training (raise awareness of the importance of coral reef ecosystems, corals are fragile organisms, divers can avoid contact). I also recommend that individuals who have not taken an official certification course should not be brought to reefs that have a higher percentage of sensitive coral species.

5.18.5 Staff Trainings/Best Practices Workshops

Tour operator crew recognize the need for coral reef conservation and expressed a strong desire about taking measures to protect the reefs from damage by snorkelers, divers, vessels, and pollution. A majority of key informants stressed that healthy coral reefs were essential for both ecological and economic reasons. Crew also mentioned their struggles with satisfying snorkeler expectations while protecting the reef. Goal 5 of Puerto Rico's Location Action Strategies for Coral Reef Conservation (2011-2015) focus is to engage stakeholders through education.

Objective 21 is the development of certification programs to train stakeholders in best management practices. Such collaborations with tour operators working around coral reefs in Puerto Rico is recommended. As an example, the Florida Keys National Marine Sanctuary (FKNMS), provides dive and snorkel operator trainings on how to utilize interpretive techniques, defined as techniques that utilize the art of relating information to the personalities and experiences of the audience (Florida Keys National Marine Sanctuary [FKNMS], 1997). The FKNMS also published the *Florida Keys Dive and Snorkel User's Guide* for dive and snorkel operators to help with their interpretative techniques.

Considered a National Ocean Service milestone, The Blue Star program, established by the Florida Keys National Marine Sanctuary, recognizes responsible dive and snorkel operators who are working to promote environmentally responsible behaviors and the diving practices that sustain and conserve coral reefs. A dive or snorkel operator can participate in the program once they have met certain criteria. Blue star operators are provided a placard and stickers to display their status, and the sanctuary staff encourage visitors to select these operators.

At the Bonaire National Marine Park, staff have developed the "Reef Ranger" course. The goal of this program is to maximize active support for coral reef conservation by providing standardized training for dive staff (Reef Resilience Toolkit Module, 2008). Such measures should be considered for best practices workshops in Puerto Rico.

5.19 Conclusion

Coral reef tourism sustains the livelihoods of many coastal people by providing income and employment opportunities. Yet despite these benefits, coral reef ecosystems are already exposed to multiple, simultaneous, local and global pressures from human activities. This includes those associated with tourism. Combined, these stressors play a significant role in degrading the ecological functions and socio-economic services provided by coral reefs. Strategies to manage tourism activities around coral reefs are a necessary component for maintaining and improving these ecosystems. It is recommended that an updated, complete, formal management plan for La Cordillera Nature Reserve be implemented and capacity for effective enforcement established. There are a variety of strategies that should be included in the management plan that can reduce the exposure of reefs in La Cordillera Nature Reserve to the negative aspects of the dive and snorkel tourism industry. Most of these strategies involve significant efforts made by dive and snorkel operators, who are at the forefront of protecting the coral reefs from human activities, through the decisions they make and the strategies they use to educate and correct harmful behaviors. Key informants interviewed expressed their willingness to collaborate with others in the industry as well as the government officials who manage, regulate, and enforce coral reef conservation. However, as evidenced by these conversations, operators feel they are getting little support and communication.

Tour operators should be involved in the management planning process since there are a number of mitigating measures they can take to reduce vulnerability. These adaptive actions include: which reefs to visit, mooring use, in-water supervision, in-water lessons for beginner snorkelers, etiquette training and careful consideration of what reefs to visit with “Discover Scuba” divers, and emphasis on the content and delivery of coral reef etiquette messages for beginners through advanced divers and snorkelers.

The island of Puerto Rico, a tourism-dependent economy, relies on coral reefs and their resources for the demands of the industry. The implementation of these adaptive actions are recommended as measures to reduce the vulnerability of coral reefs to dive and snorkel tourism.

Such strategies may allow for the continued benefits to the tourism economy on the island while conserving its valuable coral reef resources.

5.20 References

Adger, W. (2006). Vulnerability. *Global Environmental Change*, *16*(3), 268-281. https://doi.org/10.1016/j.gloenvcha.2006.02.006

Aguilar-Perera, A., Scharer, M., & Valdez-Pizzini, M. (2006). Marine protected areas in Puerto Rico. Historical and current perspectives. *Ocean and Coastal Management,49*, 961-975. https://doi.org/10.1016/j.ocecoaman.2006.08.011

Alevizon, W. (2002). MPA perspective: Conserving ecological integrity of marine reserves. *MPA News*, *46*(6)5.

Allison, W.R. (1996). Snorkeler damage to reef corals in the Maldives Islands. *Coral Reefs*, *15*(4), 215-218. https://doi.org/10.1007/BF01787454

Appeldoorn, R., Beets, J., Bohnsack, J., Bolden, S., Matos, D., Meyers, S., Rosario, A., Sadovy, Y., & Tobias, W. (1992). Shallow water reef fish stock assessment for the U.S. Caribbean. *NOAA Tech. Mem.* NMFS-SEFSC-304. https://repository.library.noaa.gov/view/noaa/6063

Appeldoorn, R., Yoshioka, P., Ballantine, D. (2009). Coral reef ecosystem studies: Integrating science and management in the Caribbean. *Caribbean Journal of Science*, *45*(2-3), 134-137. https://doi.org/10.18475/cjos.v45i2.a2

Ardoin, N.M., Wheaton, M., Bowers, A.W., Hunt, C.A., & Durham, W.H. (2015). Nature- based tourism's impact on environmental knowledge, attitudes, and behavior: A review and analysis of the literature and potential future research. *Journal of Sustainable Tourism, 23*(6), 838-858. https://doi.org/10.1080/09669582.2015.1024258

Arin, T. & Kramer, R. (2002). Divers' willingness to pay to visit marine sanctuaries: An exploratory study. *Ocean & Coastal Management, 45,*171-183. https://doi.org/10.1080/09669582.2015.1024258

Aronson, R.B. & Precht, W.F. (2006). Conservation, precaution, and Caribbean reefs. *Coral Reefs, 25*(3), 441-450. https://doi.org/10.1007/s00338-006-0122-9

Barker, N.H.L. (2003). *Ecological and socio-economic impacts of dive and snorkel tourism in St. Lucia,West Indies* (Doctoral dissertation, University of York). ProQuest Dissertations and Theses Global.

Barker, N.H.L. & Roberts, C.M. (2004). Scuba diver behavior and the management of diving impacts on coral reefs. *Biological Conservation,120*, (4), 481-489. https://doi.org/10.1016/j.biocon.2004.03.021

BoatersLand. (2017). How do I use a mooring buoy? – Taylor made mooring buoys. https://www.boatersland.com/mooring.html

Boulon, R., Chiappone, M., Halley, R., Jaap, W., Keller, B., Kruczynski, B., Miller, M, & Rogers, C. (2005). Atlantic *Acropora* Status Review Document. Report to National marine Fisheries Service, Southeast Regional Office. https://www.yumpu.com/en/document/view/30684931/atlantic-acropora-status-review-southeast-regional-office-noaa

Brown, K., Tompkins, E., & Adger, W. (2002). *Making waves: Integrating coastal conservation and development*. Earthscan.

Burgett, J. (1990). Diving deeper into Hanauma: Identifying conceptual barriers to effective management. In M. Miller and J. Auyong (Eds.), *Proceedings of the 1990 Congress on Coastal and Marine Tourism*. (Vol 1., pp. 100-105). National Coastal Resources Research Institute.

Burke, L., Reytar, K., Spalding, M., and Perry, A. (2011). *Reefs at risk revisited*. World Resources Institute.

Camp, E. & Fraser, D. (2012). Influence of conservation education dive briefings as a management tool on the timing and nature of recreational SCUBA diving impacts on coral reefs. *Ocean Coast Management, 61*, 30–37. https://doi.org10.1016/j.ocecoaman.2012.02.002

Carter, N., Vina, A., Hull, V., McConnell, W., Axinn, W., Ghimire, D., Liu, J. (2014). Coupled human and natural systems approach to wildlife research and conservation. *Ecology and Society,19*(3), 43. http://doi.org/10.5751/ES-06881-190343

Cenacchi, N. (2010). *Assessing the environmental impact of development policy lending on coastal areas: A World Bank toolkit (English)*. World Bank Group. http://documents.worldbank.org/curated/en/158041468163442038/Assessing-the-environmental-impact-of-development-policy-lending-on-coastal-areas-a-World-Bank-toolkit

Clark, J.R. (Ed.) (1991). *Carrying Capacity; A status report on marine and coastal parks and reserves*. Report prepared by the participants of the three international seminars on coastal and marine parks and protected areas. Miami, Florida and Costa Rica. 11 May – 5 June.

Daily, G.C., Alexander, S., Ehrlich, P.R., Goulder, L., Lubchenco, J., Matson, P.A. Mooney, H.A., Postel, S., Schneider, S.H., Tilman, D., & Woodwell, G.M. (1997). Ecosystem services: Benefits supplied to human societies by natural ecosystems. *Issues in Ecology*, 2,1-16. https://www.esa.org/wp-content/uploads/2013/03/issue2.pdf

Davis, D. & Tisdell, C. (1995). Recreational scuba-diving and carrying capacity in marine protected areas. *Ocean and Coastal Management*, *26*(1),19-40. https://doi.org/10.1016/0964-5691(95)00004-L

Diedrich, A. (2006). Assessment of the impacts of tourism development in coastal communities in Belize. (2006). *Dissertations and Master's Theses* Paper. https://digitalcommons.uri.edu/dissertations/AAI3239904

Dixon, J. (1993). Economic benefits of marine protected areas. *Oceanus*, 36(3) 35+.

Dixon, J.A., Fallon Scura, L.,& van't Hof, T. (1993). Meeting ecological and economic goals: Marine parks in the Caribbean. *Ambio*, *22*(2-3), 117-125.

Doney, S. (2006). The dangers of ocean acidification, *Scientific American*, 294(3), 58-65. http://doi.org/ 10.1038/scientificamerican0306-58

Florida Keys National Marine Sanctuary. (2007). Management Plan.

Frieler, K., Meinshausen, M., Golly, A., Mengel, M., Lebek, K., & Donner, S.D. (2013). Limiting global warming to 2°Celsius is unlikely to save most coral reefs. *Nature Climate Change, 3*(2),165-170. http://doi.org/10.1038/nclimate.1674

Gallopín, G.C. (2006). Linkages between vulnerability, resilience, and adaptive capacity. *Global Environmental Change*,16(3),293-303. https://doi.org/10.1016/j.gloenvcha.2006.02.004

Garcia-Sais, J., Appeldoorn, R., Battista, T., Bauer, L., Bruckner, A., Caldow, C., Carrubba, L., Corredor, J., Diaz, E., Lilyestrom, C., Garcia-Moliner, G., Hernandez-Delgado, E., Menza, C., Morell, J., Pait, A., Sabater, J., Weil, E., Williams, E., & Williams, S. (2008). The state of coral reef ecosystems of Puerto Rico. In: J.E. Waddell and A.M. Clarke (Eds.), *The state of coral reef ecosystems of the United States and Pacific Freely Associated States: 2008*. NOAA Technical Memorandum NOS NCCOS 73. NOAA/NCCOS Center for Coastal Monitoring and Assessment's Biogeography Team (pages 75 – 116).

Gardner, T.A., Côté, I.M., Gill, J.A., Grant, A., & Watkinson, A. R. (2003). Long-term region-wide declines in Caribbean corals. *Science*, *301*(5635), 958-960. https://doi.org/10.1126/science.1086050

Giglio, V., Luiz, O., Chadwick, N., & Ferreira, C. (2018). Using an educational video-briefing to mitigate the ecological impacts of scuba diving. *Journal of Sustainable Tourism, 26*(5), 782- 797. https://doi.org/10.1080/09669582.2017.1408636

Glynn, P.W. (1994). State of coral reefs in the Galapagos Islands: Natural versus anthropogenic impacts. *Marine Pollution Bulletin*, *29*(1-3), 131-140. https://doi.org/10.1016/0025-326X(94)90437-5

Great Barrier Reef Marine Park Authority. (2017). *Great barrier reef tourist numbers*. https://www.gbrmpa.gov.au/our-work/Managing-multiple-uses/tourism-on-the-great-barrier-reef/visitor-contributions2/numbers

Green, E. & Donnelly, R. (2003). Recreational SCUBA diving in Caribbean marine protected areas: Do the users pay? *Ambio, 32*(2), 140–144. http://doi.org/10.1579/0044-7447-32.2.140

Green Reef Environmental Institute et al. (2002). https://ambergriscaye.com/greenreef/

Gulko, D., Maragos, J., Friedlander, A., Hunter, C., & Brainard, R. (2002). *Status of coral reefs in Hawaiian Archipelago.* Department of Land and Natural Resources, Honolulu, Hawaii. https://www.coris.noaa.gov/portals/pdfs/status_coralreef_hawaii.pdf

Hall, V. R. (2001). The response of *Acropora hyacinthus* and *Montipora tuberculosa* to three different types of colony damage: scraping injury, tissue mortality and breakage. *Journal of Experimental Marine Biology and Ecology, 264*, 209-223. https://doi.org/10.1016/S0022-0981(01)00318-5

Halpern, B. S., Selkoe, K.A., Micheli, F., & Kappel., C.V. (2007). Evaluating and ranking the vulnerability of global marine ecosystems to anthropogenic threats. *Conservation Biology, 21*(5),1301-1315. http://doi.org/ 10.1111/j.1523-1739.2007.00752.x

Hammerton, Z. & Bucher, D. (2015). Levels of intervention – reducing SCUBA-diver impact within subtropical marine protected areas. *Journal of Ecotourism, 14*(1), 3 – 20. https://doi.org/ 10.1080/14724049.2015.1073738

Harriott, V.J. (2002). *Marine tourism impacts and their management on the Great Barrier Reef*. CRC Reef Research Centre Technical Report No 46. CRC Reef Research Centre. https://www.rrrc.org.au/wp-content/uploads/2014/04/Technical-Report-46.pdf

Harriott, V.J., Davis, D., & Banks, S.A. (1997). Recreational diving and its impact in marine protected areas in eastern Australia, *AMBIO, 26*,(3),173-179.

Hawkins, D. (1998). The relationship of tourism related revenue generation to coral reef conservation. In M. Hatziolos, A. Hooten, & M. Fodor (Eds.), *Coral Reefs Challenges and opportunities for sustainable management*. The World Bank.

Hawkins, J.P. & Roberts, C.M. (1992). Effects of recreational SCUBA diving on fore-reef slope communities of coral reefs. *Biological Conservation*, *62*(3), 171-178. https://doi.org/10.1016/0006-3207(92)91045-T

Hawkins, J.P. & Roberts, C.M. (1997). Estimating the carrying capacity of coral reefs For SCUBA diving. In H.A. Lessios, I.G. Macintyre, I.G. (Eds.), *Proceedings of the Eighth International Coral Reef Symposium.* Smithsonian Tropical Research Institute (volume 2, 1923-1926).

Hernández-Delgado, E.A., Ramos-Scharrón, C.E., Guerrero, C., Lucking, M.A., Laureano, R., Méndez-Lázaro, P.A., & Meléndez-Díaz, J.O. (2012). Long-term impacts of tourism and urban development in tropical coastal habitats in a changing climate: Lessons learned from Puerto Rico. In: M. Kasimoglu (Ed.)., *Visions from global tourism industry-creating and sustaining competitive strategies* (357-398). InTech Publications.

Hoegh-Guldberg, O., Mumby, P.J., Hooten, A.J., Steneck, R.S., Greenfield, P., Gomez, E., Harvell, C.D., Sale, P.F., Edwards, A.J., Caldiera, K., Knowlton, N., Eakin, C.M., Iglesias-Prieto, R., Muthiga, N., Bradbury, R.H., Dubi, A., Hatziolos, M.E. (2007). Coral reefs under rapid climate change and ocean acidification. *Science*, *14*(218),1737-1742. http://doi.org/ 10.1126/science.1152509.

Horta e Costa, B., Claudet, J., Franco, G., Erzini, K., Caro, A., & Goncalves, E.J. (2016). A regulation-based classification system for Marine Protected Areas (MPAs). *Marine Policy, 72*, 192-198. https://doi.org/10.1016/j.marpol.2016.06.021

Hughes, T.P., Baird, A.H., Bellwood, D.R., Card, M., Connolly, S.R., Folke, C., Grosbery, R., Hoegh-Guldberg, O., Jackson, J.B.C., Kleypas, J., Lough, J.M., Marshall, P., Nyström, M., Palumbi, S.R., Pandolfi, J.M., Rosen, B., and Roughgarden, J. (2003). Climate Change, human impacts, and the resilience of coral reefs. *Science*, *301*(5635),929-933. http://doi.org/ doi: 10.1126/science.1085046.

Hughes, T.P, Rodriques, M.J., Bellwood, D.R., Ceccarelli, D. Hoegh-Guldberg, O., McCook, L., Moltschaniwskyj, N., Pratchett, M.S., Steneck, R.S., & Willis, B. (2007) Phase shifts, herbivory, and the resilience of coral reefs to climate change. *Current Biology, 17*(4), 360-365.

Inskeep, E. (1991). *Tourism planning*. Van Nostrand Reinhold.

International Union for Conservation of Nature (IUCN). (2008). One third reef-building corals face extinction. https://www.iucn.org/content/one-third-reef-building-corals-face-extinction

International Union for Conservation of Nature /United Nations Environment Programme/World Wildlife Fund. (IUCN/UNEP/WWF). (1980). *World Conservation Strategy*. Living resource conservation for sustainable development. IUCN-UNEP-WWF. https://www.academia.edu/15924175/WORLD_CONSERVATION_STRATEGY_Living_Resource_Conservation_for_Sustainable_Development

Jameson, S.C., Ammar, M.S.A., Saadalla, E., Mostafa, H.M., & Riegl, B. (1999). A coral damage index and its application to diving sites in the Egyptian Red Sea. *Coral Reefs*,*18*(4),333- 339.

Kay, A.M., & Liddle, M.J. (1989). Impact of human trampling in different zones of a coral reef flat. *Environmental Management*, *13*(4), 509-520. https://doi.org/10.1007/BF01867685

Kenchington, R. (1993). Tourism in coastal and marine environments - a recreational perspective. *Ocean & Coastal Management, 19*(1), 1–16. https://doi.org/10.1016/0964-5691(93)90073-8

Kenchington, R., Ward, T., Hegerl, E. (2003). The benefits of marine protected areas. http://www.deh.gov.au/coasts/mpa/wpc/benefits/index.html

Krieger, J.R. & Chadwick, N.E. (2013). Recreational diving impacts and the use of pre- dive briefings as a management strategy on Florida coral reefs. *Journal of Coast Conservation*, *17*(1), 179-189. https://doi.org/ 10.1007/s11852-012-0229-9

Laffoley, D., Baxter, J., Day, J.C., & Wenzel, L. (2018). Marine protected areas. In C. Sheppard (Ed.), *World seas: An environmental evaluation. Volume III: Ecological issues and environmental impacts*. Elsevier (2nd ed., pp. 549 – 569).

Lessios, H.A., Robertson, D.R., & Cubit, J.D. (1984). Spread of *Diadema* mass mortality through the Caribbean. *Science, 226*, *(4672),* 335-338. http://doi.org/ 10.1126/science.226.4672.335.

Liddle, M.J. (1991). Recreation ecology: Effects of trampling on plants and corals. *Trends in Ecology and Evolution*,*6* (1), 13-17. https://doi.org/ 10.1016/0169-5347(91)90141-J

Liddle, M.J. & Kay, A.M. (1987). Resistance, survival and recovery of trampled corals on the Great Barrier Reef. *Biological Conservation*, *42*(1), 1-18. https://doi.org/10.1016/0006-3207(87)90049-8

Lilyestrom, C. & Hoffmaster, E. (2002). Recreational fishery statistics of coral reef fisheries in Puerto Rico. In proceedings, *coral reef fisheries Caribbean regional workshop: Collaboration on successful management, enforcement, and education methods for fisheries managers of the US Caribbean*. (pp.30-31).

Liu, J., Dietz, T., Carpenter, S., Alberti, M., Folke, C., Moran, E., Pell, A., Deadman, P., Kratz, T., Lubchenco, J., Ostrom, E., Ouyang, Z., Provencher, W., Redman, C., Schneider, S., & Taylor, W. (2007). Complexity of coupled human and natural systems. *Science,317*(5844),1513-1516. http://doi.org/10.1126/science.1144004

McClanahan, T.R. & Shafir, S.H. (1990). Causes and consequences of sea urchin abundance and diversity in Kenyan coral reef lagoons. *Oecologia,83*, 362–370. https://doi.org/10.1007/BF00317561

McKenzie-Mohr, D., & Smith, W. (1999). *Fostering sustainable behavior: An introduction to community-based social marketing* (2nd ed.). New Society Publishers. https://www.uwsp.edu/cnr-ap/UWEXLakes/Documents/ecology/shoreland/marketing/fostering_sustainable_behavior_dmm.pdf

Medio, D., Ormond, R. & Pearson, M. (1997). Effect of briefings on rates of damage to coral by SCUBA divers. *Biological Conservation*, *79*(1)*,* 91-95. https://doi.org/10.1016/S0006-3207(96)00074-2

Morelock, J., Ramirez, W.R., Bruckner, A.W., & Carlo, M. (2001). Status of coral reefs southwest Puerto Rico. *Caribbean Journal of Science*, *4*. https://www.aoml.noaa.gov/general/lib/CREWS/Cleo/PuertoRico/prpdfs/morelock-statuscoral.pdf

Mumby, P.J., Harborne, A.R., Williams, J., Kappel, C.V., Brumbaugh, D.R., Micheli, F., Holmes, K.E., Dahlgren, C.P., Paris, C.B., & Blackwell, P. (2007). Trophic cascade facilitates coral recruitment in a marine reserve. *Proceedings of the National Academy of Sciences of the United. States of America,104*(20), 8362–8367. https://doi.org/10.1073/pnas.0702602104

Mumby, P. & Steneck, R. (2008). Coral reef management and conservation in light of rapidly evolving ecological paradigms. *Trends in Ecology and Evolution*, 23(10), 555-563. http://doi.org/ 10.1016/j.tree.2008.06.011

Mundet, L. & Ribera, L. (2001). Characteristics of divers at a Spanish resort. *Tourism Management, 22*(5), 501-5 10. https://doi.org/ 10.1016/S0261-5177(01)00016-4

Murray, S., Ambrose, R.F., Bohnsack, J.A., Botsford, L.W., Carr, M.H., Davis, G.E., Dayton, P.K., Gotshall, D., Gunderson, D.R., Hixon, M.A., Lubchenco, J., Mangel, M., MacCall, A., McArdle, D.A., Ogden, J.C., Roughgarden, J., Starr, R.M., Tegner, M.J., & Yoklavich.M. (1999). No-take reserve networks: Sustaining fishery populations and marine ecosystems. *Fisheries 24*,11-24.

Musa, G. (2002). Sipadan: A SCUBA-diving paradise: An analysis of tourism impact, diver satisfaction and tourism management. *Tourism Geographies, 4*(2), 195-209. https://doi.org/10.1080/14616680210124927

National Marine Sanctuaries. (2008). https://sanctuaries.noaa.gov

National Oceanic and Atmospheric Administration Coral Reef Conservation Program (NOAA). (2009). *NOAA Coral Reef Conservation Program International Strategy 2010-2015*. https://coralreef.noaa.gov/conservation/international.html

National Oceanic and Atmospheric Administration (NOAA) - National Marine Fisheries Service (NMFS). (2014) *Endangered and threatened wildlife and plants: Final listing determinations on proposal to list 66 reef-building coral species and to reclassify elkhorn and staghorn corals.* https://www.federalregister.gov/documents/2014/09/10/2014-20814/endangered-and-threatened-wildlife-and-plants-final-listing-determinations-on-proposal-to-list-66

National Oceanic and Atmospheric Administration (NOAA). (2017). The MPA inventory. https://marineprotectedareas.noaa.gov/dataanalysis/mpainventory/

Ortiz Sotomayor, A. (2015). *Local Action Strategies (LAS) for coral reefs for coral reef conservation 2011-2015*: Puerto Rico. https://repository.library.noaa.gov/view/noaa/8069

Otero, E. & Carubba, L. (2007). *Characterization of mechanical damage to seagrass beds in La Cordillera Reefs Natural Reserve*. Final report submitted to the Puerto Rico Department of Natural and Environmental Resources. https://www.drna.pr.gov/wp-content/uploads/2015/08/Otero-and-Carrubba-Final-Report-Seagrasses-Cordillera-correc.pdf

Page, G., Olsen, S.B., Nemerson, D., Swanenberg, A., Maddalene, T. (2013). *An analysis of issues affecting the management of coral reefs and the associated capacity building needs in Puerto Rico.* https://www.coris.noaa.gov/activities/capacity_assessment/finalprcapacityassessment.pdf

Pardini, A.U. & Katzev, R.D. (1983). The effect of strength of commitment on newspaper recycling. *Journal of Environmental Systems,* 13, 245-254. https://doi.org/10.2190/6PN9-MXFP-3BFF-CHHB

Peters, H. & Hawkins, J.P. (2009)**.** Access to marine parks: A comparative study in willingness to pay. *Ocean & Coastal Management, 52(3-4)*, 219-228. https://doi.org/10.1016/j.ocecoaman.2008.12.001

Petty, R. & Cacioppo, J. (1986). *Communication and persuasion: Central and peripheral routes to attitude change*. Springer-Verlag. https://doi.org/10.1037/0022-3514.51.5.1032

Pigram, J.J. & Jenkins, J.M. (1999). *Outdoor Recreation Management.* Routledge.

Plathong, S., Inglis, G., & Huber, M. (2000). Effects of self-guided snorkeling trails on corals in a tropical marine park. *Conservation Biology, 14*(6),1821-1830. http://doi.org/10.1111/j.1523-1739.2000.99301.x

Pomeroy, R.S., Mascia, M.B., & Pollnac, R.B. (2007). *Marine protected areas: The social dimension*. In FAO (Ed.) Report and documentation of the expert workshop on marine protected areas and fisheries management: Review of issues and considerations. Rome, 12–14 June 2006. FAO Fisheries Report No. 825, pp. 149–181.

Prior, M., Ormond, R., Hitchen, R., & Wormald, C. (1995). The impact of natural resources of activity tourism: a case study of diving in Egypt. *International Journal of Environmental Studies, 48*(3-4), 201-209. https://doi.org/10.1080/00207239508710990

Professional Association of Dive Instructors [PADI]. (2018). https://www.padi.com

Puerto Rico House of Representatives (1999). *House of Representatives Bill 1466, Law 147 of 15 July 1999*. https://casedocuments.darrp.noaa.gov/southeast/matthew/pdf/Law_147.pdf

Ragster, L. & Geoghegan, T. (1992). Management Training in the Caribbean, a Necessity for Sustainable Development; the Consortium Approach. *Caribbean Perspectives. 2*, 1-17.

Rajecki, D.W. (1982). *Attitudes, themes, advances*. Sinauer Associates.

Ramos, J.C.R. (2014). *Centro Preliminary findings on user's perceptions about the management of, and conflicts over, natural resources in the maritime zone of the Northeast corridor. Preliminary Report #3*. Centro para la Conservación del Paisage Inc. https://data.nodc.noaa.gov/coris/library/NOAA/CRCP/project/527/CCP_Progress_Report_3_20150108.pdf

Reef Resilience Toolkit Module. (2008). https://reefresilience.org

Rhein, M., Rintoul, S. R., Aoki, S., Campos, E., Chambers, D., Feely, R. A., Gulev, S., Johnson, G.C., Josey, S.A., Kostianoy, A., Mauritzen, C., Roemmich, D., Talley, L.D., & Wang, F. (2013). Observations: Ocean. In T. F. Stocker, D. Qin, G.-K. Plattner, M. Tignor, S. K. Allen, J. Boschung, A. Nauels, Y. Xia, V. Bex, P.M. Midgley (Eds.). *Climate Change 2013: The physical science basis. Contribution of working group I to the Fifth Assessment Report of the Intergovernmental Panel on Climate Change.* (pp. 255–316). Cambridge University Press.

Riegl, B. & Velimirov, B. (1991). How many damaged corals in Red Sea reef systems? A quantitative survey. *Hydrobiologia, 216-217*(1), 249-256. https://doi.org/10.1007/BF00026471

Roche, R.C., Harvey, C.V., Harvey, J.J., Kavanagh, A.P., McDonald, M., Stein-Rostaing, V.R., & Turner, J.R. (2016). Recreational diving impacts on coral reefs and the adoption of environmentally responsible practices with the SCUBA diving industry. *Environmental Management, 58*(1), 107-116. https://doi.org/10.1007/s00267-016-0696-0

Roggenbuck, J. (1992). Use of persuasion to reduce resource impacts and visitor conflicts. In M. Manfredo (Ed.), *Influencing Human Behavior*, pp. 149-248. Sagamore Publishing.

Rouphael, A. & Inglis, G. (2001). "Take only photographs and leave only footprints"?: An experimental study of the impacts of underwater photographers on coral reef dive sites. *Biological Conservation*, *100*, 281 – 287.

Salm, R.N. (1986). Coral reefs and tourist carrying capacity: the Indian Ocean experience. *UNEP Industry and Environment,* Jan-Mar*,* 11-14.

Schahn, J. & Holzer, E. (1990). Studies of individual environmental concern: The role of knowledge, gender and background variables. *Environment and Behavior,22*, 767-786. https://doi.org/10.1177/0013916590226003

Schleyer, M. & Tomalin, B. (2000). Damage on South African coral reefs and an assessment of their sustainable diving capacity using a fisheries approach. *Bulletin of Marine Science, 67*(3), 1025-1042.

Schultz, L., Folke, C., & Olsson, P. (2007). Enhancing ecosystem management through social-ecological inventories: Lessons from Kristianstads Vattenrike, Sweden. *Environmental Conservation, 34*, 140-152.

Smit, B. & Wandel, J. (2006). Adaptation, adaptive capacity and vulnerability. *Global Environmental Change,16*(3), 282-292. https://doi.org/10.1016/j.gloenvcha.2006.03.008

Spalding, M., Burke, L., Wood, S., Ashpole, J., Hutchison, J., & Zu Ermgasssen, P. (2017). Mapping the global value and distribution of coral reef tourism. *Marine Policy, 82*,104-113. https://doi.org/10.1016/j.marpol.2017.05.014

Stankey, G., Cole, D., Lucas, R., Peterson, M., Frissel, S. and Washbourne, R. (1985). *The limits of acceptable change (LAC) system for wilderness planning.* General Technical Report INT-176. Ogden, Utah: U.S. Department of Agriculture–Forest Service, Intermountain Forest and Range Experiment Station.

Terk, E. & Knowlton, N. (2010). The role of SCUBA diver user fees as a source of sustainable funding for coral reef marine protected areas. *Biodiversity, 11*(1-2), 78-84. https://doi.org/10.1080/14888386.2010.9712651

Tratalos, J. & Austin, T. (2001). Impacts of recreational SCUBA diving on coral communities of the Caribbean island of Grand Cayman. *Biological Conservation*, *102*(1), 67-75. https://doi.org/10.1016/S0006-3207(01)00085-4

United States Census Bureau. (2012). Puerto Rico summary population and housing characteristics. 2010 Census of population and housing. https://www.census.gov/prod/cen2010/cph-1-53.pdf

United States Coral Reef Task Force (USCRTF) Working Group on Ecosystem Science and Conservation. (2000). *Coral reef protected areas: A guide for management. U.S.* Coral Reef Task Force, Department of the Interior. (pp. 1-14). https://www.coralreef.gov/about/blueprnt.pdf

United States Coral Reef Task Force (USCRTF) (2016). *U.S. Coral Reef Task Force Strategy FY2016 -2021.* https://data.nodc.noaa.gov/coris/library/NOAA/CRCP/other/USCRTF/uscrtf_strategy_2016_2021.pdf

Uyarra, M.C., Watkinson, A.R., and Cote, I. (2009). Managing dive tourism for sustainable use of coral reefs: Validating diver perceptions of attractive site features. *Environmental Management*, *43*(1),1-16. http://doi.org/ 10.1007/s00267-008-9198-z

Valdés-Pizzini, M., García-Quijano, C.G., & Schärer-Umpierre, M.T. (2012). Connecting humans and ecosystems in tropical fisheries: Social sciences and the ecosystem-based fisheries management in Puerto Rico and the Caribbean. *Caribbean Studies, 40* (2), 95-128. https://www.jstor.org/stable/41917605

Van't Hof, T. (1988). Management of coral reefs and associated systems and resources in the western Atlantic: A status review. In *Proceedings of the 6th International Coral Reef Symposium*, International Society for the Study of Coral Reefs (pp. 89-95).

Virapongse, A., Brooks, S., Covelli Metcalf, E., Zedalis, M., Gosz, J., Kliskey, A., & Alessa, L. (2016). A social-ecological system approach for environmental management. *Journal of Environmental Management,178*, 83-91. https://doi.org/10.1016/j.jenvman.2016.02.028

Walker, D.I. & Ormond, R.F.G. (1982). Coral death from sewage and phosphate pollution at Aqaba, Red Sea. *Marine Pollution Bulletin,13*(1), 21-25. https://doi.org/10.1016/0025-326X(82)90492-1

Weaver, D. (2008). *Ecotourism*. Milton, John Wiley & Sons.

Webler, T. & Jakubowski, K. (2016). Mitigating damaging behaviors of snorkelers to coral reefs in Puerto Rico through a pre-trip media-based intervention. *Biological Conservation, 197*, 223-228. https://doi.org/10.1016/j.biocon.2016.03.012

Werner, B.T; McNamara, D.E (2007). Dynamics of coupled human-landscape systems. *Geomorphology*, *91*(3), 393–407. http://doi.org/ 10.1016/j.geomorph.2007.04.020

White, A.T., Hale, L.Z., Renard, Y., & Cortesi, L. (1994). *Collaborative and community-based management of coral reefs: Lessons from experience*. Kumarian Press Library of Management for Development.

Wielgus, J., Balmford, A., Lewis, T.B., Mora, C., & Gerber, L. (2010). Coral reef quality and recreation fees in marine protected areas. *Conservation Letters, 3*(1), 38-44. http://doi.org/10.1111/j.1755-263X.2009.00084.x

Wilhelm, T.A., Sheppard, C.R., Sheppard, A.L, Gaymer, C.F, Parks, J., Wagner, D., & Lewis, N. (2014). Large marine protected areas – Advantages and challenges of going big. *Aquatic Conservation Marine and Freshwater Ecosystems*, *24*(52), 24-30. https://doi.org/10.1002/aqc.2499

Wilkinson, C., & Souter, D. (2008). *Status of Caribbean coral reefs after bleaching and hurricanes in 2005*. Global Coral Reef Monitoring Network, and Reef and Rainforest Research Centre. (pp. 1 -152).

World Travel & Tourism Council (WTTC). *Travel & Tourism. Economic Impact 2014*: *World*, World Travel and Tourism Council, London, 2014.

Zabinski, B., Greer, E. P., Coffey, G. T., & LaSante, R. S. (2009). Assessment and Catalogue of Puerto Rican Mooring Buoys. https://digitalcommons.wpi.edu/iqp-all/1306

Zakai, D. & Chadwick-Furman, N.E. (2002). Impacts of intensive recreational diving on reef corals at Eilat, northern Red Sea. *Biological Conservation*, *105*(2), 179-187. https://doi.org/10.1016/S0006-3207(01)00181-1

Chapter 6
Conclusion

6.1 Introduction

Globally, coral reefs are declining from exposure to a multitude of stressors and in some areas have decreased by more than 90% coverage. (Burke et al., 2011; Gardner et al., 2003; Jackson et al., 2014; United States Coral Reef Task Force, 2016). In the Caribbean, there has been increasing reports regarding coral reef degradation, coral bleaching, massive die-offs, and both coral and reef fish population declines (Appeldoorn et al., 2009; Roberts, 1997). Puerto Rico's coral reefs have been classified as the most critical (Hernandez-Delgado, 2005). Scientists postulate that if we continue on this trajectory, coral reef ecosystems may become extinct in the next several decades (Frieler et al., 2013). Both local stressors (overfishing, tourism, pollution) and global stressors (increase in sea surface temperatures and changes in ocean pH) are responsible for this decline. Combined, these stressors play a significant role in degrading the ecological functions and socio-economic services provided by coral reefs (Brown et al., 2002).

Although rare, there are remote areas around the world that have not been exposed to human activity and contain healthy, thriving coral colonies (Cinner et al, 2016). Further, researchers have also found that even in areas with increased human activity, management strategies that reduce the exposure of coral reefs to various stressors can result in healthy coral reef populations (Smith & Marx, 2015; Wooldridge & Done, 2009). This is good news. It indicates that corals are resilient and, if given a chance and enough time, they can recuperate. Examples of such recovery in areas around the Caribbean, specifically Bermuda and Bonaire, include sound management plans to improve water quality and restoration projects to increase parrotfish populations. Both have had positive impacts on coral reefs (Jackson et al., 2014). For all these reasons, it is important to reduce local stressors as much as possible by implementing sound management strategies, especially when global stressors, like warming ocean temperatures, rising sea level, and changes in ocean chemistry continue to escalate (Anthony et al., 2015).

The primary goal of this dissertation is to build on research associated with one stressor, dive and snorkel recreational activities around coral reefs. This study was completed within a popular recreation location, La Cordillera Nature Reserve, Puerto Rico. Research has demonstrated that marine recreational activities, like snorkeling and diving, can degrade coral reefs when visitors act inappropriately. Damage to the reef is often the result of inappropriate behaviors of individuals and not always the industry. Specific damaging behaviors include fins kicking coral, brushing up against the reef, holding on to coral, standing or kneeling on the reef, and walking on coral polyps (Barker, 2003; Medio et al., 1997; Prior et al., 1995; Rouphael & Inglis, 2001). Given the current and expected growth in tourism and recreational activities, the concern is that coral ecosystems will continue to be degraded by these activities without an organized management strategy specific to this stressor.

Specifically, I developed a methodology to characterize the vulnerability of coral reef resources to tour operator led snorkel and dive excursions within La Cordillera Nature Reserve located in Puerto Rico. This methodology was then applied at four popular recreational reefs within the Reserve. Determining the vulnerability of coral reefs to recreational activities includes measuring the exposure of reefs to recreational snorkelers and divers, characterizing the sensitivity of reefs to potentially harmful snorkeler and diver behaviors, and characterizing the adaptive capacity of the system by examining opportunities to influence behavior, policy, and management. Such measures can help coral reef managers determine where to focus their efforts.

In the context of this research, exposure refers to the number of potentially harmful actions that recreational snorkelers can inflict on coral reef ecosystems when they contact the reef. Sensitivity includes the qualities that make some corals experience more stress when exposed to the same stressor (the snorkeler and diver behavior) and include: the morphology of the coral, the topography of the reef, and the perceptions of snorkelers or divers. Adaptive actions in this case refer to decisions and actions taken by a variety of individuals connected to the tourism industry. For instance, the government can decide to install mooring buoys to reduce anchor damage at the reef. Vessel captains can decide which reefs to visit and where to moor. The crew of the vessel decides how to prepare tourists for the dive or snorkel experience. Finally, a snorkeler or diver can decide to behave responsibly while at the reef.

Coral reef ecosystems in the Caribbean have been declining for at least the last forty years, although pinpointing the beginning of the decline has been difficult (Appeldoorn et al., 2009). In the Caribbean, massive coral bleaching events occurring in the 1980s, 1990s, and 2000s have contributed to more than half of the decline of the reef ecosystems (Jackson et al., 2014). Despite their decline in Puerto Rico, coral reef ecosystems still play an important economic role in Puerto Rico's tourism industry. This is reflected in the number of people who visit the island, the demand for services, and the number of people employed by the industry. Knowledge on the relative vulnerability of specific reefs to damage from snorkeling within Puerto Rico is necessary for informing and prioritizing management and conservation decisions for the tourism industry. For all of these reasons, this dissertation was designed to add knowledge to:

1. Determining the threats of recreational scuba diving and snorkeling to coral reefs within La Cordillera Nature Reserve, Puerto Rico.

2. Characterizing the vulnerability of coral reef resources to snorkeling and diving by documenting exposure levels and sensitivities.

3. Exploring management actions that will be most effective at mitigating these threats within the Reserve.

6.2 Summary of Findings

6.2.1 Determining the Threats of Recreational Snorkeling to Coral Reefs within La Cordillera Nature Reserve, Puerto Rico and Documenting Exposure Levels and Sensitivities of Corals

My findings indicate that some reefs within La Cordillera Nature Reserve, Puerto Rico are vulnerable to snorkeling activities. Exposure to contacts, which includes the depth of the coral in relationship to the snorkeler, may be a potential factor since both reefs (beach entry reef at Icacos Island and Tortugas Reef) have shallow areas (less than one meter). At these reefs, there are also topographic features (fringing reefs, rocky outcrops, plateaus, and tight spaces) that can lead to more contacts. The number of potentially damaging contacts for snorkelers was high, (0.28 contacts per minute) at La Cordillera Nature Reserve when compared to St. Lucia (0.05 contacts per minute), the only other location where snorkeler contact rates were observed. When this frequency is multiplied by the number of visitor-minutes spent at reefs on a yearly basis, the scale of the problem can appear to be a significant factor for increasing vulnerability. For example, during the height of the tourist season, eight catamarans can bring approximately 40 (but up to 80 on some vessels) individuals to the reef. However, it is important to note that not every person brought out to La Cordillera Nature Reserve with a tour operator actually snorkels. Many people will stay on the vessel, swim right around the boat, or sit on the beach (at reef locations where beach access is available). If I compare the average number of snorkelers at peak times (15 minutes for Icacos Island beach reef and 25 minutes for Tortugas Reef) and calculate the total number of snorkelers at that peak time for one year (8,030 and 12,775 snorkelers respectively) the total number of snorkelers is less than carrying capacities set for other snorkeling locations. After these peak times, the number of snorkelers at each reef steadily declined.

Fin contacts were the most potentially damaging behavior. Fins add length to a snorkeler's legs, bringing the snorkeler closer to the reef. Most of the fin contacts I observed appeared unintentional and most likely caused by poor snorkeling technique. When maneuvering around the water, snorkelers (especially beginners) were often unaware that their fins had made contact with the reefs. I also observed that snorkelers tend to engage in more potentially damaging behaviors with the reef when snorkeling in a group vs. individually. Groups of snorkelers tend to pause to take their heads out of the water and discuss what they are seeing. During this time, they usually become vertical in the water and their fins are often contacting the coral, or they are standing on it. Standing on the reef was the second most common behavior (24%) observed. Unskilled snorkelers will stand on the reef to fix their equipment, rest, or find their friends. While it may be harder to stop snorkelers from kicking the reef with their fins, measures to reduce exposure from standing are possible. These specific behaviors should be targeted in education and outreach messages.

At both Icacos Island beach entry reef and Tortugas Reef, no thin branching corals were present and thick branching corals comprised only 3% (N = 15) of the transect survey at Tortugas Reef. Of this small percentage of branching coral, 50% was damaged. At Icacos Island beach entry reef, 91% (N = 259) of the coral species and 94% (N = 474) of the species at Tortugas Reef were classified as stable and less sensitive to physical contacts. The most common encrusting coral, *Porites astreoides* was present at both reefs and is classified as a rapid colonizer (Hernandez-Delgado, 2005). Rapid colonizers are successful in ecosystems that are disturbed.

Coral reef biologists state that physical damage from hurricanes was the greatest threat to the reefs at Icacos Island, followed by disturbances created by anthropogenic physical damage (Hernandez-Delgado, 2005). Impacts from snorkelers, therefore, may be contributing to a change in reef community structure. This has been reported on the Island of Bonaire in the Caribbean, where impacts from heavily dived areas are thought to have caused the loss of massive corals at the expense of faster growing corals (Hawkins et al., 1999). The morphology of the corals at Icacos Island in La Cordillera Nature Reserve indicate that less sensitive, faster growing species can handle stressors while others cannot.

6.2.2 Determining the Threats of Recreational Scuba Divers to Coral Reefs Within La Cordillera Nature Reserve, Puerto Rico and Documenting Exposure Levels and Sensitivities of Corals

My findings indicate some reefs within La Cordillera Nature Reserve are vulnerable to scuba diving activities. Dive operator data analyzed found the average number of trips during both the peak and non-peak season was the same,107 trips. The average number of divers per trip was nine. The dives lasted from 35 – 51 minutes with a mean of 45 minutes at an average depth of 50 feet. This averages to slightly more than 3,200 divers per year, which is below all of the other recommended carrying capacities in coral reef locations globally. While the average number of divers may be below carrying capacity, the contact rate for divers observed in La Cordillera Nature Reserve, was 0.5 contacts per diver per minute. This rate is five times higher than all but two other coral reef locations where research on number of contacts with reefs was conducted (Barker, 2003; Harriott et al.,1997; Krieger & Chadwick, 2013; Medio et al., 1997; Prior et al., 1995; Roche et al., 2016; Rouphael & Inglis, 2001; Talge, 1990).

Similar to other research, divers who use cameras while diving had significantly more contacts with the reef than non-camera users (Barker, 2003; Medio et al.,1997; Prior et al., 1995;

Rouphael & Inglis, 2001). Certified divers know not to stand, sit, or kneel on the reef. Only 1% of the contact behaviors fell in this category. One diver was observed kneeling on a soft coral to take a photograph. This diver was also responsible for the greatest number of contacts observed.

The reefs at Cayo Diablo had a high percentage of soft corals (98%, N = 2940) identified in random transects. These corals move with water currents. Soft branching corals are considered to have intermediate resilience to diver damage (Fox et al., 2003; Hall, 2001; Sheppard & Loughland, 2002; Stobart et al., 2005). This unpredictable movement can make it difficult for a diver to avoid a contact and may be a contributing factor to why the contact rate per minute is higher for divers in Puerto Rico. Only a small percentage of hard corals were observed along the transects at Diablo reef. 0.5% (N = 15) were mostly encrusting corals, (*Porites astreoides*), 0.4% (N = 12) boulder coral and 0.01% (N = 0.3) plated coral. Non-living boulder coral and coral rubble (mostly pieces of thick branching *Acropora palmate)* occupied 0.4 % (N = 12) of the transect. No other coral morphologies were observed

A majority of the corals characterized at Sandslide, off the coast of Palominos Island, are also classified as stable and less sensitive to human contacts. These include short, thick, stubby branching finger-like corals (*Porites porites*) occupying the largest proportion 41% (N = 675) of the substratum, encrusting corals 35%, (N=525), and soft corals at 22% (N = 300). Only a small percentage of plated 1.2% (N = 18), boulder 0.3% (N = 5), and foliose 0.3% (N = 5) corals were observed. No table, columnar, or thin branching coral were observed along the transect. Numerous pieces of non-living coral rubble were observed all along the transect.

6.3 Exploring Management Actions to Reduce Threats from Recreational Activities Within La Cordillera Nature Reserve

The islands, keys, and coral reefs within La Cordillera Nature Reserve are classified as protected because they include a variety of unique and important coastal and marine habitats. These include dry forests, mangrove lagoons, sandy habitats, sea grasses, and coral reefs. There are a variety of stakeholders who utilize the resources within the Reserve for cultural, recreational, and economic reasons. These uses all contribute to potential damage.

While I did not specifically investigate the ecological damage of snorkeler and diver contacts with the reef, researchers have correlated snorkeler and dive activity and reef conditions at many locations, supporting the claim that snorkeling and diving can be a serious threat to coral reefs (Allison, 1996; Hawkins & Roberts, 1992; Kay & Liddle, 1989; Krieger & Chadwick, 2013; Liddle, 1991; Liddle & Kay, 1987; Plathong et al., 2000; Prior et al., 1995; Riegl & Velimirov, 1991; Tratalos & Austin, 2001). As indicated by my research data, snorkel and dive activities within La Cordillera Nature Reserve, specifically at the beach reef at Icacos Island, Tortugas Reef, Cayo Diablo, and Sandslide, may contribute to increasing the vulnerability of these coral reef ecosystems. Increasing adaptive capacity and implementing management actions to reduce vulnerability, specifically actions that decrease exposure, is a tangible possibility. For these reasons, management within La Cordillera Nature Reserve needs to consider these threats to the coral reef environment and take actions to reduce the vulnerability to these systems. Damage to reefs from diving and snorkeling can be prevented and tangible actions can be implemented to help divers and snorkelers reduce and prevent contacts. These actions should include measures that reduce exposure, one of the major indicators of vulnerability. The following discusses recommendations for adaptive actions for both snorkel and dive water-based tour operator excursions within the Reserve.

6.4. Adaptive Actions - Recommendations

Tour operators are at the front line for implementing measures to reduce snorkeler and diver impacts to the reef. While my findings recognize the importance of maximizing snorkeler and diver satisfaction, my data indicate that tour operator crew recognize the need for coral reef conservation and express a strong desire for taking measures to protect the reefs from damage by snorkelers, divers, vessels, and pollution. A majority of key informants stressed that healthy coral reefs were essential for both ecological and economic reasons. Mitigating measures can be implemented that satisfy snorkeler and diver expectations while protecting the reef. Adaptive actions for snorkelers and divers are discussed separately.

6.4.1 For Snorkelers

For snorkelers, raising awareness through knowledge sharing and instruction is necessary for increasing environmentally responsible behaviors at the reef. As one key informant stated: "*one vessel with snorkelers not practicing reef etiquette can do more potential harm than several vessels with snorkelers taking measures to prevent contacts with the reef."* While all vessel crew gave informative briefings, this method was not the most effective way of providing coral reef etiquette messages that may reduce exposure.

Persuasion communication may be the best method for influencing short-term behaviors at the reef. The Elaboration Likelihood Model of Persuasion is a simple and direct method for influencing behaviors (Stephenson, 2008). Message content should incorporate behavior change theories and be delivered in several ways including short videos delivered at check-in, a signed commitment pledge before individuals board the vessel, and then on-board briefings that crew provide (Webler & Jakubowski, 2016).

It is also important to ask snorkelers about their skill level and experiences snorkeling. 35% of the snorkelers I surveyed stated they were beginner snorkelers. I expect the number of individuals who are classified as beginner is much higher since this information was self-reported. Post snorkel surveys found that more than half (55%, N = 99) were satisifed with seeing a healthy reef in Puerto Rico. Approximately 54% percent (N = 96) of snorkelers responded that they were satisfied with the diversity of marine life around the coral reefs. I suspect these snorkelers are satisified with seeing an abundance of fish and not necessarily the diversity of this abundance. The perceptions of snorkelers within the Reserve do not correlate with the scientific data about the state of the coral reefs in Puerto Rico. I also found that most snorkelers spend between 15 and 25 minutes snorkeling before heading back to the vessel. All of these reasons indicate that snorkelers participating in excursions do not have to be brought to the best reefs within the Reserve.

In addition to the method of delivery, I believe more active involvement by crew is necessary to reduce the number of contacts that snorkelers make with the reef. I believe crew should be present in situ to intervene when snorkeler contacts are made, especially intentional contacts such as standing or sitting on the reef. A majority of key informants said they corrected behaviors from the vessel, but damage occurring underwater may not be seen and, therefore, not enforced. Having crew members in the water may be more effective.

Finally, I would also recommend that all beginner snorkelers be required to take an in-water snorkel lesson. In-water lessons with small groups of individuals would also provide an opportunity for additional education about coral reef etiquette and marine life.

6.4.2 For Divers

The role of the dive instructor/dive master is significant for mitigation since their level of involvement can reduce the number of contacts with the corals while visitors are diving at the reef. Every diver surveyed for this research stated they heard the dive briefing. Several commented that briefings were strong, helpful, and contained important information. I observed divers paying attention and asking questions to dive guides during the briefings. In addition, the number of divers (average 9 individuals) also helped keep the setting for the briefings small and focused.

71% (N = 92) of the divers who completed surveys reported they were certified divers (46% open water certification and 25% advanced). Of those certified the mean number of dives completed since certification was 31. These factors indicate an investment in this activity. Thapa et al. (2006) found a positive association with this type of investment, recreation specialization, and pro-environmental behavior.

My findings suggest that divers recreating in Puerto Rico have relatively high levels of environmental awareness and are concerned about how divers can impact the marine environment. A majority of scuba divers 87% (N = 80) disagreed that scuba divers and snorkelers have a right to collect things at the reef. 88% (N = 81) of divers who responded to the survey felt that dive instructors and dive masters should correct divers whose behavior could be damaging the coral reef. 57% (N = 52) of the divers surveyed in Puerto Rico felt that the coral reef crisis was real and 51% (N = 47) agreed that humans do damage corals reefs. These responses indicate that if the content of the briefings and messages is effective, and divers are capable of processing, understanding, and accepting the message, environmentally responsible behaviors may increase.

A majority of divers in Puerto Rico follow social norms during dive trips, are supportive of learning, being corrected, and following the rules for both safety reasons and conservation reasons. For all of these reasons, I recommend that dive crew continue to utilize teachable moments via interactions with divers. Standard messages via briefings should be revised to include persuasion communication, specifically the central route to persuasion, as a promising mechanism for individuals. My findings suggest that divers will use effort to process the information in a message in order to determine its merit and accept the content.

My findings also indicate that dive crew based out of Fajardo do a thorough job making sure the divers in their group descend away from the reef and establish buoyancy before the group begins the dive. During the initial dive, guides kept the group parallel to the reef and not over it. These are good examples of active management and support the role that dive leaders can play in reducing the exposure of coral reefs to physical contacts.

Dive instructors and dive masters lead small groups for the entire dive, constantly checking on the divers along the way. It is recommended that dive guides should correct a behavior that may be harmful to the reef or marine life when observed. Interventions can be signals or demonstrations of the correct behavior in order to prevent, correct, and reduce the number of contacts divers make with the reef.

Finally, non-certified divers, 26% (N = 27) of divers surveyed in Puerto Rico, should be restricted to reefs with coral species that are less sensitive to diver contact. For example, a majority of the corals observed at Diablo Reef were soft corals. The unpredictable movement of these corals can increase diver contacts. A first-time diver may not have the ability to maneuver around these organisms thus increasing the frequency of contacts. He/she may also be anxious, nervous, and a bit compulsive. Conservation messages should be added to the Discover Scuba lessons since they are an important part of the training (raise awareness of the importance of coral reef ecosystems, corals are fragile organisms, divers can avoid contact).

6.4.3. For Industry and Government

A theme that resonated among key informants was a need for improvement in the relationship between tour operators and government officials in charge of managing the activities that take place within the Reserve. A majority of tour operators stated they are not getting the support they need from the government and their voices are not being heard when it comes to actions that would help the tourism industry while protecting the quality of the coral reefs. Several informants stated that each snorkeler taken to the reef has to pay a small fee for conservation of the Reserve and yet they felt no additional measures were being taken with these funds. For example, more mooring buoys are needed at Icacos Island at both the beach entry site and La Tortugas Reef. Currently, there are only three mooring buoys at each location and yet there can be up to eight large tour operation vessels at the reef each day. Often times the commercial moorings are utilized by recreational vessels visiting the Reserve. On one given weekend day I counted 175 small vessels at the reef. These private vessels do utilize the moorings making it difficult for large catamarans to anchor in a safe location. Key informants from both dive operations based out of Fajardo refuse to visit reefs with damaged or missing moorings. This puts more visitor strain on the only reefs they can visit and can affect carrying capacities at frequently visited dive sites.

Other adaptive measures key informants supported included increased policing within the reserve reefs (especially during peak season and holidays), enforcing of the Reserve rules, and sharing of Reserve rules and regulations with all stakeholders including private boat owners, fishers, and other tourism-related operators visiting the Reserve. Key informants felt that more enforcement for better compliance by recreationists not affiliated with snorkeling excursions is needed at the Reserve. Additional research needs to be conducted to determine what impacts these smaller vessels and the activities they are participating in have at the reef and should be included in a larger vulnerability assessment.

Several key informants interviewed stated they felt they were not aware of all of the policies and regulations for the Reserve which suggests consistent operator workshops (A Coral Reef Task Force Local Action Strategy) are needed and may help improve communication between government officials, managers, and commercial operators. It is recommended that tour operators be involved when management plans and decisions for La Cordillera Nature Reserve are revised. Such measures can increase compliance.

6.5 Concluding Thoughts

This dissertation should inform management decisions designed to mitigate the impacts that dive and snorkel tourism have on coral reef systems in order to decrease the overall vulnerability of these systems. The island of Puerto Rico is a tourism-dependent economy and depends on coral reefs and their resources for the demands of the industry. Recommended measures can be implemented to reduce the vulnerability of the system which then can continue to provide benefits to those who depend on this economy for their livelihood and well-being. The recommended management strategies discussed in this dissertation are a necessary component for improving and maintaining the coral reefs within La Cordillera Nature Reserve, Puerto Rico. Increasing adaptive capacity and implementing management actions to reduce vulnerability, specifically actions that decrease exposure is a tangible possibility. Reducing contacts is one such measure. Actions to encourage pro-environmental behaviors at the reef include revising briefings that reinforce etiquette at the reef and social norms that empower snorkelers, and both certified and non-certified divers to make a greater effort to not contact the reef. Crew should consider the skill and perceptions of their guests, mooring use, in water supervision, interventions, attending best practices workshops, and emphasis on the content and delivery of coral reef etiquette messages.

When snorkelers and divers return home (whether tourists or residents), it is important that they had a good experience, gained a greater awareness and appreciation of coastal marine ecology, and learned how to behave responsibly around coral reef ecosystems. This is vital for reducing the vulnerability of coral reefs to recreational activities, conserving these ecosystems, and sustaining the tourism economy of Puerto Rico and beyond.

6.6 References

Allison, W.R. (1996). Snorkeler damage to reef corals in the Maldive Islands. *Coral Reefs*, *15*(4), 215-218. https://doi.org/10.1007/BF01787454

Anthony, K.R.N., Marshall, P. A., Abdulla, A., Beeden, R., Bergh, C., Black, R., Eakin, C.M., Game, E.T., Gooch, M., Graham, N.A.J., Green, A., Heron, S.F., van Hooidonk, R., Knowland, C., Mangubhai, S., Marshall, N., Maynard, J.A., McGinnity, P., McLeod, E., Mumby, P.J., Nyström, M., Obura, D., Oliver, J., Possingham, H.P., Pressey, R.L., Rowlands, G.P., Tamelander, J., Wachenfeld, D., & Wear, S. (2015). Operationalizing resilience for adaptive coral reef management under global environmental change. *Global Change Biology*, *21*(1), 48-61. https://doi.org/10.1111/gcb.12700

Appeldoorn, R., Yoshioka, P., Ballantine, D. (2009). Coral reef ecosystem studies: Integrating science and management in the Caribbean. *Caribbean Journal of Science, 45*(2-3),134-137. https://doi.org/10.18475/cjos.v45i2.a2

Barker, N.H.L. (2003). *Ecological and socio-economic impacts of dive and snorkel tourism in St. Lucia, West Indies* (Doctoral dissertation, University of York). ProQuest Dissertations and Theses Global.

Brown, K., Tompkins, E., & Adger, W. (2002). *Making waves: Integrating coastal conservation and development.* Earthscan. https://www.academia.edu/40512533/Making_Waves_Integrating_Coastal_Conservation_and_Development

Burke, L., Reytar, K., Spalding, M., & Perry, A. (2011). *Reefs at Risk Revisited*. World Resources Institute. https://www.wri.org/publication/reefs-risk-revisited

Cinner, J.E., Huchery, C., MacNeil, M. A., Graham, N.A.J., McClanahan, T.R., Maina, J. Maire, E., Kittinger, J.N., Hicks, C. C., Mora, C., Allision, E.H., D'Agata, S.D., Hoey, A., Feary, D.A., Crowder, L., Williams, I.D., Kulbicki, M., Vigliola, L., Wantiez, L.,…Mouillot,D. (2016). Bright spots among the world's coral reefs. *Nature, 535*(7612), 416-419. https://doi.org/10.1038/nature18607

Fox, H.E., Pet, J.S., Dahuri, R. & Caldwell, R.L. (2003). Recovery in rubble fields: Long-term impacts of blast fishing. *Marine Pollution Bulletin,46*(8):1024-1031. https://doi.org/10.1016/S0025-326X(03)00246-7

Frieler, K., Meinshausen, M., Golly, A., Mengel, M., Lebek, K., Donner, S.D. (2013). Limiting global warming to 2°Celsius is unlikely to save most coral reefs. *Nature Climate Change, 3,* 165 – 170. http://doi.org/10.1038/nclimate1674

Gardner, T.A., Côté, I.M., Gill, J.A., Grant, A., & Watkinson, A. R. (2003). Long-term region-wide declines in Caribbean corals. *Science*, *301*(5635), 958-960. https://doi.org/10.1126/science.1086050

Hall, V. R. (2001). The response of *Acropora hyacinthus* and *Montipora tuberculosa* to three different types of colony damage: Scraping injury, tissue mortality and breakage. *Journal of Experimental Marine Biology and Ecology*, *264*(2), 209-223. https://doi.org/10.1016/S0022-0981(01)00318-5

Harriott, V.J., Davis, D., & Banks, S.A. (1997). Recreational diving and its impact in marine protected areas in eastern Australia, *Ambio,26*, (3),173-179.

Hawkins, J.P. & Roberts, C.M. (1992). Effects of recreational SCUBA diving on fore-reef slope communities of coral reefs. *Biological Conservation*, *62*(3), 171-178. https://doi.org/10.1016/0006-3207(92)91045-T

Hawkins, J.P., Roberts, C., Van't Hof, T., De Meyer, K., Tratalos, J., & Aldam, C. (1999). Effects of recreational scuba diving on Caribbean coral and fish communities. *Conservation Biology, 13*(4), 888-897. https://doi.org/10.1046/j.1523-1739.1999.97447.x

Hernández-Delgado, E.A. (2005). *Natural history, characterization, distribution and current status of Puerto Rico coral reefs. Puerto Rico biodiversity: Terrestrial vertebrates and ecosystems.* Natural History Series. San Juan, Puerto Rico: Editorial Instituto de Cultura Puertorriqueña, 281-356.

Kay, A.M., & Liddle, M.J. (1989). Impact of human trampling in different zones of a coral reef flat. *Environmental Management*, *13*(4), 509-520. https://doi.org/10.1007/BF01867685

Krieger, J.R. & Chadwick, N.E. (2013). Recreational diving impacts and the use of pre-dive briefings as a management strategy on Florida coral reefs. *Journal of Coast Conservation*, *17*(1), 179-189. https://doi.org/ 10.1007/s11852-012-0229-9

Jackson, J.B.C., Donovan, M.K., Cramer, K.L., & Lam, V.V. (2014). *Status and trends of Caribbean coral reefs: 1970-2012.* Global Coral Reef Monitoring Network, IUCN. https://portals.iucn.org/library/efiles/documents/2014-019.pdf

Liddle, M.J. (1991). Recreation ecology: Effects of trampling on plants and corals. *Trends in Ecology and Evolution*, *6* (1), 13-17. https://doi.org/ 10.1016/0169-5347(91)90141-J

Liddle, M.J. & Kay, A.M. (1987). Resistance, survival and recovery of trampled corals on the Great Barrier Reef. *Biological Conservation*, *42*(1), 1-18. https://doi.org/10.1016/0006-3207(87)90049-8

Medio, D., Ormond, R. & Pearson, M. (1997). Effect of briefings on rates of damage to coral by SCUBA divers. *Biological Conservation*, *79*(1)*,* 91-95. https://doi.org/10.1016/S0006-3207(96)00074-2

Plathong, S., Inglis, G., & Huber, M. (2000). Effects of self-guided snorkeling trails on corals in a tropical marine park. *Conservation Biology, 14*(6),1821-1830. http://doi.org/10.1111/j.1523-1739.2000.99301.x

Prior, M., Ormond, R., Hitchen, R., & Wormald, C. (1995). The impact of natural resources of activity tourism: A case study of diving in Egypt. *International Journal of Environmental Studies, 48*(3-4), 201-209. https://doi.org/10.1080/00207239508710990

Riegl, B. & Velimirov, B. (1991). How many damaged corals in Red Sea reef systems? A quantitative survey. *Hydrobiologia, 216-217*(1), 249-256. https://doi.org/10.1007/BF00026471

Roberts, C. M. (1997). Connectivity and management of Caribbean coral reefs. *Science, 278*(5342),1454-1457. http://doi.org/ 10.1126/science.278.5342.1454

Roche, R.C., Harvey, C.V., Harvey, J.J., Kavanagh, A.P., McDonald, M., Stein-Rostaing, V.R., & Turner, J.R. (2016). Recreational diving impacts on coral reefs and the adoption of environmentally responsible practices with the SCUBA diving industry. *Environmental Management, 58*(1), 107-116. https://doi.org/10.1007/s00267-016-0696-0

Rouphael, A. & Inglis, G. (2001). “Take only photographs and leave only footprints”?: An experimental study of the impacts of underwater photographers on coral reef dive sites. *Biological Conservation*, *100*, 281 – 287. http://doi.org/10.1016/S0006-3207(01)00032-5

Sheppard, C. & Loughland, R. (2002). Coral mortality and recovery in response to increasing temperature in the southern Arabian Gulf. *Aquatic Ecosystem Health Management, 5*(4), 395-402. https://doi.org/10.1080/14634980290002020

Smith, S.H. & Marx, D.E. Jr. (2015). De-facto marine protection from a navy bombing range: Farallon De Medinilla, Mariana Archipelago, 1997-2012. *Marine Pollution Bulletin, 102*(1)187-198. http://doi.org/10.1016/j.marpolbul.2015.07.023

Stephenson, R. (2008). *An evaluation of the naturalist on board interpretive program in the Flower Garder Banks National Marine Sanctuary*. (Doctoral Dissertation). San Marcos, Texas, 1 – 349.

Stobart, B., Teleki, K., Buckley, R., Downing, N., & Callow, M. (2005). Coral recovery at Aldabra Atoll, Seychelles: Five years after the 1998 bleaching event. *Philosophical Transactions of the Royal Society, 363*, 251-255. https://doi.org/10.1098/rsta.2004.1490

Talge, H. (1990). Impact of recreational divers on coral reefs in the Florida Keys. In: *Proceedings of the American Academy of Underwater Science 10th Annual Scientific Diving Symposium*, 364-374.

Thapa, B., Graefe, A.R., & Meyer, L. (2006). Specialization and marine based environmental behaviors among SCUBA divers. *Journal of Leisure Research, 38*(4)*,*601-615. https://doi.org/10.1080/00222216.2006.11950094

Tratalos, J. & Austin, T. (2001). Impacts of recreational SCUBA diving on coral communities of the Caribbean island of Grand Cayman. *Biological Conservation*, *102*, 67-75. http:doi.org/10.1016/S0006-3207(01)00085-4

Webler, T. & Jakubowski, K. (2016). Mitigating damaging behaviors of snorkelers to coral reefs in Puerto Rico through a pre-trip media-based intervention. *Biological Conservation, 197*, 223-228. https://doi.org/10.1016/j.biocon.2016.03.012

Wooldridge, S. & Done, T. (2009). Improved water quality can ameliorate effects of climate change on corals. *Ecological Applications, 19*(6),1492-1499. https://doi.org/10.1890/08-0963.1

United States Coral Reef Task Force (2016). *U.S. Coral Reef Task Force Strategy FY2016 -2021*. https://data.nodc.noaa.gov/coris/library/NOAA/CRCP/other/USCRTF/uscrtf_strategy_2016_2021.pdf

Appendix A

Snorkeler Survey Instrument

A research project funded by the National Oceanic and Atmospheric Administration (NOAA) and their Fisheries Habitat Conservation Program Office and the non-profit Social and Environmental Research Institute (SERI).

We are asking snorkelers to self-report on their snorkel experiences in Puerto Rico. This information will be used to manage the coral reef resource so that visitors can continue to enjoy their beauty. The survey is voluntary and completely anonymous.

Results will be published at: www.seri-us.org

Instructions: This survey should take less than 10 minutes to answer. *It is critical that you complete the entire survey.*

Please think about **only one of the snorkel experiences you did today** when answering the questions. It can be the last snorkel you did or whichever one is easiest for you to remember best. The questions pertain to **only one snorkel** you have selected to tell us about.

What was your total time snorkeling? __________minutes.

Did you use an underwater camera *at all* during the snorkel?
□ YES □ NO

Did you feed fish *at all* during the snorkel?

□ YES □ NO

Did you collect conch, shells, coral, or any other sea life (living or dead) during the snorkel?

□ YES □ NO

In the last 12 months, do you recall seeing or hearing **public service announcements** about ways to protect coral reefs? *Please check all that apply*.

□ On TV □ On the radio

□ On the internet
□ At the airport
□ In a brochure
□ None
□ On a billboard
□ In a magazine
□ Other__________

Was a briefing given today about proper snorkeling etiquette at the reef?

□ YES □ NO

How would you classify your snorkeling skill?

□ Beginner

□ Intermediate

□ Advanced

We need an accurate picture of how divers interact with the reef. The questions are **not** intended to judge you. This survey is completely anonymous. Please give honest reports of your dive experience.

While still focusing only on the same snorkel, please *write the number of times you did these things during the dive,* whether they were accidental or on purpose.

Interaction with the Reef	**Number of times during the dive**
My fin action stirred up silt near the reef	
I kicked the reef with my fins	
My body brushed the reef	
I stood, sat, or kneeled on the reef	
I touched the reef with my hands	
I grasped the reef	
My camera touched the reef	
My equipment touched the reef	
I broke a piece of coral	
I touched something living other than coral	
I picked up shells or other marine invertebrates	

Now we would like to ask you a few questions about **how satisfied you were** with today's snorkel trip.

Please circle the best answer.

Snorkel Trip Experiences	**Not at all Satisfied**	**Slightly Satisfied**	**Moderately Satisfied**	**Very Satisfied**	**Extremely Satisfied**
Equipment fit and comfort	1	2	3	4	5
On-board hospitality	1	2	3	4	5
Other people on the trip	1	2	3	4	5
Guide's knowledge of the ecosystems	1	2	3	4	5
Safety conditions	1	2	3	4	5
Water visibility	1	2	3	4	5
Seeing a healthy reef	1	2	3	4	5
Seeing diverse marine life	1	2	3	4	5
Cost of the trip	1	2	3	4	5
Overall, with today's diving experience	1	2	3	4	5

Is Puerto Rico your primary residence at the present time?
□ YES □ NO

What is your gender?
□ FEMALE □ MALE

Please use this space to offer any additional insights into diver behavior at coral reefs:

Appendix B
Key Informant Interview Instrument

1. Describe your experience and familiarity with recreational diving and snorkeling in Puerto Rico.

2. How did you become involved in the industry?

3. Identify the reef locations where your vessel regularly takes divers/snorkelers on excursions.

4. What factors help you decide which site to visit each day?

5. How does weather factor into your decision?

6. How does the quality of the reef factor into your decision?

7. How does visitor satisfaction or experience enter into your decision?

8. Do you feel you can accurately estimate the number of people from your vessel that visit the reef?

9. How many dive or snorkel vessels do you feel is acceptable at the reef?

10. Do you provide a briefing on board your vessel? If so, what are the main messages you provide divers/snorkelers?

11. Do you use a mooring buoy at each reef site visited?

12. In your opinion, what is the best way to ensure that coral reefs remain healthy for future generations to enjoy?

13. Do you believe recreational scuba divers damage coral reefs?

14. Do you believe recreational snorkelers damage coral reefs?

15. Do you believe dive instructors, dive masters, crew, and staff should correct divers and snorkelers whose behavior could be damaging to the coral reef?

Appendix C

Key Informant Informed Consent Form

Dear ___________________________________,

Thank you for your interest in my doctoral dissertation research. The purpose of this letter is to inform you about my research and to obtain your written permission to use the information discussed in our interview.

Purpose of my research:

The purpose of my research is to develop a methodology to assess the vulnerability of coral reefs in Puerto Rico to recreational stressors caused by snorkeling and scuba diving. This methodology will be demonstrated at select reefs within La Cordillera Nature Reserve. I would like to gain a better understanding of how you and the crew you work alongside make key decisions about which reefs to visit as well as how you prepare visitors for the experience of diving and snorkeling.

I am asking you to participate in a 45-minute, audio recorded, interview to talk about your work. All personal information will be kept confidential. I will provide an opportunity for you to examine, edit, and approve our original interview transcript. I would also like your confirmation of my interpretations of what you said. Within 30 days of the interview I will mail you a copy of the interview transcript along with any written interpretations that I make. You will then have the opportunity to make any edits and then return the transcript to me in a stamped return addressed envelope. In the case that I need further clarification about anything you said during the interview, I may contact you for follow up questions.

Research Consent

I ____, permit Karin Jakubowski the full use of this information (including audio tapes and transcriptions and all other materials in this interview), and herby grant and assign to Karin Jakubowski all rights pertaining to this information, whether or not such rights are known, recognized, or contemplated.

____ ______________

Signature of Participant Date

Understood and agreed to:_______________________________. ______________

Signature of Researcher Karin Jakubowski Date

Appendix D

SCUBA Diver Survey Instrument

A research project funded by the National Oceanic and Atmospheric Administration (NOAA) and their Fisheries Habitat Conservation Program Office and the non-profit Social and Environmental Research Institute (SERI).

We are asking divers to self-report on their dive experiences in Puerto Rico. This information will be used to manage the coral reef resource so that visitors can continue to enjoy their beauty. The survey is voluntary and completely anonymous.

Results will be published at: www.seri-us.org

Instructions: This survey should take less than 10 minutes to answer. *It is critical that you complete the entire survey.*

Please think about **only one of the dives you did today** when answering the questions. It can be the last dive you did or whichever one is easiest for you to remember best. The questions pertain to **only one dive** you have selected to tell us about.

First, what is the name of the reef where you completed this dive?

____
(name of reef or dive site)

What was your total bottom time for the dive? __________minutes.

Did you use an underwater camera *at all* during the dive?
□ YES □ NO

Did you wear gloves *at all* during the dive?
□ YES □ NO

Did you feed fish *at all* during the dive?
□ YES □ NO

Did you collect conch, shells, coral, or any other sea life (living or dead) during the dive?
□ YES □ NO

Did you ever feel uncomfortable controlling your buoyancy during the dive?

□ YES □ NO

In the last 12 months, do you recall seeing or hearing **public service announcements** about ways to protect coral reefs? *Please check all that apply*.

- □ On TV
- □ On the radio
- □ On the internet
- □ On a billboard
- □ At the airport
- □ In a magazine
- □ In a brochure
- □ Other__________
- □ None

Was a briefing given today about proper diving etiquette at the reef?

□ YES □ NO

Did you see a dive instructor or dive master correct someone's inappropriate behavior while at the reef?

□ YES □ NO

How many dives have you logged in your life? ______________

What level of certification do you presently hold? *Check the highest level you obtained.*

- □ None
- □ Enrolled in a SCUBA Course
- □ Open Water
- □ Advanced
- □ Dive Master
- □ Instructor
- □ Other ______________________

Here are some statements that reflect commonly-held beliefs. *Please tell us to what extent you disagree or agree with each statement by circling the best number.*

Strongly Disagree	Disagree	Neutral	Agree	Strongly Agree
1	2	3	4	5
It is my right to collect things at the reef.				
1	2	3	4	5
I do not want a dive instructor or dive master telling me not to touch the reef.				
1	2	3	4	5
Dive instructors and dive masters should correct divers whose behavior could be damaging the coral reef.				
1	2	3	4	5

I am knowledgeable about marine ecology and coral reef ecosystems.
1 2 3 4 5 The so-called "coral reef crisis" facing humankind has been greatly exaggerated.
1 2 3 4 5 The balance of nature is strong enough to cope with the impacts of modern industrial societies.
1 2 3 4 5 The Earth is like a spaceship with limited room and resources.
1 2 3 4 5 Humans are severely damaging coral reefs.

We need an accurate picture of how divers interact with the reef. The questions are **not** intended to judge you. This survey is completely anonymous. Please give honest reports of your dive experience.

While still focusing only on the same one dive, please *write the number of times you did these things during the dive,* whether they were accidental or on purpose.

Interaction with the Reef	**Number of times during the dive**
My fin action stirred up silt near the reef	
I kicked the reef with my fins	
My body brushed the reef	
I stood, sat, or kneeled on the reef	
I touched the reef with my hands/gloves	
I grasped the reef	
My camera touched the reef	
My SCUBA equipment touched the reef	
I broke a piece of coral	
I touched something living other than coral	
I picked up shells or other marine invertebrates	

Now we would like to ask you a few questions about **how satisfied you were** with today's diving trip.

Please circle the best answer.

Diving Trip Experiences	Not at all Satisfied	Slightly Satisfied	Moderately Satisfied	Very Satisfied	Extremely Satisfied
Equipment fit and comfort	1	2	3	4	5
On-board hospitality	1	2	3	4	5
Other people on the trip	1	2	3	4	5
Guide's knowledge of the ecosystems	1	2	3	4	5
Safety conditions	1	2	3	4	5
Water visibility	1	2	3	4	5
Seeing a healthy reef	1	2	3	4	5
Seeing diverse marine life	1	2	3	4	5
Cost of the trip	1	2	3	4	5
Overall, with today's diving experience	1	2	3	4	5

These questions ask about **your beliefs** about coral reefs **in Puerto Rico.** *Please circle the answer that best describes your opinion.*

Strongly Disagree	Disagree	Neutral	Agree	Strongly Agree
1	2	3	4	5
Recreational **SCUBA divers** damage coral reefs.				
1	2	3	4	5
More experienced **SCUBA divers** cause less damage to coral reefs than new divers.				
1	2	3	4	5
Recreational **SCUBA divers** who take underwater photographs damage coral reefs.				
1	2	3	4	5
Recreational **snorkelers** damage coral reefs in Puerto Rico.				
1	2	3	4	5
It is important to me that **dive operators** practice good reef etiquette.				
1	2	3	4	5
It is important to me that **dive operators** do not anchor their boats on the reef.				

1	2	3	4	5

Dive operators should inform customers about how to practice low impact diving.

Is Puerto Rico your primary residence at the present time?

□ YES □ NO

What is your gender?

□ FEMALE □ MALE

Please use this space to offer any additional insights into diver behavior at coral reefs:

Appendix E

Permission to Use Figure 5.2 Mooring Buoy Sketch

From: Werner Schreiner [redacted]
To: Karin Jakubowski [redacted]
Subject: Permission to use your work.

Dear Karin,
You have my consent to use the mooring buoy image I sketched.

Sincerely,
Werner Schreiner

Karin Jakubowski [redacted] wrote:

Dear Werner,

I am an Antioch University student who is writing my dissertation and would like to ask your permission to use your work (mooring buoy sketch) in my dissertation as well as reproduce your work in my dissertation. My dissertation will be published online at the following:
Antioch University Repository and Archive (AURA) which is open access
OhioLINK Electronic Theses and Dissertations Center - which is open access
ProQuest Dissertations and Theses Database - which is a print-on-demand service.
I have included the image and note below, so that you can see exactly how it will appear in my dissertation. If you have any questions please do not hesitate to contact me. If you allow me to use your image, written approval by e-mail would be appreciated.

Thank you,
Karin Jakubowski