Adaptive Governance of Coral Reefs: Cases of Florida and the Caribbean

by

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Abstract

Coral reefs are one of the most imperiled yet one of the most valuable ecosystems on the planet, providing food, medicine, and property protection to hundreds of millions of coastal people all over the world. Coral reefs are being lost at an unprecedented rate throughout their range. In the Florida Reef Tract alone, 98% of hard coral has died due to heat waves, disease, and poor water quality, making modern reefs almost unrecognizable. Given the stress that coral reefs are facing due to human and natural causes, there are two key knowledge gaps that are essential to address: the significance of the losses of culturally important benefits that coral reefs provide to people, and the ways that people are adapting to the rapid loss of coral reefs. This dissertation aims to address both gaps.

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CESM2-LE	Community Earth System Model version 2 large ensemble
CMIP6	Sixth Phase of the Coupled Model Intercomparison Project
CRCP	Coral Reef Conservation Program
CRPA	Florida Coral Reef Protection Act
DHM	Degree Heating Months
ECA	Ecosystem Conservation Area
EPA	Environmental Protection Agency
FDEP	Florida Department of Environmental Protection
FKNMS	Florida Keys National Marine Sanctuary
FWC	Florida Fish and Wildlife Conservation Commission
IPBES	Intergovernmental Science-Policy Platform on Biodiversity and Ecosystem Services
IUCN	International Union for Conservation of Nature
LAS	Local Action Strategies
MPA	Marine Protected Area
NCAR	National Center for Atmospheric Research
NGO	non-governmental organization
NOAA	National Oceanic and Atmospheric Association
SCTLD	stony coral tissue loss disease
SCUBA	Self Contained Underwater Breathing Apparatus
SEFCRI	Southeast Florida Coral Reef Initiative
SPA	sanctuary preservation area

SSP	Shared Socio-economic Pathway
USCRTF	United States Coral Reef Task Force

Chapter 1

Cultural Services of Reefs: The Case of the Cayman Islands MPAs and What Would Be Lost With A Major Infrastructure Project

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1.1. What are Ecosystem Services?

Just after my fifth birthday my father took me fishing for the first time. He set my tiny Mickey Mouse fishing rod on the dock and did his best to explain to me the fundamentals of freshwater fishing. Hooks, bobbers, and bait were the subjects at hand. It seemed very complicated, but I eagerly nodded my head as though I understood the lessons he was teaching me. I was certainly more interested in the excitement of pulling a live fish from the depths than learning the techniques needed to accomplish this feat.

He showed me how to carefully put a worm on the hook and I was ready to go. I dropped the line in the water and expected a quick bite. Nothing. The minutes crept by and it seemed the fish had much less interest than I did. My attention span waned as I sat waiting for something to bite. I began to look around. I heard the water lapping against the dock. The birds calling to one another from the shrubs and trees lining the pond. I smelled the warm Alabama breeze and admired the clouds lazily drifting overhead. There was so much happening, and yet nothing was happening all at once. As the morning turned to afternoon, it was obvious that the fish were not interested in our bait, and we left the pond without catching a thing.

While it's true that we weren't able to get a fish, all was not lost. Something else had stirred in my young mind. For the first time in my life I felt connected to something more. I was only a tiny piece of something greater, something far more connected than I could comprehend at the time. Even though we didn't catch anything, I wanted more. I found value in the connectedness and the beauty of the Alabama ecosystem. I felt like a fisherman. I will always fondly remember this morning on the dock with my father as the first time I truly felt like I had an identity beyond that of a child.

While it is certainly true the ecosystem plays a vital part in providing resources to the humans that inhabit them, in this instance it was the immaterial benefit that I found to be far more valuable. In other words, it was the experience itself over the fresh fish that could have been caught for a meal that was valuable. In this chapter we will dive further into these types of benefits and show the importance of these cultural ecosystem services.

Ecosystem services are defined as the advantages or aid provided to humans from the ecosystem. Several scholars have refined this definition and perhaps the most noteworthy explanation of ecosystem services can be found in the Millennium Ecosystem Assessment published in 2005. The authors define ecosystem services as "the benefits people obtain from ecosystems"

(Millennium Ecosystem Assessment (Program), 2005). Within this broad definition, the benefits provided can be further grouped into four different types of benefits; provisioning services, regulating services, cultural services, and supporting services. These four categories provide us with a reference point with which we can group almost any benefit provided to humans from the ecosystem. It also gives us a starting point to analyze the value these benefits provide to the human population.

The first category provided by the Millennium Ecosystem Assessment are provisioning services. These are defined as anything acquired or extracted from the ecosystem which benefits people such as food, water, timber, oils, natural gas, and a multitude of other resources (Millennium Ecosystem Assessment (Program), 2005). Provisioning services provide living things, and especially humans, with the resources needed to sustain life. Each of us has undoubtedly experienced some benefit from the extraction of at least a few of these resources. How would we survive without food to sustain our bodies, or building materials to construct our homes? Since the first human stepped foot on the Cayman Islands, provisioning services such as food and water have played a fundamental role in sustaining human well being. Life on the Caymans has been tied to the resources which humans can extract from the island, and more importantly, the waters surrounding the island.

The next category is regulating services. Regulating services are the benefits provided by nature that control or regulate natural processes. Pollination, erosion prevention, and carbon storage are examples of regulating services (Millennium Ecosystem Assessment (Program), 2005). Many of the provisioning services, such as food and water would not be possible without regulating services such as pollination or water purification.

The third type of ecosystem services are supporting services. These services include any processes that allow the earth to provide for living things and the ecosystems in which they exist. Photosynthesis, soil formation, and nutrient cycling are all examples of supporting services (Millennium Ecosystem Assessment (Program), 2005). The main distinction in differentiating supporting services from the other categories of ecosystem services are the key words "activities" or "processes." These actions build the foundation for all other ecosystem services.

The fourth and final type of benefit outlined in the Millennium Ecosystem Assessment, and the focus of this chapter, are cultural services. Cultural services are defined as the non-material benefits that aid in the betterment of human culture. This includes benefits from recreational activities, spiritual practices, acquisition of knowledge, and even inspiration provided from the natural setting (Millennium Ecosystem Assessment (Program), 2005). Cultural services even provide individuals and groups with a sense of identity, from which further benefits such as unity and enthusiasm for the future can be derived.

Other scientific organizations have attempted to define ecosystem services as well. Of note, the Intergovernmental Science-Policy Platform on Biodiversity and Ecosystem Services (IPBES) utilizes the same definition ("the benefits people obtain from ecosystems") in their 2019 global assessment report on biodiversity and ecosystem services. IPBES categorizes these services into the same categories (provisioning, regulating, cultural, and supporting services) as the Millennium Ecosystem Assessment (IPBES, 2019).

We chose this definition because it encompasses the wide range of benefits provided by the ecosystem and has been widely accepted among scientists and scholars. Almost any benefit, either material or immaterial, can be grouped into one of these categories. By categorizing these benefits, we can focus our efforts on discussing the merits and values associated with each category. It gives us a chance to disentangle the different ecosystem services from one another and present an informative analysis of each category. In keeping with the Millennium Ecosystem Assessment definition of ecosystem services and the categories used in this definition, in this chapter we will simply define cultural ecosystem services as "the nonmaterial benefits people obtain from ecosystems through spiritual enrichment, cognitive development, reflection, recreation, and aesthetic experiences (Millennium Ecosystem Assessment (Program), 2005) ."

The Millennium Ecosystem Assessment and IPBES are not alone in attempting to group cultural ecosystem services together. Other scholars have grouped cultural ecosystem services into different categories with slightly different definitions, however the services these functions provide are typically the same. Some different names for the same services include "cultural services" (Constanza 1997), "life-fulfilling functions" (Daily 1999), "information functions" (de Groot et al. 2002), "amenities and fulfillment" (Boyd and Banzhaf 2007), "cultural and amenity services" (de Groot et al. 2010, Kumar 2010), or "socio-cultural fulfillment" (Wallace 2007).

A majority of cultural ecosystem services definitions agree that the effect is intangible and often hard to quantify. Because they are hard to define and quantify, this category of ecosystem services has received less attention than the other categories when analyzing their importance and value as they relate to humans. Some scholars have argued that because these benefits are difficult to qualify, they should receive more consideration in future research (Milcu et al., 2013). Because of this, cultural ecosystem services are often not valued appropriately or integrated into management plans (R. de Groot et al., 2022). More often than not cultural ecosystem services are not reflected by surrogate economic indicators such as real estate prices (Carpenter et al., 2009, Martín-López et al., 2009).

1.2. Our approach

To analyze our data we have chosen to use Fish et al's 2016 framework for cultural ecosystem services. Frameworks allow us to study abstract ideas using real world data, and define concepts in concrete terms to compare them across different respondents, in our case, the people who care about the coral reefs of the Cayman Islands. We use two components of Fish et al. 2016's wider framework, the complete details of which are broken down in the Appendix for this chapter. First we focus on their *theory of cultural practices*. These cultural practices are the activities that relate people to each other and the natural world. For example, in the Cayman Islands snorkeling and diving are very popular activities which provide several benefits to the local population. Fish et al. further break down cultural practices into four categories of activities that people engage in, which builds this connection. These categories include playing and exercising, creating and expressing, producing and caring, and gathering and consuming (Fish et al., 2016) .

1.2.1. Cultural Practices and Ecosystem Services

Playing and exercising includes activities which involve some type of physical interaction between people and the natural environment. These can be fitness or leisure activities that could be either individual pursuits or communal endeavors. Important examples of playing and exercising in the Caymanian context include free diving, snorkeling, SCUBA diving, and relaxing on the beach. Out of 175 responses, 100% of respondents reported engaging in this type of activity while visiting the Caymanian reefs.

Creating and expressing activities are defined as those which involve the creation of representations of life, nature, or any other artistic impression. This includes activities such as painting, sketching, writing, poetry, photography, music, or storytelling. Customs, rituals, or performances that emulate or are inspired by the natural environment are also included in this category of cultural practices. Photography is the most popular activity in this category reported in the Caymanian case.

The third type of cultural practice in the framework is *producing and caring*. These activities are defined as those which involve work or leisure activities related to conserving or managing the natural environment. This includes any employment activities that involve conservation or management of natural resources such as agriculture, fishing, environmental volunteering, or scientific research. In the context of the Cayman Islands, fishing outside of the MPA was the most popular type of activity in this category.

The fourth and final type of cultural practice is *gathering and consuming*. These are defined as activities that may occur as either work or leisure endeavors that encompass collecting or consuming products from the natural world. This includes the consumption of local food, gathering of natural products such as wood products, and the consumption of local art, media, or even performances. In the Cayman Islands, gathering of conch from the reef was the most popular activity in this category.

1.2.2. Cultural Ecosystem Benefits

Next we focus on Fish et al's theory of cultural ecosystem benefits. This is best described as the dimensions of human well-being associated with cultural practices. These benefits are further broken down into three parts; identities, experiences, and capabilities (Fish et al., 2016) described in further detail later in this chapter.

Identities are the aspects of the natural world which enable people to connect with their environment to better understand their own existence and meaning. Identities include feelings of belonging, a sense of place, rootedness, and spirituality. *Experiences* are events and the physical or emotional feelings people gain when interacting with the natural environment. Benefits associated with experiences include feelings of tranquility, inspiration, escape, and discovery. *Capabilities* are the benefits from interacting with the natural environment which lead to an individual's ability to learn new skills to better their lives. Examples of capabilities include the gaining of skills or knowledge about the environment or one's self.

We selected a definition of cultural ecosystem services that focuses on centering the voices of stakeholders because cultural ecosystem services are created by the people (“co-produced”), so they're different wherever you go, and the thing that creates them is how people interact with ecosystems. For example, the intangible benefits of inspiration and connectedness that I experienced fishing as a youth wasn't something I simply plucked from the pond. They were formed within my mind, my interaction with the natural world, and synergized through my interactions with my father.

Understanding cultural ecosystem services can be difficult. The primary reason for understanding their values and importance is because of the intangibility of these services. Many of the benefits obtained from cultural ecosystem services are nondescript and instinctual (Kenter et al., 2011). Oftentimes, observation of these benefits aren't as obvious or pronounced as provisioning and regulating services. They cannot be observed directly and we must utilize other indicators to gain an understanding of their value (Anthony et al., 2009). Critics of the Millennium Ecosystem Assessment have argued that this definition of cultural ecosystem services does not clearly delineate the differences between the services ecosystems provide, the benefits associated with these services, and how these benefits should be valued (Chan et al., 2012).

1.3. Potential Loss of Reefs to Infrastructure

In the Cayman Islands, tourism is a major industry. Most of the tourists that visit the island arrive on cruise ships in George Town Harbour. In 2013 the Caymanian government announced that it would seek to expand its current cruise berthing facility in a project that would include construction of an additional pier, land reclamation, and dredging operations. The government was concerned that the major cruise operators such as Royal Caribbean and Carnival Cruise would bypass the Cayman Islands in favor of ports with more accessible amenities[1]. After years of intense debate among citizens, the government, and interest groups, the situation reached a tipping point. Opponents of the project gathered the signatures of over 25% of eligible Caymanian voters in order to prompt a people's initiated referendum in which the question of the expansion of the cruise berthing facility would be put to a vote. After a delay due to the lack of a legal precedent of a referendum and procedural questions about how votes would be tallied, the vote was scheduled for 2020. However, due to the COVID-19 pandemic, the vote was indefinitely paused and the expansion project was shelved. The current Caymanian government has claimed that they will not pursue the project further, however it is likely the same interest groups who initially pushed for the expanded infrastructure project will continue to advocate for a similar project in the future (Bailey et al., 2022). Our research asks how cultural services would be impacted by a major infrastructure project that would result in a significant loss of coral reef ecosystems.

[1] The current cruise berthing facility is a tender port in which passengers are ferried between the ship and the island. The proposed expansion project would allow large cruise ships to dock directly at the piers, simplifying the movement of passengers on and off of the cruise ships.

1.4. Cultural Services of Caymanian Reefs

Table 1 displays the most popular reef locations according to respondents living on the Cayman Islands, with the proposed port expansion project potentially impacting all of the most popular reefs through the negative impacts of dredging. All reefs in these systems fall under one or more statutory protections for coral reefs including falling within an Marine Protected Area (MPA) and/or containing threatened and endangered species.

Table 1: *Most popular reefs*

Location	**Percentage of responses that mention site (*n*=176)**
Eden Rock	0.40
George Town Harbour	0.17
Macabuca	0.12

Of the four categories of cultural ecosystem benefits, experiences were the most important to Caymanians (80 percent of statements mentioned this category), followed by identities (25 percent of statements), capabilities (21 percent of statements), and other benefits that don't clearly fall into one of the other categories (11 percent of statements). Table 2 contains this breakdown. This suggests of primary importance to Caymanian coral reef stakeholders are services involving experiences to the greatest degree. An example was feeling a sense of wonder while diving on Eden Rock, a grotto-like cave system filled with tiny silvery fish in the summer.

Table 2: *Portions of statements containing each type of cultural ecosystem benefit*

Concept	Portion of statements with concept mentioned
Identities	0.25
Experiences	0.80
Capabilities	0.21
Other	0.11

Of the four concepts for cultural practices, playing and exercising were the most important (100 percent of statements mentioned this category), followed by producing and caring (21 percent of statements), gathering and consuming (18 percent of statements), and creating and expressing (2 percent of statements). Table 3 contains this breakdown. This suggests of primary importance to

Caymanian coral reef stakeholders are practices involving playing or exercising to the greatest degree, followed by producing and caring as well as gathering and consuming which are nearly tied in terms of their relative importance. The following section provides examples of each type of statement from respondents to clarify meaning.

Table 3: *Portions of statements containing each type of cultural ecosystem service*

Concept	Portion of statements with concept mentioned
Playing and exercising	1.0
Creating and expressing	0.02
Producing and caring	0.21
Gathering and consuming	0.18

1.4.1. Experiences on the Reef

Cultural benefits related to experiences were the most important types of cultural services to respondents in this study. Statements touching on experiences were often focused on specific reefs that respondents liked to spend time on, such as Eden Rock, South Sound, or the popular wreck dive of the U.S.S. Kittiwake, which according to the words of one respondent constitute "places of healing for the people." Experiencing the reef took place via glass bottom boats, snorkeling, diving, accessing reefs via sailboat, and others suggesting these livelihoods are linked to the cultural benefits.

Many of the statements on experiences noted that Caymanian reefs are easy to get to, with access often coming directly from shore. This means that not just those with access to a boat or funds to purchase a seat on a charter boat have access to Caymanian reefs. The following statement is representative of this concept:

> *"Eden Rock is one of the most beautiful reefs. I remember diving through the tunnels and seeing the huge tarpon swim by. I felt one with nature, and awe inspired by the incredible beauty. I also love that it is swimmable from the shore. It's one of the best snorkel spots on this side of the island"*

1.4.2 Reefs as Caymanian Identity

Cultural services related to Caymanian identity followed three patterns with statements having to do with 1) who Caymanians are as a culture, 2) how reefs are important parts of cherished memories going all the way back to childhood, and 3) how reefs are linked to spirituality. First, respondents saw coral reefs as an essential part of what it means to be a Caymanian person. For example, respondents would make statements about how they knew that reefs were symbolic of their "home" of the Cayman Islands, or that Caymanians have something special or rare in their reefs and this is an essential part of Caymanian culture. This sentiment is evidenced in the following statement:

> *"I enjoyed knowing this is my home and we have something special that many rarely (if ever) have the opportunity to experience, and yet this underwater world that is outside my doorstep [and] is something I can experience at any time- with respect and appreciation*."

The second type of statement about reefs being a part of Caymanian identity include ones that reminisce about spending time on reef from early childhood through adulthood, and how these experiences shaped their current lives as adults.

> *"I have been snorkeling all these reefs since I was 2 and diving since I was 10. They are still and always will be fascinating and dear to me. Each time I snorkel or dive it is like it is the first time yet it feels like I am visiting my old neighborhood again! I never get tired or bored even though I know each part of these reefs intimately. My best friend and I made a pact when I was 17 that we will still be diving these reefs when we are in wheelchairs!"*

The third and final component of identity based cultural benefits has to do with finding a form of spirituality on the reefs, broadly defined. These statements often touched on ideas of divinity or god. Take for example the following representative statement: "In awe of the creative power of God. The colors and varieties of sea life gives me a sense of peace and wonder." Another example of spirituality among respondents includes the following statement:

> *"I view my world through a secular lens but if there were any spiritual experiences I could credit to developing both my soul and psyche it would be due to the being of a human - simply being - amongst the rich tapestry of biodiversity and Creation that are the reefs of the Cayman Islands*."

1.4.3. Learning on the reef

Statements involving capabilities were made by respondents acquiring knowledge or engaged in conservation for their jobs or as volunteers. Often, statements focused on teaching one's children about biodiversity and conservation by bringing them to the reefs of the Cayman Islands. The words of the following respondent are characteristic of this type of cultural benefit:

> *"I had my two children holding each others' hands as we snorkeled. We would stop and dive down to look under huge coral heads and see the lobsters' antennae and fish hovering there. Once a large moray eel came out and surprised us. It was like introducing them to a magic world - pointing at all the extraordinary creatures and the joy when they spotted something amazing."*

The importance of transmitting knowledge to future generations was valued by respondents on its own, but also as a mechanism for conservation. Educating young children about the importance of biodiversity conservation is one way to ensure that conservation is a priority to younger generations.

1.4.4. Playing and exercising on the reef

The cultural practice of playing and exercising was the most important cultural practice to the Caymanian people. 100% of respondents reported engaging in some sort of playing or exercising activity while visiting the reefs around the islands. Examples of these practices from respondents include snorkeling, diving, and relaxing on the beach. This sentiment is shown in the words of this Caymanian respondent:

> *"I have dived the Georgetown reefs so many times! The last time I dived Eden Rock when the silversides were in was the most magical ever! I spent an entire two hours underwater, most of that time was spent just lying on the sandy bottom in one of the tunnels watching the silversides. I was absolutely mesmerized!"*

1.4.5. The importance of recreational fishing

The cultural practice of producing and caring was the second most reported practice by Caymanian respondents (21% of responses). The most popular practice reported pertained to fishing in or around the islands for species like grouper and snapper. The following response shows just how pronounced this practice is for the Caymanian people:

> *"As we are a premium dive and tourist destination our pristine waters and the beautiful reefs and supporting marine life are of paramount importance. Many locals livelihood and even food source depend on a healthy marine environment so this needs to be protected by all means necessary."*

1.4.6. Local taste for shellfish

Gathering and consuming was the third most reported cultural practice reported by Caymanian respondents (18% of responses). Of note, respondents generally reported gathering conch and lobster from the reef as an example of a gathering and consuming cultural practice. To illustrate the importance of this practice one Caymanian responded "The reefs are life-sustaining to the island… Not just to the underwater ecosystem, but the reefs define Cayman. they are not an accessory."

1.5. Losses of Cultural Services with Major Infrastructure Projects

The previous section has shown that with negative ecological impacts to popular sites such as Eden Rock and the reefs of the Georgetown Harbour accompany a loss of ecosystem services. These services include experiences like accessing reefs via glass bottom boat, Caymanian identity which links the reefs to Cayman way of life, and potential teaching and learning about biodiversity. People's ability to exercise, play, fish, and harvest shellfish will be lost if major infrastructure projects are allowed.

We asked respondents if they would still visit these sites for cultural reasons if the quality and clarity of the water were degraded. Opinions were split, however 41% of respondents reported they would be less likely to visit the reefs (Figure 1). Additionally we asked respondents about the role of coral reefs in Caymanian culture (Figure 2) and identity (Figure 3). Almost all respondents were in agreement that the reefs were an important part of Caymanian culture, with over 91% responding that they "Strongly Agree" with the sentiment, and 85.7% "Strongly Agree" that the reefs were an important part of Caymanian Identity.

Figure 1: *Responses to the question: "If the water was cloudy in the Georgetown Harbour, would you visit the reefs (Eden Rock, Devil's Grotto) less?"*

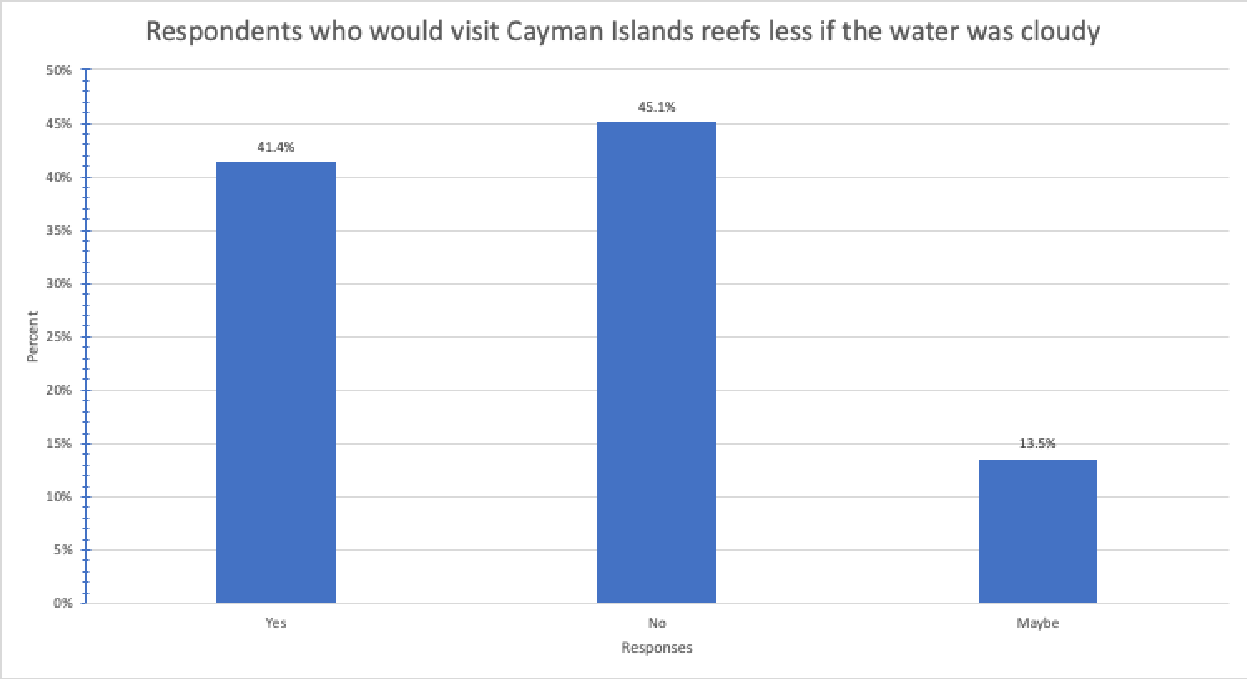


Figure 2: *Respondents agree with the statement "Coral reefs are an important part of Caymanian culture."*

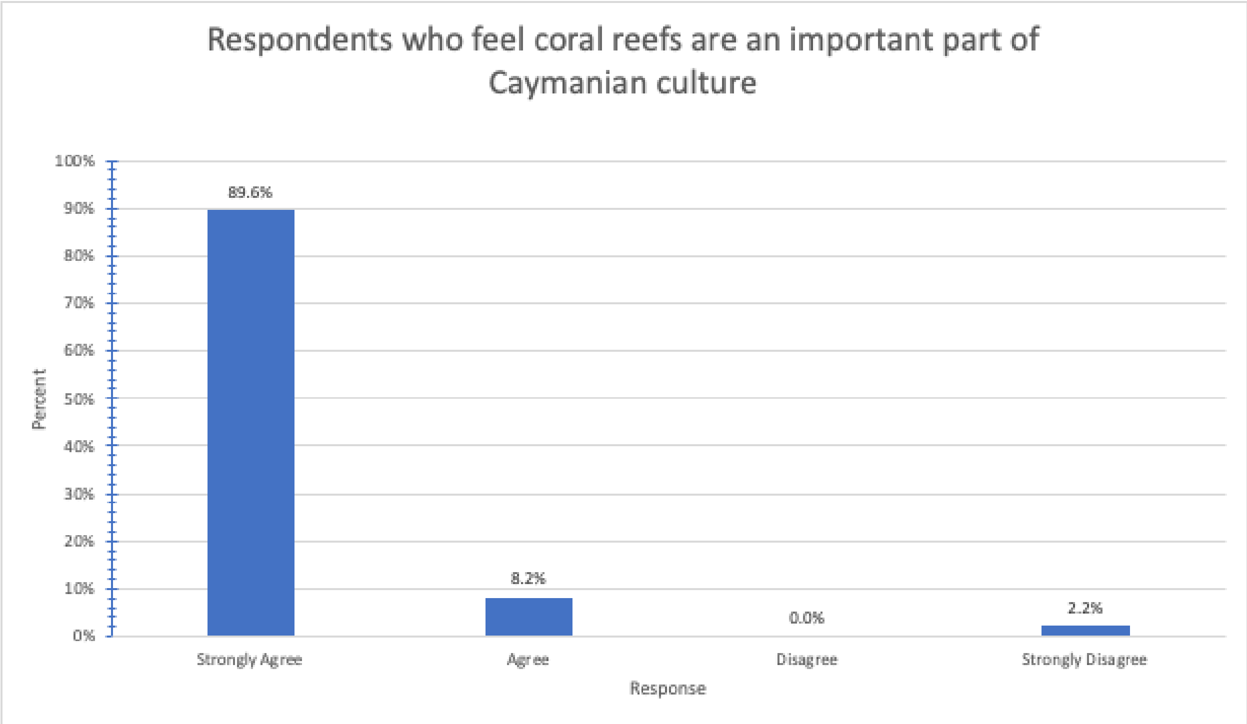
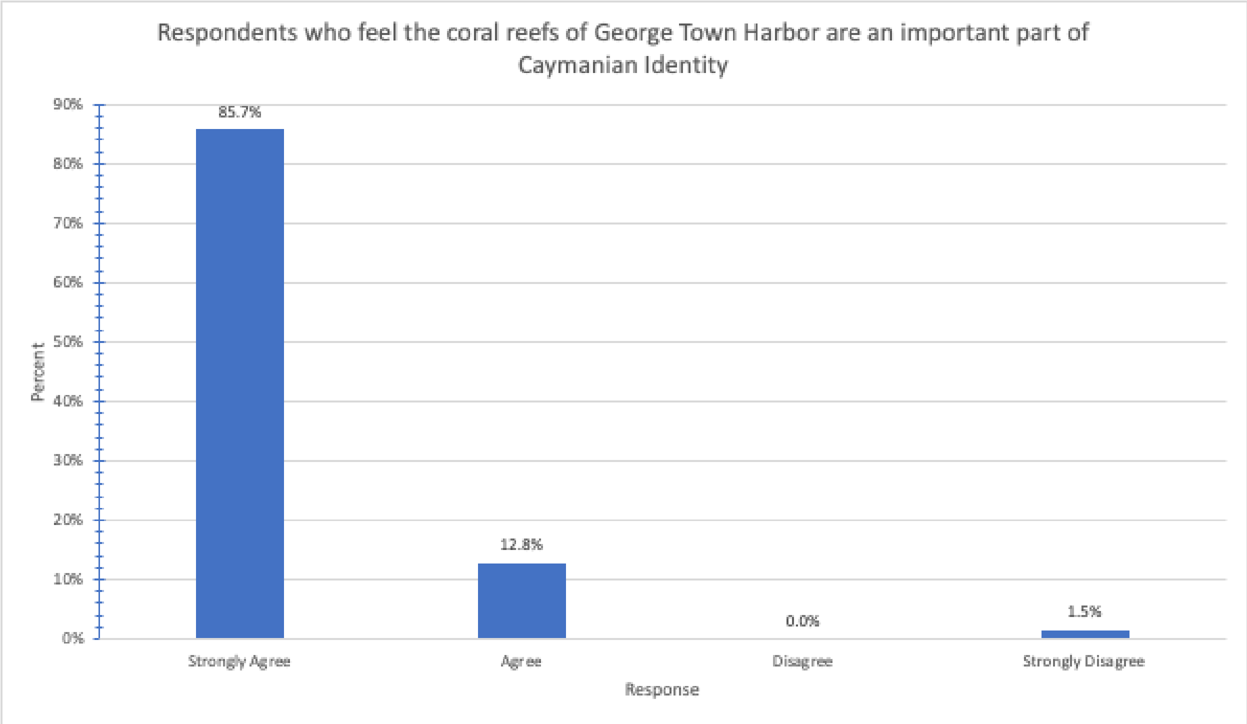


Figure 3: *Respondents agreement with the statement "The coral reefs of George Town Harbour (Eden Rock, Devil's Grotto) are an important part of Caymanian identity."*



Additionally, Caymanians felt very strongly about the potential loss of the reefs around the islands. When asked "If the coral reefs of the Cayman Islands were to be destroyed, how would you feel?" Respondents used powerful, emotional words like devastation, sadness, and betrayal when describing their feelings. The following statements characterize a majority of the responses Caymanians provided to this question: "Devastated. It would be hard for me to look my son in the eye. It would be difficult to show him pictures of what was once there." Another respondent said the following: "[I would feel] Very sad and distraught. The one thing that made us so unique has now gone and we have nothing left to boast about being the best island in the Caribbean." Additional responses include the following representative statements:

> *"Heartbroken. It makes me want to cry thinking about it, actually. Destroying these places in the harbour would not only affect Caymanians, but those of use who have grown to love this island like our second home. Cayman is UNIQUE (sic). We don't need another harbour town cruise stop. We need the unique beauty and splendor of the natural creation in Cayman. To undo this would be a travesty."*

> *"I would feel very sad that this important part of Cayman's culture has been lost, and also very angry that our greedy politicians were willing to sacrifice George Town Harbour, and very likely Seven Mile Beach, instead of preserving it for our children, grandchildren and all future generations of Caymanians."*

1.6. Conclusion

While many of cultural ecosystem services may be intangible or hard to quantify, this research should help bridge the gap in appropriately assessing the value these resources provide to the Caymanian people, beyond the provisioning, supporting, and regulating services of coral reefs. Without assessing the cultural benefits, enabled by cultural practices in the Cayman Islands, we do not get a clear picture of the full value of these resources and the importance they hold for the people who rely on these resources every day. Consideration of the cultural values of an ecosystem should be carefully analyzed by decision makers when considering trade-offs related to the alteration or loss of a specific resource, such as the potential loss of coral reef cover due to the proposed cruise berthing facility expansion in the Cayman Islands. This case study provides us with a clear example of how stakeholders opinions related to a resource hold value and matter to the user groups who rely on these resources. Much like my experience fishing as a young man, there is much to gain from properly managing these resources and protecting them for the benefit of future generations.

Chapter 2

How changes projected by climate models inform adaptation policies for vulnerable ecosystems in the Florida Keys National Marine Sanctuary

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ABSTRACT

Coral reefs are highly important ecosystems providing habitat for a large variety of marine life. However they face immense risks from climate change. To date, climate models have aided global discussions on possible policy responses, but tailored climate projections at a useful scale for ecosystem managers are often prohibitively expensive to produce. Model outputs can be difficult to understand and therefore use in decision-making. Our research addresses these challenges by presenting a novel type of collaborative, participatory research that integrates 1) site specific climate metrics from the Community Earth System Model version 2 large ensemble (CESM2-LE), 2) ecosystem response models to determine Degree Heating Months and coral bleaching impacts, and 3) collaborative social science data from decision-maker engagement to see how managers are enacting adaptive governance of coral reefs, stewarding them through climate impacts of the future. We use simple, compelling narratives referred to as *scenarios* to present CESM2-LE projections for coral reef impacts in 10 and 20 years on one of the most popular reefs in the Florida Keys National Marine Sanctuary (FKNMS), focusing on this site because management actions and ecosystem condition relationships are strong. 42 interviews and 382 public stakeholder comments analyzed deductively suggest that experimental methods for ensuring inclusive stakeholder dialogue, as well as rapidly scaling up coral restorations, are major responses to climate impacts in FKNMS. Results are relevant to managers of all climate vulnerable systems, with our proposed novel interdisciplinary methods blending climate and social science as an essential next step to understand our options to adapt to climate change.

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2.1 INTRODUCTION/BACKGROUND

Floridians have witnessed the world's third largest barrier reef, the 564 kilometer Florida Reef Tract, rapidly deteriorate to a nearly unrecognizable ecosystem, having lost 95-98% of its living hardcover, reef building coral (NOAA Coral Reef Conservation Program, 2020). The deterioration of coral reefs is disastrous for Floridian communities as reefs generate billions of dollars in tourism, protect communities from storms, and form a core component of Floridian natural heritage and way of life (Wynveen et al., 2013). Climate change is a significant factor in the loss of both Florida and global reefs, with coral reefs among the most climate-sensitive ecosystems on earth, requiring narrow temperature ranges to survive (Hughes, Barnes, et al., 2017; Hughes, Kerry, et al., 2017). Prolonged exposure to elevated temperatures from anthropogenic greenhouse gas emissions as little as ~1°C (1.8°F) above the regional summer maximum can lead to stress and mortality events in coral reefs (Hoegh-Guldberg, 1999; Hughes et al., 2003; Magel et al., 2019). Rising atmospheric carbon dioxide and greater uptake by oceans has led to acidification and biological impacts to corals, showing declines in calcification and the structure of reefs (Feely et al., 2004).

The responsibility for steering the Florida Reef Tract through climate disturbances falls on the federally managed Florida Keys National Marine Sanctuary (FKNMS). FKNMS contains ~60% of the Florida Reef Tract, was established in 1990, and is a prototype American management framework for protecting one of America's most iconic natural and cultural marine resources (*About Your National Marine Sanctuaries | Office of National Marine Sanctuaries*, n.d.). FKNMS is critical to Florida's economy and communities; for example, as of 2022 the FKNMS contributed 43,000 jobs and $4.4billion to Florida's economy ("National Marine Sanctuary Foundation Announces Grants to Scale Up Coral Restoration Through Mission," n.d.). With so much rapid change occurring on the Florida Reef Tract, its decision-makers are faced with a high stakes policy problem demanding urgent and experimental responses that require equal parts science and social science to understand.

Our research is the first of its kind using tailored climate model outputs from the the National Center for Atmospheric Research (NCAR)'s Community Earth System Model (CESM2 Large Ensemble Project), to predict future conditions at some of the most popular FKMNS reefs, and turn these tailored projections into social science questions to engage policy-makers. Climate model outputs used in decision-making exercises (e.g. the Assessment Reports of the Intergovernmental Panel on Climate Change) typically have a coarse resolution, on the scale of 1° due to the high costs and computational intensiveness of the analyses (Frieler et al., 2013; Taylor et al., 2012; van Hooidonk et al., 2015). Discussions of policy-makers at global and regional scales can consider the coarse resolution projections (Lemos & Rood, 2010), but in ecosystems like the FKNMS, policy-makers require more locally-tailored projections, at the scale where human organizations and institutions have management authority and capacity to act (Oreskes et al., 2010).

What makes our approach novel is our prototype process turning climate modeling outputs into a human-scale collaborative learning tool to discuss climate impacts with decision-makers, translate scientific knowledge to them, and co-create current and future adaptation strategies. To do this, we used *scenarios*, or short narrative stories about future conditions, which are widely accepted as a powerful heuristic tool for engaging decision-makers. The greatest challenge of interdisciplinary research teams is differences in terminology or ambiguity in key concepts (Groves & Game, 2016). Between social scientists and climate scientists the word *scenario* means markedly different things. For this paper, we draw a distinction between narrative scenarios, which are stories based on climate model projections, and the emissions scenarios used by climate modelers to drive different potential climate outcomes (e.g., the levels of greenhouse gasses and other radiative forcings that might occur in the future as a result of the different pathways the world could take over the next century). The latest iteration of emissions scenarios used for the Sixth Phase of the Coupled Model Intercomparison Project (CMIP6) are based on a set of so-called Shared Socio-economic Pathways (SSPs) that examine how global society, demographics and economics might change over the next century. In the following, we use the term *pathway*, when referencing the future climate scenario used to force the model. We use the term *scenario* to mean the narrative stories, generated based on the climate model outputs, depicting coral reef outlooks that are used as heuristics to engage decision-makers with social science methods. Due to the resources required to generate tailored climate forecasts, they are rarely used in the published literature to create scenarios in social science questionnaires. Instead, secondary sources of coarser resolution climate forecasts (e.g. scenarios from the Millennium Ecosystem Assessment) are adapted for scenarios (Bohensky et al., 2006). To date, federal and state managers of the FKNMS are using our preliminary data to inform planning.

Our findings are of general interest to coral reef managers, and more broadly to managers of biodiverse ecosystems that are sensitive to climate change. Recent coral reef management literature suggests that scenario-based research is essential for resilience-focused coral reef management (Mcleod et al., 2019). Many of these groundbreaking studies relate climate projections to secondary data on socio-economic responses to reef degradation. McCleod et al. suggest that the process of integrating climate models with ecosystem response models and decision-maker social science data can inform robust strategies for improving adaptive governance (Mcleod et al., 2019). To date however, other research uses biophysical data exclusively to create climate scenarios to examine coral reef resilience (Anthony et al., 2015; Delevaux et al., 2018; Mcleod et al., 2019) but no study has brought the ecological outputs of scenarios to decision-makers themselves, inviting them to the table as co-creators of knowledge. Our research builds on these studies, adding participatory, stakeholder-focused research that asks stakeholders directly how they are adapting to climate change in the FKNMS. Our hope is that this model of research becomes increasingly common, where climate scientists, social scientists, and stakeholders who depend on the resource collaborate to engage in learning that goes in both directions.

The Importance of Coral Reefs

Throughout the world, the importance of coral reefs and the marine ecosystems they create cannot be overstated. For the humans that live and work in these ecosystems, coral reefs are of even more importance. As of 2007, approximately 850 million people in the world live within 100 kilometers of a coral reef and almost certainly experience some benefit from the ecosystem services provided by the reef (Reytar & Burke, 2011). The benefits of these ecosystem services can be provisioning, regulating, cultural, or supporting services (Millennium Ecosystem Assessment (Program), 2005). Despite covering less than 1% of the earth's surface (Moberg & Folke, 1999), coral reefs provide an estimated $375 billion every year in economic value (Babbitt & Daley, n.d.).

Corals in the *Acropora* genus are of particular importance to these ecosystems. Members of the *Acropora* genus, such as elkhorn (*Acropora palmata*) and staghorn (*Acropora cervicornis*) coral are considered reef-builders and are responsible for constructing the structure of reefs with their hard calcium carbonate skeletons. According to the International Union for Conservation of Nature (IUCN), both elkhorn and staghorn corals are considered critically endangered (R. Aronson, 2008b, 2008a). These stony corals have contributed to the creation of vast reef zones in the Western Atlantic and Caribbean Sea, such as the Florida reef tract, in the past 12,000 years (Kuffner et al., 2017). Research has shown that as stony coral cover declines, the abundance of reef fish also declines (Alevizon & Porter, 2015).

To fully understand the value of coral reefs and the benefits they provide, we must first examine the ecosystem services they provide for life on earth. According to the Millennium Ecosystem Assessment [2005], ecosystem services can be categorized into 4 distinct groups; provisioning, regulating, cultural, and supporting services. Provisioning ecosystem services are defined as the material benefits humans gain from extracting a resource from the natural environment such as food, water, oil, pharmaceuticals, and even genetic materials (Millennium Ecosystem Assessment (Program), 2005). The primary resource humans obtain from coral reefs is food, and more specifically, the fish and other marine species that live in the ecosystem that humans consume for subsistence. It is estimated that a quarter of the earth's marine life depends on coral reefs at some point in their lives (US EPA, 2017b). The habitat provided by coral reefs serves as a vital feeding ground, spawning location, and even as a nursery for most of these species. Experts have assessed that 10% of all fish that humans consume come from reef areas (Smith, 1978).

Coral reefs also fill an important role in providing regulating ecosystem services. As outlined in the Millennium Ecosystem Assessment, regulating ecosystem services are benefits provided by the regulation or control of a natural process (Millennium Ecosystem Assessment (Program), 2005). Examples of regulating services include decomposition, pollination of flowers by insects, and even erosion control provided by the roots of trees and plants. The regulating services provided by coral reefs is very important to the humans that live in adjacent communities. The first and perhaps the most important of these regulating services is the coastal protection coral reefs provide. The structures of the reef serve as shields for these communities protecting them from damaging storms and harmful erosion by dissipating the energy of waves before they reach the coast. Analysis has shown that reef complexes can reduce wave energy by as much as 97% (Ferrario et al., 2014) and even prevent more than $4 billion in damages to adjacent coastlines around the world (Beck et al., 2018). If these reef barriers are damaged or no longer continue to build upon themselves, the benefits of coastal protection will diminish and the effects of storms and strong waves will lead to other problems along the coast such as erosion and greater damage from storm surges (Gillis et al., 2014).

Perhaps the most understudied services coral reefs provide to humans are cultural ecosystem services. The Millennium Ecosystem Assessment [2005] defines cultural ecosystem services as "the nonmaterial benefits people obtain from ecosystems through spiritual enrichment, cognitive development, reflection, recreation, and aesthetic experiences." These include benefits gained from human interactions with the environment such as inspiration, creativity, acquisition of knowledge, and various recreational activities (Moberg & Folke, 1999). Recreation benefits from coral reefs can have a huge impact on local economies and many of these communities rely on tourism associated with these recreational activities, such as SCUBA diving, snorkeling, or wildlife viewing tours (Dixon et al., 1993; Pendleton, 1995). Beyond the economic impacts associated with recreation provided by coral reefs, they also provide important spiritual benefits for those that live and rely on the reefs. For example, when asked about the importance of the coral reefs surrounding the Cayman Islands, respondents nearly unanimously reported that the reefs were an important part of both Caymanian culture and identity (Dunning et al, forthcoming).

Supporting ecosystem services, defined as the services that are fundamental to the creation of all other ecosystem services, are the final category of ecosystem service provided by coral reefs (Millennium Ecosystem Assessment (Program), 2005). In the case of coral reefs, the biodiversity provided by the reefs serve as the vital supporting function, providing a genetically diverse location for fishes and other marine life to develop. Both the habitat and the biodiversity provided by that habitat support the other types of ecosystem services provided by the reef (Woodhead et al., 2019). Current estimates on coral reef biodiversity calculate there to be 830,000 multicellular species present on coral reefs around the world, however these data suggests that this could be a conservative estimate and it is likely that in truth there are even more species present on the reefs (Fisher et al., 2015). Because coral reefs are of vital importance in the life cycle of many species, the reefs also serve as a genetic depository for biological diversity, preserving many species for the future (Moberg & Folke, 1999). Other important studies have shown that the structural complexity and density of coral has a positive effect on the presence of fish biomass on the reef (Graham & Nash, 2013). Therefore, a loss in coral reef structure and habitat could lead to direct effects on future reef fishes and their ability to interconnect with seagrass beds and mangrove forests (Gillis et al., 2014).

Threats to Coral Reefs

As we move forward in the Anthropocene, the threats to these fragile marine ecosystems will only continue to increase. Climate change caused by increases in greenhouse gas emissions will only exacerbate these threats and pose the greatest challenge to coral reef sustainability in the future. Among the greatest threats to coral reefs caused by rising global temperatures are increasing sea surface temperatures, rising ocean acidification, and increased prevalence of coral diseases, which directly influence the degradation of the reef and its ability to build structure and provide a habitat for marine species. Independently, each of these stressors can negatively affect the living coral organisms and lead to the death of corals, and the reefs ability to grow and repair itself, leading to a degradation of the ecosystem services provided by the reef. Collectively, these stressors can be extremely devastating to coral reefs.

Coral polyps are a unique marine species that exist in symbiosis with the dinoflagellate algae zooxanthellae of the genus *Symbiodinium*. The zooxanthellae lives within the tissue of the coral and provides up to 90% of the coral energy needs (Berkelmans & van Oppen, 2006). When stressed the corals expel the zooxanthellae and if conditions do not return to normal the coral will not accept the algae back and the corals will eventually die in a process known as coral bleaching (Berkelmans & van Oppen, 2006; Hoegh-Guldberg, 1999). The primary driver that stresses corals and ultimately causes coral bleaching is thermal stress attributed to rises in sea surface temperature.

The temperature of the water on the ocean surface is known as sea surface temperature. Greenhouse gas emissions from the burning of fossil fuels have increased throughout the twentieth century. As greenhouse gasses increase, more heat is trapped in the atmosphere, which is in turn absorbed by the ocean. This results in increases in sea surface temperature. The Environmental Protection Agency estimates that sea surface temperatures have risen by 0.14 degrees Fahrenheit (F) per decade since 1901. They also note that in the last three decades these increases have been considerably higher than any time since observations began in 1880 (US EPA, 2016). Bleaching events have occurred throughout the twentieth century as a result of increases in sea surface temperature and has resulted in significant coral mortality and losses in structure building coral cover on reefs around the globe (Hoegh-Guldberg, 1999; Hughes et al., 2018).

Coral bleaching is a relatively recent event on the Florida Reef Tract. Since 1980 coral bleaching events in Florida have intensified and become more deadly to corals in the Florida Reef Tract. The first bleaching event of note occurred in 1983 and again in 1987, with very little coral mortality observed. Significant loss of coral was first observed along Florida's reefs following a bleaching event in 1990. Between 1997 and 1999 these reefs again experienced extensive inshore and offshore coral mortality due to coral bleaching that was exacerbated by Hurricane George (Florida Reef Resilience Program, n.d.).

Another major threat facing coral reefs around the world are changes to ocean chemistry, in particular rising ocean acidification. Greenhouse gas emissions and land use changes such as deforestation increase the amount of carbon dioxide present in the atmosphere. It is estimated that the ocean absorbs around 30% of the carbon dioxide from the atmosphere, but with more CO_2 present in the atmosphere, even greater amounts of CO_2 are being absorbed by the oceans waters, leading to changes in the pH of the water. It is estimated that since the industrial revolution, CO_2 emissions have led to a 30% increase in ocean acidity. These changes in the pH of the ocean have negative impacts on structure building coral species such as elkhorn (*Acropora palmata*) and staghorn (*Acropora cervicornis*) coral. These organisms utilize the carbonate ions and calcium from their seawater environment to build calcium-carbonate skeletons, forming the structure of the reefs we see today. As the concentration of CO_2 in the ocean increases, the concentration of hydrogen ions also increases. The carbonate ions bond with the excess hydrogen ions which results in a decrease in carbonate ions available to coral organisms to utilize in building of their calcium carbonate structures. Prolonged exposure to more acidic ocean waters can even lead these calcium carbonate skeletons to dissolve, severely degrading the structure and complexity of the ecosystem and the benefits it provides (Kleypas & Yates, 2009; *Ocean Acidification*, n.d.).

In addition to the impacts rising sea surface temperature and ocean acidification are having on coral reefs around the world, these fragile ecosystems are also increasingly susceptible to threats from coral diseases. In recent years coral diseases such as white-band disease and stony coral tissue loss disease (SCTLD) have contributed to coral mortality throughout the Caribbean. Research suggests that thermal stressors, such as increases in sea surface temperature give coral pathogens an increased opportunity to affect coral organisms and also increase the spatial range where these pathogens can be found (C. D. Harvell et al., 2002; D. Harvell et al., 2009). Thermal stress to corals limit immune response in infected hosts and also leads to an increase in frequency of disease outbreaks (C. D. Harvell et al., 2002). Additionally, as thermal stress events become more common on the reef, the capacity for corals to recover between events is severely limited (Baker et al., 2008).

In order to better understand how adaptive environmental governance is being used to manage coral reef ecosystems, we have focused our research on examining the most important and largest coral reef ecosystem in the United States, the Florida Reef Tract. The state of Florida is home to the third largest barrier reef in the world (US EPA, 2017a) which extends over 350 miles from St. Lucie Inlet in Martin County to Dry Tortugas National Park in Monroe County. According to the US Census Bureau, since 2010 the state of Florida has been among the fastest growing states in the nation, reporting a 14.6% increase in population over this time (Bureau, n.d.). Along with increases in population, the state has also experienced one of the fastest rates of urbanization in the US (DeSteno, n.d.). With increases in population and urbanization, the threats to the Florida Reef Tract have increased as well. The greatest threats facing the Florida Coral Reef tract are anthropogenic and include land based sources of pollution, damage from human activities such as fishing and boating, rising sea surface temperatures, and rising ocean acidification levels, which lead to increases in coral related diseases such as Stony Coral Tissue Loss Disease and Coral Bleaching. (R. B. Aronson et al., 2005; Green et al., 2008; Hoegh-Guldberg, 1999; Knowlton, 2001; *Resilience Action Plan for Florida's Coral Reef 2021-2026*, 2019). Because of these disturbances the Florida Reef Tract has experienced a loss of reef building corals which has also resulted in an increase in more stress tolerant species such as mustard hill coral (*Portites astreoides)* and massive starlet coral *(Siderastrea siderea)* (Toth et al., 2019).

Management of Coral Reefs in Florida

Management of Marine Protected Areas (MPA) in the state of Florida is complex. Along the Florida Reef Tract there are multiple different marine protected areas which we highlight in our research. These include two National Parks, a State Park, an Ecosystem Conservation Area, a National Marine Sanctuary, and an Ecological Reserve. The major protected areas included in this study are the Kristin Jacobs Coral Reef Ecosystem Conservation Area, Biscayne National Park, Florida Keys National Marine Sanctuary (FKNMS), John Pennekamp State Park, Tortugas Ecological Reserve, and Dry Tortugas National Park. Each protected area along the Florida Reef Tract manages the resources found in their waters differently. In Table 4 you will find a brief description of these areas and where they are located along the reef tract. A majority of these resources are found in the waters of two Florida counties, Miami-Dade County and Monroe County. Miami-Dade County is the northernmost county in our study area and encompasses the city of Miami, a major urban area along the south Florida coast. Monroe county, the southernmost county in Florida and in our study area, encompasses the Florida Keys National Marine Sanctuary and most of what we call the island chain that stretches south from the Florida peninsula, bordering both the Gulf of Mexico to the west and the Atlantic Ocean to the East.

Table 4: *Major Marine Protected Areas along the Florida Reef Tract*

Name	Year Established	Adjacent County	Management Authority
Kristen Jacobs Coral Reef Ecosystem Conservation Area (Coral ECA)	2018	Martin, Palm Beach, Broward, and Miami-Dade County	• Florida Department of Environmental Protection (FDEP)
Biscayne National Park	National Monument - 1968 National Park - 1980	Miami-Dade County	• National Park Service
Florida Keys National Marine Sanctuary	1990	Monroe County	• National Oceanic and Atmospheric Association (NOAA) • FDEP
John Pennekamp State Park	1963	Monroe County	• FDEP Division of Recreation and Parks (DRP)
Tortugas Ecological Reserve	2001	Monroe County	• NOAA • FKNMS
Dry Tortugas National Park	National Monument - 1935 National Park -1992	Monroe County	• National Park Service

The history of environmental management in Florida using policies, laws, and conservation initiatives began in 1963 with the establishment of the John Pennekamp Coral Reef State Park off of the island of Key Largo. This park was established as the first underwater park in the world and was designed to mitigate coral reef losses in the Florida Keys throughout the first half of the twentieth century. In the years that followed, other conservation initiatives, such as the passage of the Marine Protection, Research, and Sanctuaries Act of 1972, the establishment of the Key Largo National Marine Sanctuary in 1975, and the establishment of the Looe Key National Marine Sanctuary in 1981. Finally in 1990, President George H. Bush signed into law the Florida Keys National Marine Sanctuary and Protection Act, which established the Florida Keys National Marine Sanctuary, incorporating the Key Largo and Looe Key sanctuaries into its larger footprint, protecting over 2,800 square nautical miles of waters surrounding the Florida Keys. Table 5 highlights a list of key events, legislation, and policy changes throughout the history of the FKNMS.

Table 5: *Key Events and Legislation in the establishment of the Florida Keys National Marine Sanctuary*

Event	Year	Details
Florida Keys Overseas Highway opens	1938	Highway allows increased access to the Keys ecosystem
Establishment of John Pennekamp Coral Reef State Park	1963	World first underwater park established off of Key Largo in order to preserve coral reef ecosystem
National Marine Sanctuaries Act	1972	Authorizes protection of marine environments with significant conservation, recreational, ecological, historical, scientific, cultural archaeological, educational, or esthetic values as national marine sanctuaries
Establishment of the Key Largo National Marine Sanctuary	1975	Authorized protection of coral reef habitat adjacent to John Pennekamp State Park as a national marine sanctuary
Establishment of the Looe Key National Marine Sanctuary	1981	Authorized protection of coral reef habitat adjacent to Big Pine Key as a national marine sanctuary
Florida Keys National Marine Sanctuary and Protection Act	1990	Florida Keys National Marine Sanctuary established in order to protect marine environment and resources of the Florida Keys. Incorporates previously existing Key Largo and Looe Key National Marine Sanctuaries into the FKNMS.
First Florida Keys National Marine Sanctuary Management Plan published	1997	Management plan published in order to protect the sustainable use of the Florida Keys marine environment
Tortugas Ecological Reserve established within FKNMS waters	2001	Established the reserve in order to preserve biodiversity in the FKNMS by implementing more strict regulations in this area
Revised Florida Keys National Marine Sanctuary Management Plan published	2007	Updated previous management plan and provided information on successful strategies and future initiatives within the FKNMS

Today the Florida Keys National Marine Sanctuary, which extends the entire length of Monroe County Florida, is administered by the National Oceanic and Atmospheric Association (NOAA), however it is also jointly managed by the Florida Department of Environmental Protection (FDEP) because around 60% of the sanctuary lies in Florida state waters (FKNMS, n.d.). In order to better represent the stakeholders and user groups who rely on the waters of the FKMNS, the Florida Keys National Marine Sanctuary and Protection Act provisioned the formation of the Sanctuary Advisory Council. This council is composed of 20 voting members and 16 non-voting members who typically serve a term of three years on the council. These members are made up of federal, state, and local agency employees holding governmental positions related to the management of natural resources, local stakeholders, conservationists, scientists, members of the academic community, industry leaders, and members of the public with interest in the protection and management of the FKNMS. Of note, Monroe County is required to designate one elected official to serve on the council as a voting member. Non-governmental members serving on the council as voting members include a wide range of relevant stakeholders, as put forth in the council charter. The 16 non-voting members, including the Sanctuary superintendent, are either selected or appointed and represent a wide range of federal, state, and local agencies and governments. Table 6 shows the breakdown of the voting and non-voting council members and which relevant area they represent. The primary role of the council is to provide the sanctuary superintendent with advice from a wide range of relevant stakeholders and governmental localities with a vested interest in the protection and management of the FKNMS. The council is only advisory however, and its members are not given the authority to make decisions or perform any operational or management functions on behalf of the FKNMS or NOAA (Florida Keys National Marine Sanctuary, 2018).

Table 6: *FKMNS Sanctuary Advisory Council Voting Members and Associated Stakeholder Group*

Voting/Non-Voting	Position	Agency, Activity, Industry, or Stakeholder Group Represented
Voting	Government Official	Monroe County Elected Official
Voting	Non-governmental position	Boating Industry
Voting	Non-governmental position	Citizen at Large - Upper Keys
Voting	Non-governmental position	Citizen at Large - Middle Keys
Voting	Non-governmental position	Citizen at Large - Lower Keys
Voting	Non-governmental position	Conservation and Environment
Voting	Non-governmental position	Conservation and Environment

Voting	Non-governmental position	Diving - Upper Keys
Voting	Non-governmental position	Diving - Lower Keys
Voting	Non-governmental position	Education and Outreach
Voting	Non-governmental position	Fishing - Charter Fishing Flats Guide
Voting	Non-governmental position	Fishing - Charter Sports Fishing
Voting	Non-governmental position	Fishing - Commercial; Marine/Tropical
Voting	Non-governmental position	Fishing - Commercial; Shell/Scale
Voting	Non-governmental position	Fishing - Recreational
Voting	Non-governmental position	Research and Monitoring
Voting	Non-governmental position	South Florida Ecosystem Restoration
Voting	Non-governmental position	Submerged Cultural Resources
Voting	Non-governmental position	Tourism - Upper Keys
Voting	Non-governmental position	Tourism - Lower Keys
Non-Voting	Superintendent	Sanctuary Superintendent
Non-Voting	Agency position	Florida Department of Environmental Protection
Non-Voting	Agency position	Florida Fish and Wildlife Conservation Commission, Division of Law Enforcement
Non-Voting	Agency position	Florida Fish and Wildlife Conservation Commission, Fish and Wildlife Research Institute

Non-Voting	Agency position	NOAA Fisheries Service
Non-Voting	Agency position	NOAA Office of General Counsel
Non-Voting	Agency position	NOAA Office of Law Enforcement
Non-Voting	Agency position	National Park Service
Non-Voting	Agency position	U.S. Coast Guard
Non-Voting	Agency position	U.S. Environmental Protection Agency
Non-Voting	Agency position	U.S. Fish and Wildlife Service
Non-Voting	Agency position	U.S. Navy
Non-Voting	Local Government position	Islamorada, Village of Islands
Non-Voting	Local Government position	City of Key Colony Beach
Non-Voting	Local Government position	City of Key West
Non-Voting	Local Government position	City of Layton
Non-Voting	Local Government position	City of Marathon

To further highlight the importance of protecting the resources of the reef, President Bill Clinton established the United States Coral Reef Task Force (USCRTF) through executive order 13089. This order charged the USCRTF, in cooperation with state, territorial, and local government agencies, with planning and coordinating research, mapping existing coral reef resources, identifying threats, and developing mitigation efforts in order to preserve these unique and valuable ecosystems (Executive Order No. 13089, 1998). In order to better achieve these objectives, the Coral Reef Task Force adopted Resolution 8-1: Improving Procedures of the U.S. Coral Reef Task Force, known as the “Puerto Rico Resolution” in 2002. This charged each of the seven member U.S. states, territories and commonwealths with developing short term Local Action Strategies (LAS). These strategies were to be locally developed and implemented with an aim at protecting reef resources, while balancing resource use and protection, with maximum stakeholder cooperation. In order to implement this strategy, under guidance from the Florida Department of Environmental Protection and the Florida Fish and Wildlife Conservation Commission (FWC), the Southeast Florida Coral Reef Initiative (SEFCRI) was formed. This initiative was made up of government officials, local stakeholders, marine resources professionals and scientists who sought to develop strategies to protect the coral reef resources extending from Miami-Dade County to Martin Country. This led to the establishment of the

Southeast Florida Coral Reef Ecosystem Conservation Area in 2018. This area was renamed the Kristin Jacobs Coral Reef Ecosystem Conservation Area, or Coral ECA for short, in 2021. Table 7 highlights a list of key events, legislation, and policy changes throughout the history of the Coral ECA.

Table 7: *Key Events and Legislation in the establishment of the Coral ECA*

Event	Year	Details
Florida Department of Environmental Protection created	1993	Established FDEP as the state's lead agency for management and stewardship of Florida's natural resources
United States Coral Reef Task Force created	1998	Established by presidential executive order to spearhead preservation and protection of US coral reef ecosystems
Florida Fish and Wildlife Conservation Commission created	1999	Established to regulate and manage the states fish and wildlife populations, and provide enforcement for these regulations
Coral Reef Task Force adopts Resolution 8-1: Improving Procedures of the U.S. Coral Reef Task Force, known as the "Puerto Rico Resolution"	2002	Tasked Coral Reef Task Force member states with developing Local Action Strategies.
Southeast Florida Coral Reef Initiative (SEFCRI) established	2003	SEFCRI established as part of Florida's Local Action Strategy (LAS) outlined in the Puerto Rico Resolution
Florida Department of Environmental Protection Coral Reef Conservation Program (FDEP CRCP) established	2004	Program initiated to support implementation, development and management of Florida's LAS
Florida Coral Reef Protection Act (CRPA) passed by Florida Legislature	2009	Established FDEP as the lead trustee for Florida's coral reef resources, and charged FDEP with protection of reefs through enforcement methods such as fines for those who damage reefs
Southeast Florida Coral Reef Ecosystem Conservation Area established	2018	Set aside offshore lands and waters containing coral reef ecosystems from Martin to Miami-Dade County as conservation areas
Southeast Florida Coral Reef Ecosystem Conservation Area	2021	Renamed to honor environmental advocate and state representative Kristin Jacobs. Also

renamed the Kristin Jacobs Coral Reef Ecosystem Conservation Area		known as the Coral ECA.

To accomplish their goals, the SEFCRI team focuses their work in 5 major areas: 1) Awareness and appreciation 2) fishing, diving, and other uses 3) land based sources of pollution 4) maritime industry and coastal construction impacts 5) reef resilience. The SEFCRI team is composed of up to 64 voting members, who are charged with serving as intermediaries between the Florida Department of Environmental Protection Coral Reef Conservation Program (FDEP CRCP) and their constituents or communities. The team formulates, develops and provides recommendations to the FDEP CRCP Manager on how to implement the agreed upon Local Action Strategies (LAS). However the SEFCRI team can only make recommendations to the FDEP CRCP manager and they do not have the authority to make operational or management decisions regarding the Coral ECA (Southeast Florida Coral Reef Initiative, 2019). Table 8 shows a breakdown of the SEFCRI Team membership. This list is only an example of the roles represented on the SEFCRI Team and highlights the balance of agency and stakeholder groups represented.

Table 8: *Southeast Florida Coral Reef Initiative Team Membership*

Membership Category	Position
Federal Agency	NOAA – Coral Reef Conservation Program
Federal Agency	NOAA – National Marine Fisheries Service (SE Fisheries Sci Center)
Federal Agency	NOAA – National Marine Fisheries Service (Habitat Cons. Division)
Federal Agency	NOAA – National Marine Fisheries Service (Protected Resources Division)
Federal Agency	NOAA – National Marine Sanctuaries (FKNMS)
Federal Agency	National Park Service – Biscayne National Park
Federal Agency	National Park Service – Dry Tortugas National Park
Federal Agency	National Park Service – Everglades National Park
Federal Agency	U.S. Fish and Wildlife Service – Hobe Sound NWR
Federal Agency	U.S. Army Corps of Engineers – Regulatory
Federal Agency	U.S. Army Corps of Engineers – Civil Works
Federal Agency	U.S. Coast Guard – Sector Miami

Federal Agency	U.S. Department of Agriculture – Regional/Local
Federal Agency	U.S. Environmental Protection Agency – Regional/Local
Federal Agency	U.S. Geological Survey – Regional/Local
State Agency	Florida DEP – Beaches, Inlets, and Ports Program
State Agency	Florida DEP – Southeast Regulatory District (Submerged Lands & Environmental Resource Program)
State Agency	Florida DEP – Southeast Regulatory District (Water)
State Agency	Florida DEP – Southeast Regulatory District (Communications)
State Agency	Florida DEP – Florida Park Service (Bill Baggs Cape Florida State Park)
State Agency	Florida DEP – Florida Park Service (John D. MacArthur State Park)
State Agency	Florida DEP – Florida Park Service (John Pennekamp Coral Reef State Park)
State Agency	Florida DEP – Florida Park Service Dr. Von D Mizell-Eula Johnson State Park
State Agency	Florida DEP – Florida Park Service (St. Lucie Inlet Preserve State Park)
State Agency	Florida DEP – Aquatic Preserves (Biscayne Bay Aquatic Preserves)
State Agency	Florida Fish and Wildlife Conservation Commission – Fish and Wildlife Research Institute
State Agency	Florida Fish and Wildlife Conservation Commission – Division of Marine Fisheries Management
State Agency	Florida Fish and Wildlife Conservation Commission – Division of Habitat and Species Conservation
State Agency	Florida Fish and Wildlife Conservation Commission – Law Enforcement (Marine)
State Agency	South Florida Water Management District
County/Regional Government Entity	Miami-Dade County – Division of Environmental Resources Management

County/Regional Government Entity	Broward County – Natural Resources Planning and Management Division
County/Regional Government Entity	Palm Beach County – Environmental Resource Management
County/Regional Government Entity	Martin County – Coastal Management Division
County/Regional Government Entity	Local Drainage Districts
County/Regional Government Entity	Utilities
Academia	Education & Outreach – Teachers, K - 12
Academia	Education & Outreach – SeaGrant/Nature Centers
Academia	Research Institutes – National Coral Reef Institute
Academia	Research Institutes – Smithsonian Institute
Academia	Universities – Florida Atlantic University
Academia	Universities – Florida Institute of Technology
Academia	Universities – Florida International University
Academia	Universities – Nova Southeastern University
Academia	Universities – University of Florida
Academia	Universities – University of Miami
Non-Governmental Organizations	Conservation/Environmental NGO - Local
Non-Governmental Organizations	Conservation/Environmental NGO – National
Non-Governmental Organizations	Conservation/Environmental NGO - International
Diving Industry	Charter Boat Operator
Diving Industry	Dive Instructor/Store
Diving Industry	Recreational Diver/Hunter

Diving Industry	Reef Research Team Diver
Diving Industry	Diving Club
Fishing Industry	Charter Fishing
Fishing Industry	Recreational Fishing
Fishing Industry	Commercial Fishing
Fishing Industry	Fishing Club
Fishing Industry	Fishing Tournament Organization
Private Business	Consultants – Environmental/Engineering
Private Business	Landscape Industry
Private Business	Marine Industries – Recreational Boating/Fishing
Private Business	Marine Contractors
Private Business	Tourism
Other Stakeholder Groups	Ports – Port of Miami
Other Stakeholder Groups	Ports – Port Everglades
Other Stakeholder Groups	Ports – Port of Palm Beach
Other Stakeholder Groups	Water Sports – Surfing, Wind Surfing, Paddle Boarding
Other Stakeholder Groups	Citizens at Large

Biscayne National Park lies in Biscayne Bay, near the city of Miami in Miami-Dade County. It was authorized as a National Monument by President Lydon B Johnson in 1968 and later recognized as a National Park in 1980. Biscayne National Park is unique in that 95% of the park is underwater and only accessible by boat. The park is over 170,000 acres and preserves the coral reefs, seagrass beds, and mangroves of Biscayne Bay (U.S. National Park Service, 2022). The park lies adjacent to the southern boundary of the Coral ECA and borders the north and east boundaries of the FKNMS. Management of the park is handled by the National Parks Service, a federal agency found within the Department of the Interior.

Status of Florida's Coral Reefs

In order for humans to get the most benefit from the ecosystem services provided by Florida's coral reefs they must remain vibrant and healthy. Thermal stress from rising sea surface temperatures leading to coral bleaching events, rising levels of carbon dioxide leading to increases in ocean acidification, degraded water quality, and increased prevalence of coral diseases all affect the health of the Florida Reef Tract. To assess the impacts these disturbances are having in these ecosystems, NOAA's Coral Reef Conservation Program and the University of Maryland Center for Environmental Science released a series of status reports assessing the current status and trends of coral reef ecosystems in both the Atlantic and Pacific Oceans. Each report scored the ecosystem based on three monitoring data themes, which include "Climate," "Corals and Algae," and "Fish." Each reef ecosystem was rated on a 100 point scale and a condition rating was assigned based on this score. Reefs could be rated Very Good (90-100%), Good (80-89%), Fair (70-79%), Impaired (60-69%), or Critical (0-59%). According to the 2020 report, Florida's coral reefs are rated as "Impaired" (NOAA Coral Reef Conservation Program, 2020). The rating of "Impaired" means that these reefs are heavily impacted or have experienced a level of considerable decline. The report notes that climate is a major factor contributing to thermal stress and rising ocean acidification along the reef, both of which negatively influence the health of these ecosystems. Table 9 highlights each region of the Florida Reef Tract assessed in the report and highlights critical vulnerabilities found in the report.

The report divides the Florida reefs into three sections, Southeast Florida, which encompasses the Coral ECA, the Florida Keys which encompasses the waters of the FKNMS, and the Dry Tortugas which includes the Dry Tortugas National Park and Tortugas Ecological Reserve. Within the report, the Southeast Florida portion of the reef scored the lowest among the three regions. This region is rated as "Impaired." According to the report, subsections for both "Corals and Algae" and "Fish" are rated as "Critical", while the "Climate" subsection is rated as "Fair." Critical vulnerabilities identified in the report include critical ratings for reef material growth, adult coral, coral cover, macroalgae, sustainability and diversity of fish species. However, unlike the other two regions in the assessment, temperature stress in the Southeast Florida region was rated as "Good" (NOAA Coral Reef Conservation Program, 2020).

The report found the Florida Keys region of the Florida Reef Tract to be in slightly better shape. This region, which includes the reefs of the FKNMS, scored an overall 71% and was considered to be rated "Fair." Critical vulnerabilities identified in the report include the sustainability of fish and a lack of reef material growth. This region fared better than the rest of Florida's reefs in presence of adult coral and fish diversity, and received a rating of "Good" and "Very Good" in these areas.

The final region of the Florida Reef Tract assessed in this report was the Dry Tortugas region. This region scored 73% overall and received a rating of "Fair." The only critical area identified in the Dry Tortugas in the report was a lack of reef material growth, a common trend throughout the Florida Reef Tract. The Dry Tortugas region scored highest in reef fish and fish diversity, receiving a "Good" rating in each.

Table 9: *Current status of Florida's Coral Reefs*

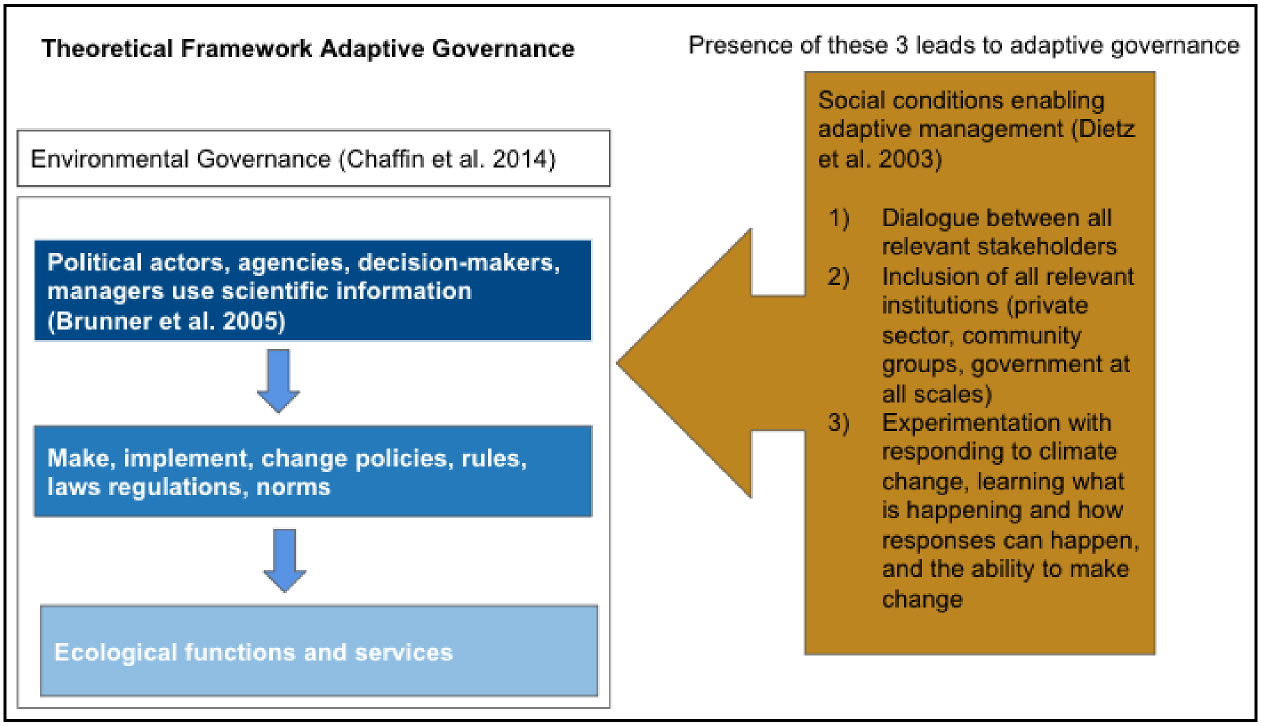
Location	Key Protected Areas	Current Status	Critical vulnerabilities outlined by status report	Areas rated "Good" or "Very Good" by status report
Florida	All Florida Reef Tract protected areas	Impaired (69%)	Reef material growth; fish sustainability	Fish diversity
Southeast Florida	Coral ECA, Biscayne National Park	Impaired (62%)	Adult coral; coral cover; macroalgae; fish sustainability and biodiversity; reef material growth	Temperature stress
Florida Keys	FKNMS, John Pennekamp State Park	Fair (72%)	Fish sustainability; reef material growth	Adult coral; fish diversity
Dry Tortugas	Dry Tortugas National Park, Tortugas Ecological Reserve	Fair (73%)	Reef material growth	Reef fish; fish diversity

2.3. ADAPTIVE GOVERNANCE: DECISION-MAKERS RESPOND TO CLIMATE CHANGE

In this study, we use the theoretical framework of adaptive governance for assessing the ways that decision-makers are responding to the impacts of climate change. Governance is defined in the literature as the set of regulatory processes through which political actors influence ecosystems (Chaffin et al., 2014; Lemos & Agrawal, 2006). Environmental governance requires scientific information about ecosystems which policy-makers use in decision-making(Brunner, 2005; Chaffin et al., 2014). Using this information, policy-makers implement regulations which influence ecological functions and services (See figure 4 in blue).

Our research focuses on the process for which environmental governance becomes adaptive governance, defined as management for which policy-makers learn lessons from the interventions they make for ecosystem conservation that enable changes or adaptations based on learning (Walters and Holling 1990, Williams 2003). Dietz et al. 2003 argue that three social conditions are necessary to ensure adaptive governance: 1) inclusive dialogue between stakeholders, 2) the involvement of all necessary stakeholders (e.g. government at all scales, private sector, and community groups), and 3) the ability for decision-makers to experiment and learn (Figure 4).

Figure 4: *Framework of social conditions leading to adaptive environmental governance*



2.4. CASE JUSTIFICATION

We focus on the FKNMS as at that site there are strong links between ecosystem conditions and management actions, stakeholders and adjacent communities have a strong sense of stewardship, and there are resources present for scientific monitoring and management (Anthony et al., 2015; McCook et al., 2010).

Our research is a single case study, which in the field of public management is a widely accepted research design providing information that improves how public officials and citizens can solve collective problems arising both in the factual context of the case itself, but more importantly in contexts other than the one we study (Barzelay, 1993). The single case offers theoretical insights into how people define the social and ecological conditions created by the climate crisis and how decision-makers are problem solving in these conditions to better inform adaptive governance to climate impacts all over the world.

2.5. METHODS

The overarching design for this interdisciplinary, collaborative research is contained in Figure 5. The design contains climate model outputs, ecological model outputs, and qualitative interview outputs to develop a framework of adaptive environmental governance for the FKNMS.

Figure 5: *Research design*

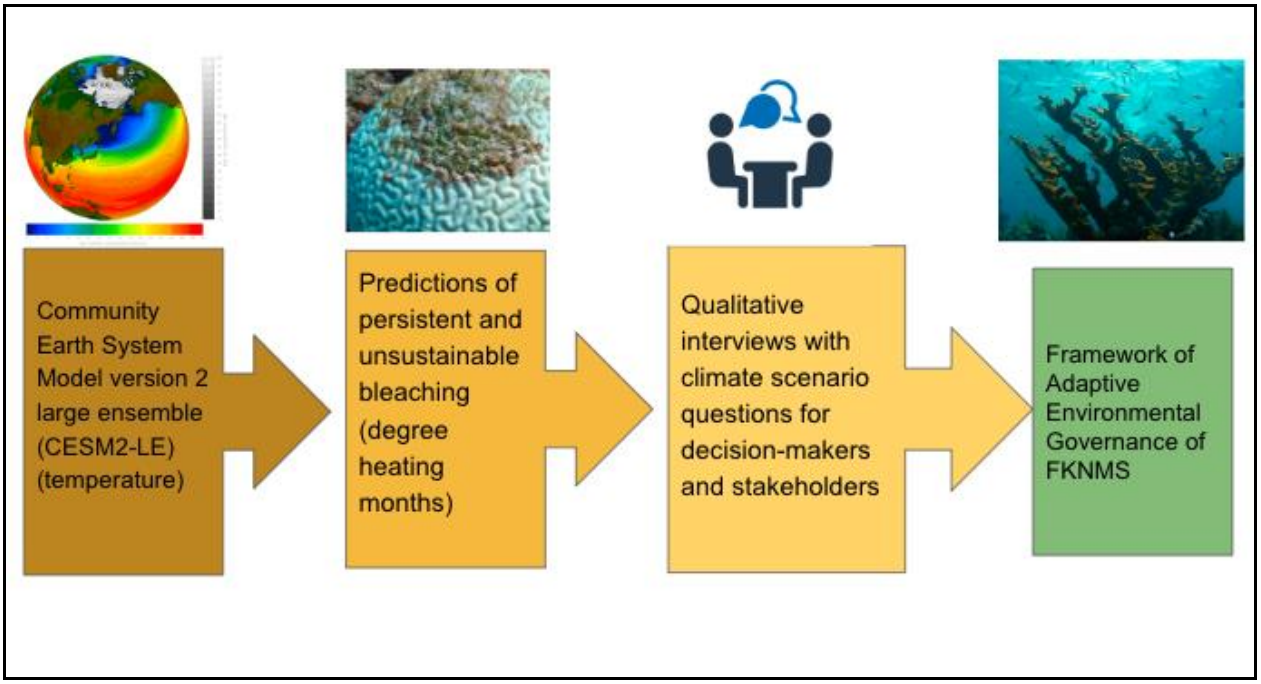


Image credits: NCAR/UCAR, NOAA, and Florida Department of Environmental Protection

To conduct our research, our theoretical framework of adaptive governance requires decision-makers to use scientific information. In our case, this information is the altered variability and change in the climate system (Rodgers et al., 2021). To describe climate variability and change on the Florida Reef Tract to collaboratively engage policy-makers, we developed scenarios, or heuristic tools for policy-makers defined as storylines which describe human-environmental interactions under a range of possible futures due to the uncertainty of climate change (IPCC, 2000; *Managing the Risks of Extreme Events and Disasters to Advance Climate Change Adaptation — IPCC,* n.d.). Scenarios are plausible, simplified descriptions of the future based on assumptions about driving forces and relationships ("Ecosystems and Human Well-Being: Findings of the Scenarios Working Group of the Millennium Ecosystem Assessment.," 2005). The use of narrative climate scenarios helps us gain understanding of adaptation and remaining vulnerabilities (Rounsevell & Metzger, 2010).

Scenarios were used to ask decision-makers how they are currently responding to disturbances on the reef, and how they can respond in the future based on our climate predictions. We created scenarios using climate and ecosystem models respectively. Beginning with climate models, to gauge broad-scale forced change for the reefs of the FKNMS we used the Community Earth System Model version 2 large ensemble (CESM2-LE)(Rodgers et al., 2021). The CESM2-LE is a new, publicly available, large ensemble of fully coupled CESM2 simulations unprecedented due to its size, duration, and spatial resolution(Rodgers et al., 2021). We used 50 members of the CESM2-LE which are all forced using the same forcing but differ slightly in their initial conditions. The small differences at initialization produce a spread in the timing of the natural (internal) climate variability of the model (for further description of initial condition large ensembles see Deser et al., 2020) allowing us to isolate the forced signal from the internal variability. The 50 members we used are the CESM2-LE "CMIP6" members using the biomass burning emissions provided by CMIP6 protocols (see Rodgers et al. 2021 for details). We extracted monthly sea surface temperatures (SSTs) from 2° boxes around each site. The SST timeseries for each site were used as inputs for a coral bleaching model. The spread of ensemble members allows us to quantify the likelihood of coral bleaching each year over the 21st century.

For the location for temperatures, we selected Molasses Reef in the FKNMS, known for being easily accessible to sanctuary users, the reef is also a special zone within the FKNMS known as a Sanctuary Preservation Area, home to shallow reefs and important species. With diving, boating, and snorkeling allowed, Molasses Reef is the most heavily visited reef in the Upper Keys – perhaps the world – for diving(Sanctuary, n.d.; *Sanctuary Preservation Areas | Restoration Blueprint | Florida Keys National Marine Sanctuaries*, n.d.).

To translate climate data to coral bleaching projections, data from the CESM2-LE were extracted for the FKNMS site for the period 1850–2100. CESM2-LE follows the historical (1850–2014) and SSP3-7.0 (2015–2100) forcing protocols provided by the CMIP6. SSP3-7.0 represents a medium to high end of the range of future forcing pathways, assuming no additional mitigation beyond what is currently in force. Corals begin to experience heat stress once temperatures exceed the normal annual maximum temperature at their location by 1-2 degrees Celsius. Most bleaching calculations rely on a fixed climatology of the normal maximum temperature. Here we included an "adaptation metric" similar to that used by Teneva et al. (2011), which utilizes a rolling climatology based on the average annual maximum temperature of the previous 30 years (fast rate of adaptation) and previous 50 years (normal rate of adaptation) (Teneva et al., 2012). We then determined Degree Heating Months (DHM) for each year of each ensemble member, computed as the sum of the excess temperature over the previous 3 months. DHM values above 1 are considered conditions that cause moderate coral bleaching; above 2 causes severe bleaching; and above 3 causes very severe bleaching with high mortality. The year when coral bleaching became persistent was determined for each ensemble member, as the year when the sum of the DHM for the previous 10 years exceeded a value of 5. The year when coral bleaching became unsustainable was also determined for each ensemble member, as the year when the sum of the DHM for the previous 10 years exceeded a value of 7. The definitions of persistent versus unsustainable are somewhat arbitrary, but based on the concept that there is a threshold that prevents coral recovery when bleaching becomes too severe and/or too frequent.

Table 10: *Persistent and Unsustainable Bleaching Predictions for FKNMS reefs showing the years when persistent bleaching and unsustainable bleaching occur starting in the year 2020. The 50-year adaptation rate is more accepted.*

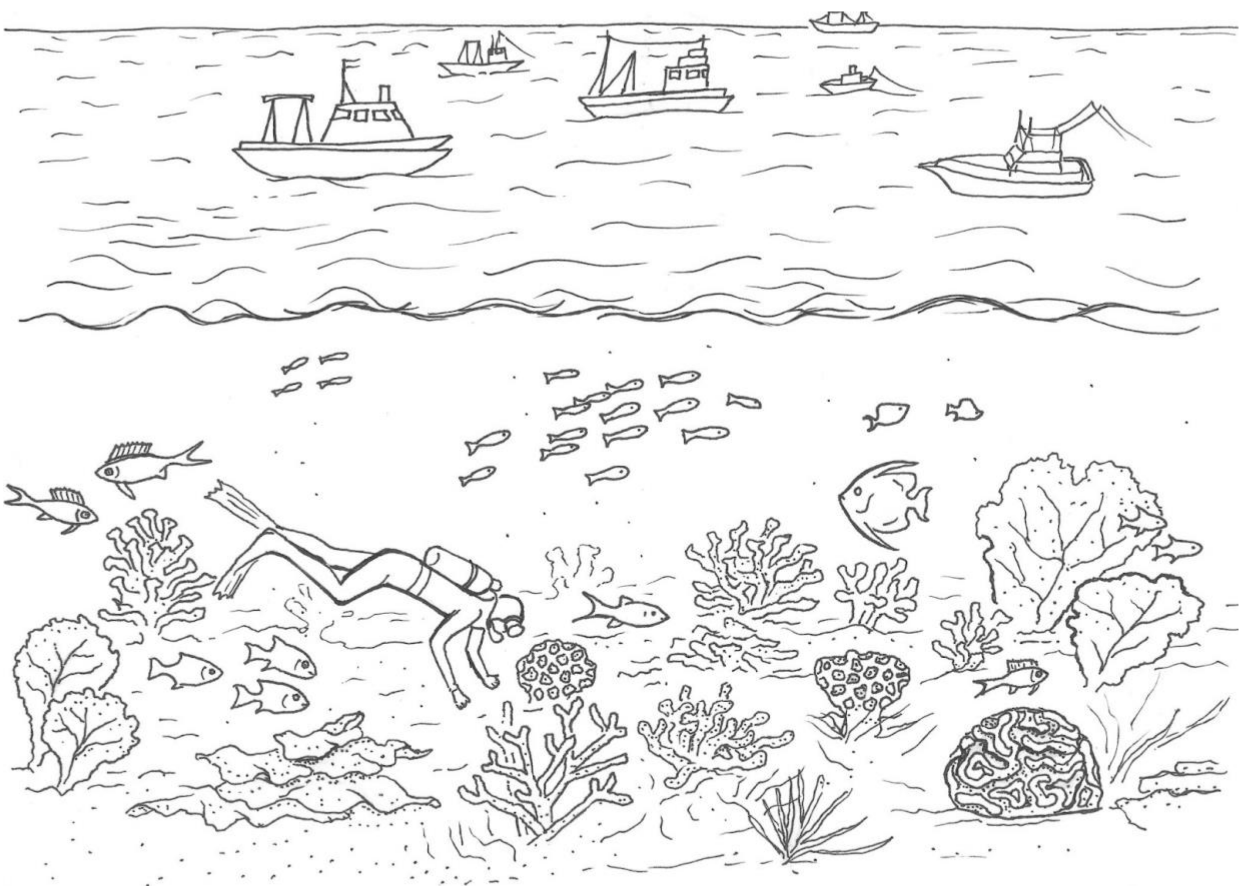
Reef Site	**30-year adaptation rate**				**50-year adaptation rate**			
FKNMS Reefs	**Median**	**Mean**	**Min**	**Max**	**Median**	**Mean**	**Min**	**Max**
Persistent	2025.0	2028.8	2020	2052	2023.0	2024.4	2020	2039
Unsustainable	2050.0	2050.4	2020	2091	2043.5	2045.5	2020	2085

Using climate and ecosystem model outputs in addition to expert elicitation from coral reef and climate scientists at NCAR, we created a qualitative interview manual asking decision-makers and stakeholders in the FKNMS twelve questions based on the three part framework of adaptive governance: dialogue, inclusion, and experimentation. Questions were co-designed with coral reef scientists, climate modelers, and social scientists at a workshop in May 2022 at NCAR and piloted with FKNMS stakeholders in June 2022. Two questions contained climate scenarios depicted in Box 1. Climate scenarios were accompanied by an image depicting the scenario to allow the respondent to see the scene being described in the climate scenario. The interview manual was piloted and edited with the help of sanctuary and state level decision-maker partners.

Figure 6: *Climate scenario questions*

Scenario 1: 10 years into the future

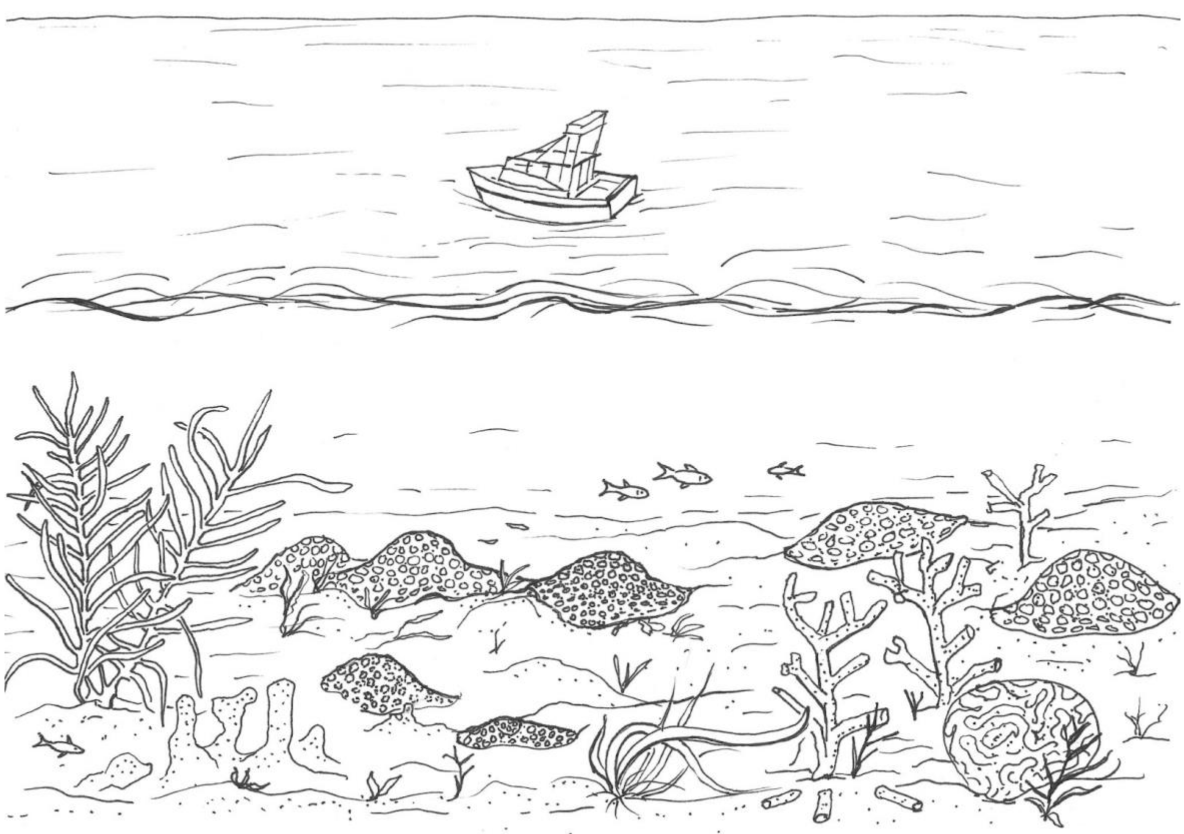
By the year 2032 (10 years from now), there will be *persistent* levels of bleaching at least once every year, which means that the reefs will be under stress and ultimately a percentage of the coral will die. Most remaining corals will be broken or diseased and will be noticeably less colorful. The surviving corals will not be able to replace broken or damaged coral fast enough, and the structure of the reef will appear greatly diminished. Key species that use the reef as habitat/home like lobster, snapper, and grouper will be noticeably less present. Even with this scenario, however, it is possible that some corals will be more heat tolerant, and those will be the ones you will start seeing more frequently.



Artist: Kristen Krumhardt

Scenario 2: 20 years into the future

By the year 2042 (20 years from now), there will be *unsustainable* levels of bleaching at least twice every year, meaning the reefs will be under stress and most of the coral will die. Very few unbroken and healthy corals will remain. The vibrant colors of the reef will be completely gone. The surviving corals will not be able to replace broken or damaged coral fast enough, and the structure of the reef will appear greatly diminished. At this point, octocorals (commonly known as sea plumes) are the dominant coral on the reef, and stony coral like elkhorn and staghorn are no longer visible. The amount of fish and other reef species on the reef will decrease as well, meaning people will need to spend more time looking for them to view or fish for them. Other key species that use the reef as habitat/home like lobster, snapper, and grouper will be noticeably less present. That said, some corals are showing signs of being heat tolerant, and those will be the ones you will start seeing more frequently.



Artist Kristen Krumhardt

Qualitative data is the result of fieldwork conducted in June and December of 2022 where 42 interviews were conducted lasting approximately 1-2 hours per interview. Responses were transcribed in person, and collected under Auburn University IRB #21-548 EX 2111. Our sampling logic for respondents was purposeful sampling, a widely used qualitative research technique for identifying and selecting information-rich data sources related to a phenomenon of interest (Palinkas et al., 2015). Purposeful sampling entails selecting respondents with first-hand or detailed information on the phenomenon of interest (Creswell & Plano Clark, 2018). To triangulate our data, we also analyzed the public comments of 382 stakeholders who attended Sanctuary Advisory Council meetings, stakeholders with a strong interest in managing the sanctuary for their livelihoods in fishing and tourism.

Using the theoretical framework of adaptive governance, we coded data in instances where managers referenced each concept to describe management responses to climate change on the Florida Reef Tract. Coding took place in two cycles. In cycle one, we looked for the components of adaptive governance, specifically dialogue, inclusion, and experimentation (Strauss & Corbin, 1997) (See Table 11). For the initial round of qualitative coding, *in vivo* coding was used to draw on the speaker's own language to develop codes (Saldaña, 2016). After the first sorting of theoretical concepts, a second round of coding took place using deductive methods to place in vivo codes into one of three concepts from our theoretical framework. Phase two required that we refine the initial codes into what Saldaña 2016 refers to as "consolidated meaning," where you group similar codes within an overarching category.

Table 11: *Codebook for the adaptive governance framework*

Concept	Criteria to assign this code to data (Can be coded as an absence if this is not occurring)	Example
Dialogue	Stakeholder provides their perception on an issue relevant to decision-making in the sanctuary; there is opportunity to discuss different perceptions among people who agree and disagree	A commercial angler is able to provide their opinion on whether changes to marine zoning will impact their livelihood.
Inclusion	Stakeholder feels that they have a seat at the decision-making table, they understand how to contribute to decisions being made about the sanctuary	A spear fisherman and owner of a spear fishing charter notes that while the opportunity to participate in decision-making has been advertised, they opted to not attend the meetings.
Experimentation	Stakeholders feel that they can implement a new conservation or research intervention within the sanctuary to manage the rapidly changing ecosystem and related environmental change.	A scientist working for a research institution is able to receive grants to study genomes of coral that are resistant to climate change and disease, and then grow these corals in a nursery, and receive permits to replant these corals in the sanctuary.

Analysis was a multi-coder effort with multiple coders assessing inter-coder reliability. Three total coders assigned codes between March and June 2022, and three of coders selected approximately 25% of codes at random to check the work and ensure agreement between the previous coder. Instead of hypotheses, qualitative research instead uses expectations grounded in the theoretical framework of the research. Due to the exploratory nature of this research, our expectations are simply that we anticipate variability in the presence or absence of components of adaptive governance including 1) opportunities for dialogue for stakeholders of the FKNMS, 2) opportunities for inclusion in the decision-making of FKNMS, and 3) opportunities for experimentation in the management of FKNMS. Characterizing the presence or absence of components of adaptive governance can help decision-makers understand where there are gaps in capacity to respond to climate change.

2.6. FINDINGS

Table 12 provides an overview of the major themes for each component of the adaptive governance framework used in our research. We collapsed the concepts of dialogue and inclusion into a single concept because in the FKNMS the process for including stakeholders was the same process for ensuring dialogue, that of the conservation plan revision process known as the Restoration Blueprint enacted by the collection of stakeholders known as the Sanctuary Advisory Council. Experimentation is occurring in response to climate change in the form of coral restoration projects, which started as small, disjointed efforts from NGOs in the early 2000s, with efforts now scaled up into a flagship program of the federal government even receiving international investment. We revised the framework for adaptive governance, in the context of collaborative, interdisciplinary, and participatory research to include blockages to climate responses so that gaps can be addressed. Scenarios, by their nature, asked decision-makers how they are responding to climate impacts on sanctuaries, and many respondents listed their responses and critical gaps in capacity that can be filled as we respond to climate change over coming decades.

Table 12: *Revised Framework for Adaptive Governance from collaborative research with decision-makers and stakeholders*

Concept	How this is present or absent in the case site	Example quote from interviews
Dialogue & Inclusion	These theoretical concepts were collapsed into one because the process for including stakeholders is also that which ensures dialogue. We found evidence for a large scale, multi-year public comment and stakeholder engagement process to re-write the management plan, a process known as the Restoration Blueprint managed by a stakeholder engagement advisory committee called the Sanctuary Advisory Council	"The advisory council, in the government act that created the FKNMS created the Sanctuary Advisory Council [which includes], all public agencies, (state, federal, and local) who interact with the Sanctuary Advisory Council. For example there are two environment seat holders, there are fishing and diving seats, there are research, education, and public at large seats. All Sanctuary Advisory Council members serve a 3 year term. Keep in mind, we are "advisory," meaning we do not make the decisions, but we do pass resolutions to recommend management actions to the managers of the FKNMS." (Respondent 5)
Experimentation	Experimental responses to climate	"Restoration professionals are

	impacts focused on coral restoration which includes transplanting coral from donor to recipient reefs, growing coral in nurseries, using emerging technologies like micro-fragmentation, and genetic prioritization of heat and disease tolerant coral. Originally, restoration was fragmented and conducted by NGOs and aquarium industry leaders in the early 2000s, by 2019 it became a mainstream, flagship policy of the FKNMS inviting private sector, all scales of government including international donors, and NGOs to partake in a rapid and cutting edge response to global change. Managers also frequently noted the need to consider new and emerging diseases like stony coral tissue loss when enacting restoration processes.	looking for corals that have survived stony coral tissue loss and saving genotypes, going behind the disease's pathway to get the heartiest survivors, from the shallowest hottest water, and growing those corals in nurseries, and replanting them." (Respondent 32)
Blockages to climate response	Blockages included interorganizational coordination, permitting, and physical space limits for nurseries	"Restoration groups require permitting by the American Zoological Association, and the Endangered Species Act. Also, the Florida Department of Agriculture and Consumer Services, the Army Corps of Engineers, NOAA Fisheries, Florida Fish and Wildlife, and then FKNMS requires its own phased permitting. We know why this is all required, so that it is done right, but it is a lot. It is so much easier to experiment in other countries." (Respondent 31).

THE FUTURE IS NOW

Every respondent that participated in our research noted that despite our scenarios asking about 10 and 20 years in the future, the conditions described in the scenarios were in fact occurring today. A representative quote from a reef management leader embodies this perception: "I've already seen this, it's just going to get worse. 20 years ago you could have told me this." (Respondent 22). The unwittingly conservative nature of our projections highlighted stakeholders who were already adapting to climate change and had been for years, for example this charter boat captain:

> *"I am already responding to this future. The climate has changed so much in recent years, that I have had to drive taxicabs at night. I have been a charter [boat] captain for longer than you have been alive. I have never had to do this before. I have people come in from out of state, we can't do any snorkeling or diving, so I drive a cab. (Respondent 1)"*

This type of adaptation, where stakeholders change livelihoods from reef-based to non reef-based signifies a widespread change in the fabric of life of the Florida Keys that is already currently taking place. The Keys bring in over $3 billion in tourism traffic, suggesting that climate impacts will create significant economic shifts (Respondent 23). Similar ongoing and future shifts in livelihood strategies were echoed by commercial fishermen, an industry spanning generations and dating back to when the Florida Keys were a collection of small fishing villages. Commercial fishing is the second largest employer in the Keys behind tourism, responsible for 4500 jobs with 1650 permit holders worth $935 million dollars. 20 members of the Sanctuary Advisory Council are also prominent commercial anglers. Fishermen are already adjusting where and when they fish for target species due to temperature shifts (Respondent 22).

DIALOGUE AND INCLUSION

The FKNMS has innovative pathways for stakeholder inclusion in decision-making and dialogue on management interventions. The most important of which is the multi-year process of eliciting stakeholder participation and dialogue to redraft the management plan first written in 1997. This process, known as the *Restoration Blueprint*, includes the elicitation of hundreds of public comments from a wide range of stakeholders compiled into a Notice of Proposed Rulemaking. Agency staff, seafood and tourism industry groups, members of the public, and non-governmental organizations (NGOs) collaborate within the Sanctuary Advisory Council, tasked with creating dialogue among stakeholders while capturing and cataloging thousands of varying perceptions among hundreds of stakeholders over decades of management. The Sanctuary Advisory Council is countering rapidly emerging and intensifying challenges like new diseases and intensifying thermal stress, while still complying with state and federal regulations that govern the FKNMS.

An example of one of the most important proposed changes in the *Restoration Blueprint* involves that of the locations and rules of several sanctuary preservation areas (SPAs)[2] that show uncharacteristically high coral cover relative to the rest of the FKNMS. Managers establish SPAs to protect particularly biodiverse reefs with critical marine species, a reason why they serve as the most popular dive sites in FKNMS. Proposed management changes to SPAs would protect unique nearshore patch reef habitats, habitats that are underrepresented in the FKNMS, by ensuring that these corals that are resilient to bleaching and disease (indicated by their continued survival) would fall within SPAs. This SPA protection will entail stronger limitations on human

[2] The Restoration Blueprint specifically plans to eliminate two SPAs (French Reef and Rock Key), combine two into one (Key Largo Dry Rocks and Grecian Rocks), and add two new SPAs (Turtle Rocks and Turtle Shoal). SPAs limit human activity like fishing, where there is only fishing (trolling and catch and release) allowed in 4 of 18 SPAs.

uses. To do this, catch and release fishing that was once permitted in the SPAs is being phased out[3] alongside previously-permitted anchoring on sandy bottom for dive vessels that are unable to find a mooring buoy, with the revised plan installing additional mooring buoys. The planned changes to SPAs are aimed at protecting corals that have survived the spread of a decimating coral disease, Stony Coral Tissue Loss Disease, as well as sensitive, replanted corals as part of restoration activities. Responding to Stony Coral Tissue Loss Disease is an urgent and recent task, emerging as a management challenge in 2014 and causing harm to 22 species of stony coral in Florida and the Caribbean.

While proposed changes to SPAs are not universally accepted, managers are working to build trust with those opposing management changes, namely some recreational and commercial angler groups, through collaborative science between sanctuary managers and fishermen. In the words of a prominent commercial angler: “It used to be that the biggest threats to our business were hurricanes and tropical storms, nowadays it is management and decisions and what those in charge do with rules and regulations. We do a significant amount of cooperative research with these management agencies and provide input on regulations. They come in, and we work with them to do a study on traps, coral damage, catch methods, we want to help and make sure they are getting good data that we accept as valid.”

Stakeholder inclusion is not limited to management planning. It is also occurring with transformative scientific research used in decision-making. Commercial anglers were grappling with plans over the coming years to possibly move northward to follow commercially valuable species like spiny lobster. At the forefront of commercial angler respondents’ minds was the unavoidable Northward march of spiny lobster. In the words of one respondent, which echoed several others, “We will soon be going up to Palm Beach, which used to be the Northern threshold.” Decision-makers are adapting to the possible shift in lucrative fisheries by partnering with civil society actors to tag and monitor lobsters. In the words of a prominent fisherman, “We are also looking at the knock on effects of [climate] in the increasing intensity of storms, which can devastate commercial traps for both lobster and stone crabs” and “we want to be preemptive, [help scientists] tag lobsters, see what happens. If we are not a part of the research, we do not trust it, so we have learned to help.” Fishermen noted vulnerabilities if fisheries would shift elsewhere from the Keys, “Presently, money stays in the keys, it is earned here and stays here, this 100 mile chain of islands we are the largest commercial seaport in the state of FL providing enormous economic value to the state. If fisheries move, this is eliminated.”

In addition to expanding SPAs, the *Restoration Blueprint* is also proposing 4 expansion zones capturing deep reef habitat to protect spawning aggregations of key species like black grouper and cubera snapper, spiny lobster migration corridors, and deep water coral colonies.

EXPERIMENTAL SOLUTIONS: POLICY & INSTITUTIONS

Our research suggests that inclusion, dialogue, and experimentation in the sanctuary are not separate characteristics as our theoretical framework would suggest. Instead, the FKNMS has institutional characteristics (e.g. norms, regulations, decision-making protocols) that are

[3] The fishing ban proposed in SPAs is meant to standardize regulations in the sanctuary making them easier to understand and comply with.

experimental due to the way that they elicit extensive dialogue and input from all stakeholders. For example, managing processes that ensure inclusive dialogue over many years requires agencies and other organizations to collaborate and manage this workload in experimental ways. The capacity for many government and non-governmental organizations to work together to assemble and consider stakeholder dialogue can be traced to the legal act of Congress which created the sanctuary itself (Rep. Fascell, 1990). This act created the management institution known as the Sanctuary Advisory Council, which represents a wide range of stakeholders and government agencies that aren't the sanctuary's main management authority (NOAA), inviting them to dialogue (Respondent 5). The institutional structure of the FKNMS itself is an experimental co-trusteeship between the state, the Florida Department of Environmental Protection, and the NOAA Office of Marine Sanctuaries all operating with some authority within the Sanctuary. Several manager respondents noted that the inclusion and dialogue to inform a new management plan every 10 years is extremely time consuming, "It takes forever because [managers] ask everyone what they want. Some ask, 'Why are we doing this again? We have already heard all these people, we have heard them so many times,' –well we do it again because there's a chance you may hear something new through the Sanctuary Advisory Council" (Respondent 34).

EXPERIMENTAL SOLUTIONS: RESTORATION

Nearly every respondent noted that the most important experimental response is coral reef restoration being deployed by government agencies, NGOs, and the private sector. Several types of coral restorations are being enacted in FKNMS including 1) direct transplantation of coral fragments from a donor to a recipient reef, 2) coral nurseries that allow coral to grow prior to outplanting, 3) micro-fragmenting of massive and encrusting corals, a process developed at Mote Marine Lab in the Florida Keys, and 4) selecting coral species for nursery growth based on genotypes that may be heat tolerant and disease resistant.

Although restoration has been occurring for some time in a decentralized way, in 2019, the federal managers at the FKNMS launched an experimental management effort known as *Mission: Iconic Reefs*, aiming to restore 3 million square feet of reef, one of the largest coral restoration efforts in history. *Mission: Iconic Reefs* directs federal funds and foundation donations to restoration efforts with the explicit purpose, as of 2022, of scaling up restoration as quickly as possible. Restoration priorities for the *Mission: Iconic Reefs* program include a genetic management plan for restored coral, building organizational capacity for large scale restorations, restoring grazer populations such as Caribbean King Crab and Long-Spined Sea urchin, and monitoring results. Federal funds have built much of the capacity to launch this large-scale project, but international collaboration is also underway with the United Arab Emirates donating $3.5 million to a local NGO, the United Way of Collier and the Keys, to support restoration in 2022 (Respondent 32). Private companies, NGOs, research institutions, and prominent donors are also working collaboratively to implement this project.

Just like with the institutional innovations required to invite the large volume of stakeholder commentary, the large-scale collaboration of government, NGOs, private sector, and international governments conducting restorations is experimental. In the early 2000s, NGOs began working on reef restoration which, according to respondents, was initially met with skepticism among sanctuary managers. This skepticism has, in 20 years, changed to become a large, formal management program within the Sanctuary, as part of its *Mission: Iconic Reefs* Program. In the words of an NGO leader: “The ultimate aim in creating these [coral restoration] responses [in the early 2000s] was scaling up the reef resilience work with more government, NGOs, and so on involved. The ultimate aim being that we no longer do it ourselves, but we have empowered people like managers to do it.” Without early experimentation from NGOs, it is possible that restoration could never have turned into a mainstream experimental policy response to climate change (Respondent 6).

Experimental responses in restorations today are focusing on genomes that are resilient to heat and disease. In the words of one respondent from the private sector, who formed a lean, start-up style company to rapidly innovate in restoration technology: “[We have] found genomes that are tolerant to warmer conditions. There is a lot of great stuff going on here. The innovation that I have seen since I have moved to the keys 30+ years ago is pretty cool, a lot of great minds working on this stuff” (Respondent 22).

The institutional design of the Sanctuary Advisory Council and its prioritization of dialogue ensures that managers in state and federal agencies are aware of and can take advantage of emerging scientific knowledge. For example, Mote Marine Lab is enacting a multi-pronged approach to its restoration work. They are 1) working to understand disease ecology of new and emerging diseases like Stony Coral Tissue Loss, 2) determining which genotypes of corals are most resilient to ocean acidification to select them for restoration, 3) selecting corals that reach sexual maturity in the shortest period of time once out-planted to drive natural recovery, and 4) banking genotypes to archive reef building coral genotypes and selecting for the ones that will ensure survival under thermal stress, among other research priorities (Respondent 32).

Those engaged in coral restoration are not arguing that restoration will solve the issue of climate change. In the representative words of one stakeholder:

> *“We are fully aware as practitioners that our restoration is not going to fix this problem. We make no claims that it will. We are concerned with maintaining genetic diversity and lessening the effects until more appropriate solutions— that are far outside the scope and capabilities of a [single NGO]— can be found. (Respondent 10). “*

BLOCKS TO RESPONDING TO CHANGE

Our prototype methodology for combining climate models, ecological models, and social science creates its biggest contribution by asking real people on the ground where they are experiencing blockages when they try to respond to climate change impacts. Surprisingly, respondents frequently noted that financial resources were not the limiting factor in responding to climate change. Instead, physical limitations to the space needed to create coral nurseries at a scale never before attempted appear to be a key issue. In the words of one respondent,

> *“I've never been at [a research lab] with more resources. We have issues though with space which is a big issue here in the Keys. We operate 3 nurseries in the keys: Summerland, Islamorada, and a smaller satellite one being built in Key Largo. To*

properly scale restoration on a landscape scale you need a much more substantial additional footprint built out or up, plus it is horrendously expensive down here. We need an innovative way to expand nursery space in limited space." (Respondent 32)

Another blockage to maximizing potential of a large-scale restoration is bureaucratic delays, specifically interagency coordination and permitting. With so many independent (NGO and private) and government (federal and state) agencies working on the same goal, stakeholders cite running into issues where an NGO will be out-outplanting coral, then the same plot a nearby university does the same, and then a private firm. Questions on how to monitor all interventions through time, and coordinate many actors doing the same thing at the same time to maximize desired ecological outcomes. One scientist stakeholder notes:

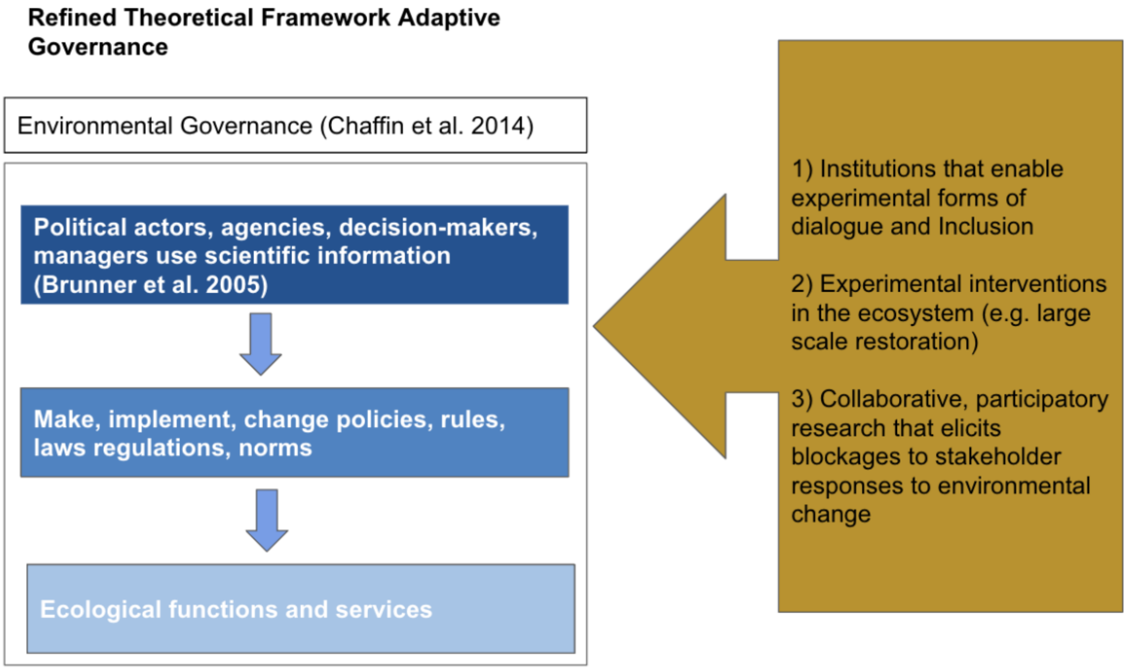
"How do we adapt our methods and cooperation with other organizations to achieve the same goal? We all use different techniques, materials, and have a different ethos in the way that we move forward in outplanting. We need to allow for some streamlining and some variation, but it is not clear how. FKNMS has come in as a mediator and a director, which is great, they're good at what they do, but they move at a slow pace (government). They are a bottleneck and a godsend at the same time." (Respondent 32)"

Permitting was also described by stakeholders engaging in restoration as a challenge, with several respondents citing a long list of agencies whose permission is required: Florida Department of Agriculture and Consumer Services, the Army Corps of Engineers, the National Marine Fisheries Service, Florida Fish and Wildlife, and then FKNMS requires 5 iterations of permitting. Restoration groups are also permitted by the American Zoological Association, working in that regulatory framework as well as by the Endangered Species Act. One respondent called this a "spider web of regulations" that slows the pace required to restore landscape scale reef parcels (Respondent 32).

2.7. CONCLUSION: IMPLICATIONS FOR ADAPTIVE GOVERNANCE

Our research presents a revised framework for adaptive governance shaped through collaborative, participatory research that engages stakeholders and decision-makers. Theory suggests that three key concepts enable adaptive governance including: inclusion of all stakeholders, opportunities for dialogue, and experimental management. We slightly refine this theory to be more relevant to collaborative, participatory research projects like ours. We argue that adaptive governance is enabled via 1) experimental institutions that foster inclusive opportunities to ensure stakeholder dialogue, 2) experimental solutions to climate impacts, and 3) elicitation of current blockages to scaling up experimentation. Figure 7 represents this revised framework for adaptive governance.

Figure 7: *Revised framework for adaptive governance (in yellow)*



As a management institution, the federal FKNMS has shown remarkable capacity to adapt to extreme outcomes on the reef. In the early days of coral reef restoration, interviewees noted that previous generations of FKNMS managers were skeptical of allowing restoration within the sanctuary. Thanks to the decades long work of private sector companies and NGOs, as well as community buy-in for the restoration process, this shifted significantly culminating in the adoption of the *Mission: Iconic Reefs* program, akin to a "moon shot" attempt to replant more coral than has ever been attempted in a rapid response to climate impacts and disease. The role of the FKNMS is that of mainstreaming an experimental approach, facilitating the financial and regulatory pathways for the constellation of organizations to engage in restoring reefs. There are improvements that can be made in the process, such as the sheer number of additional governmental agencies that need to also permit restoration work. Could it be possible that the loss of Florida's reefs is so urgent, a novel permitting process could be developed where all permitting agencies come together to develop a single permit process that can be used by all agencies? It is these human system blockages that can be a major venue for reforms, compared to other blockages that are harder to engage, such as the lack of space for coral nurseries.

Our research method, linking climate science and social science, generated collaborative research where stakeholders and decision-makers in the FKNMS were able to shape and prioritize the direction of our research. Other studies that use scenarios in ecosystem management contexts have likewise found that scenarios trigger important discussions with stakeholders, a valuable process in ecosystem stewardship (Malinga et al., 2013). Some cases of participatory scenario planning have found that using scenarios helps reach consensus on management strategies to desired ecological futures (Palomo et al., 2011). Our research supports this assertion, in that nearly every respondent interviewed suggested that experimenting with restoration, and rapidly scaling it up, was the best shot that FKNMS has to manage severe degradation from the past 30 years.

The next steps to this type of research could be using several scenarios, grounded in tailored climate projections, as competing scenarios with tradeoffs in the policy-making process, similar to Palomo et al. 2011 and Palacios-Agundez et al. 2013. The inclusive process where the FKNMS invites all stakeholders to advise its decisions as the Sanctuary Advisory Council would provide an ideal setting for this type of cutting edge management practice, and possibly provide a way forward for management planning decisions over which it is unable to reach consensus (Palacios-Agundez et al., 2013). An additional next step of this research could be using tailored climate modeling and scenarios to predict ecosystem services fluxes under different management scenarios similar to the work that has been done in South Australia coastal zones (Sandhu et al., 2018).

Our contribution is the first attempt at combining climate model outputs and long form, qualitative interviews with decision-makers and stakeholders with learning that goes two ways. Researchers transmitted information on predicted climate futures to stakeholders and stakeholders transmitted knowledge on how they are responding and will respond to changing climate. This collaborative learning between researchers, stakeholders, and decision-makers is essential for meeting the extreme challenges that we face from climate change.

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Appendix 1

Theoretical Framework

To best conceptualize the importance of cultural ecosystem services, and the values they hold for the people who rely on these ecosystems, we must clearly define some of the key terms outlined in our theoretical framework, derived from Fish et al 2016. In this framework the fundamental building block for understanding how cultural ecosystem services and the benefits they provide work in tandem. It begins with the biophysical domain in which humans interact with their environment. The biophysical domain is defined as nature's condition and ecological functioning (independent of interactions with people/benefits/services). Stated simply, the biophysical domain provides the material components of the environmental spaces where these interactions take place. Additionally, the biophysical domain provides opportunities for the various cultural practices enabled by environmental spaces. The environmental spaces and cultural practices (described in further detail below) both work to shape the biophysical domain. In the Cayman Islands, the reefs in Georgetown Harbor being threatened or lost by the port expansion project are the biophysical domain and the environmental spaces being examined in this chapter.

Environmental spaces are defined as the physical locations or sites in which humans and the societies and cultures they populate, interact within the ecosystem. This can include meadows, streams, mountain tops, and in the context of the Cayman Islands, the beaches and reefs surrounding the islands. These spaces provide a context for the linking of the biophysical domain with cultural practices and cultural ecosystem benefits, as these spaces shape the biophysical domain and enable cultural practices and benefits.

In the case of the Cayman Islands, a majority of the environmental spaces which provide these benefits are reefs, beaches, lagoons, and other marine environments surrounding the islands. Popular locations around the three islands (Grand Cayman, Little Cayman, and Cayman Brac) include Eden Rock, Devil's Grotto, Macabuca, Cheeseburger Reef, Seven Mile Beach, and the USS Kittiwake.[4]

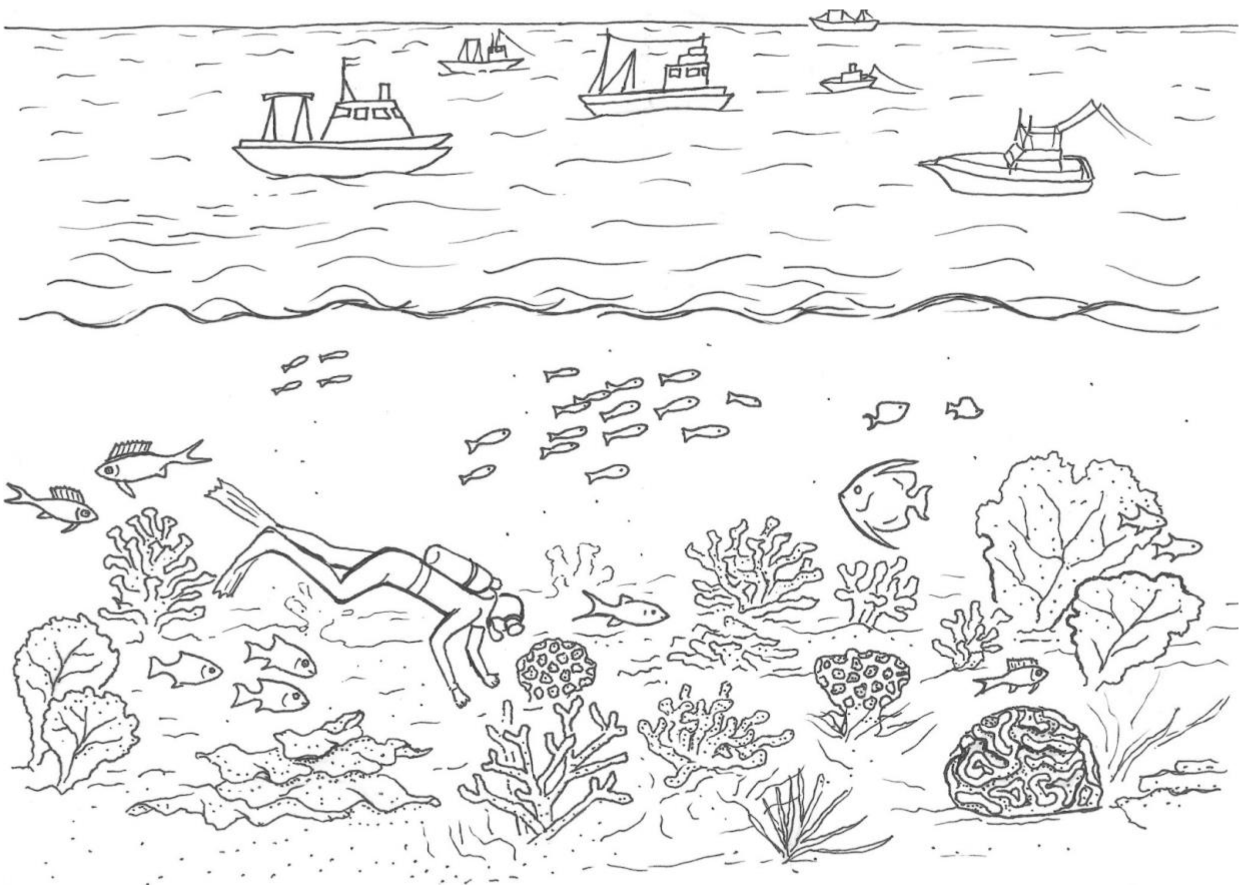
[4] Eden Rock, Devil's Grotto, Macabuca, and Cheeseburger Reef are dive sites in the Cayman Islands. Seven Mile Beach encompasses several popular dive sites. The USS Kittiwake is a shipwreck dive site.

Appendix 2

Interview Questions

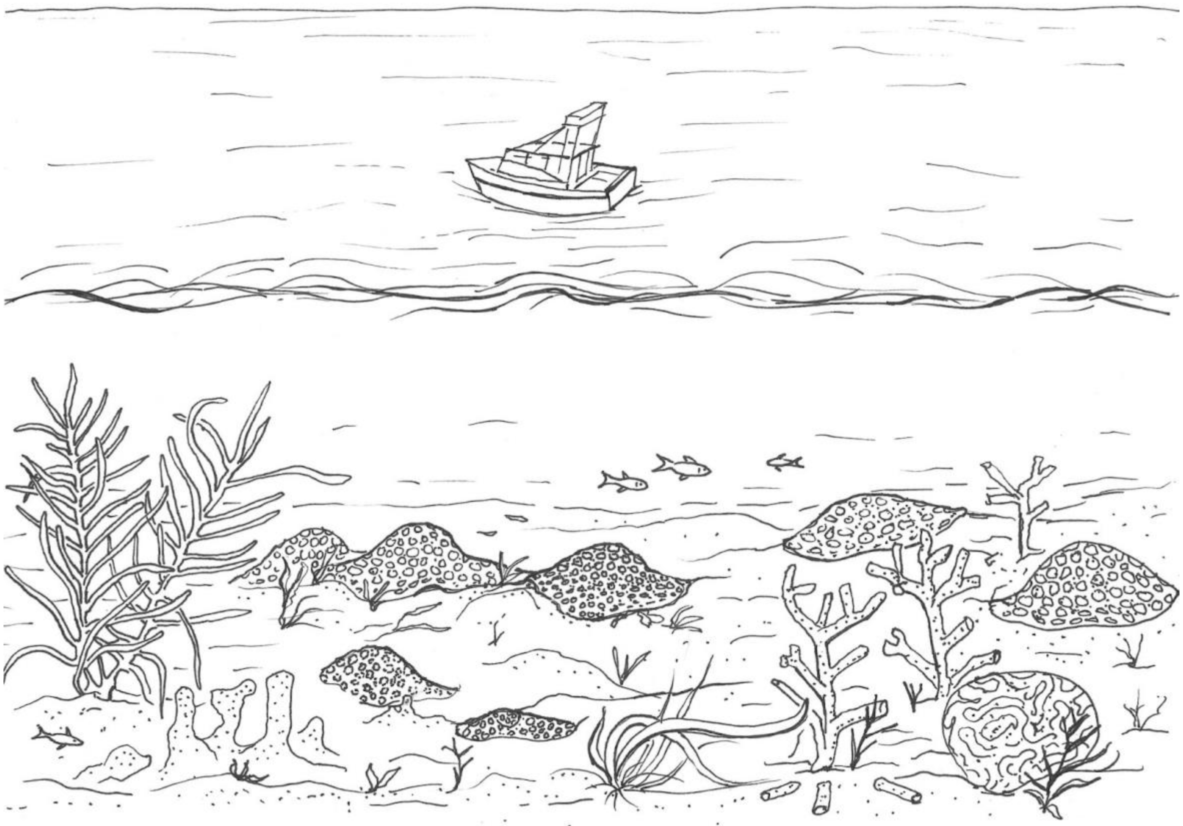
1. What are the primary ways you interact with the reefs (e.g. manager, user, business, etc.)?
2. What type of management do you do on the reefs of the FKNMS?
3. Can you describe formal opportunities for talking to others who use and manage the reef?
4. Can you describe informal opportunities for talking to others who use and manage the reef?
5. Can you describe how stakeholders are or are not included in decision-making in the management of the FKNMS?
6. Can you describe the way that your organization/user group is invited to play a role in management?
7. Scenario 1: 10 years into the future

By the year 2032 (10 years from now), there will be *persistent* levels of bleaching at least once every year, which means that the reefs will be under stress and a percentage of the coral will die. Most remaining corals will be broken or diseased and will be noticeably less colorful. The surviving corals will not be able to replace broken or damaged coral fast enough, and the structure of the reef will appear greatly diminished. Key species that use the reef as habitat/home like lobster, snapper, and grouper will be noticeably less present. Even with this scenario, however, it is possible that, some corals will be more heat tolerant, and those will be the ones you will start seeing more frequently. What are your options to respond? (If respondents needed more information, we'd estimate coral mortality at 50%).



8. Scenario 2: 20 years into the future

By the year 2042 (20 years from now), there will be *unsustainable* levels of bleaching at least twice every year, meaning the reefs will be under stress and most of the coral will die. Very few unbroken and healthy corals will remain. The vibrant colors of the reef will be completely gone. The surviving corals will not be able to replace broken or damaged coral fast enough, and the structure of the reef will appear greatly diminished. At this point, octocorals (commonly known as sea plumes) are the dominant coral on the reef, and stony coral like elkhorn and staghorn are no longer visible. The amount of fish and other reef species on the reef will decrease as well, meaning people will need to spend more time looking for them to view or fish for them. Other key species that use the reef as habitat/home like lobster, snapper, and grouper will be noticeably less present. That said, some corals are showing signs of being heat tolerant, and those will be the ones you will start seeing more frequently. What are your options to respond? (If respondents needed more information, we'd estimate coral mortality at 50%).



Artist Kristen Krumhardt

9. What are the blockages to respond to climate impacts?
10. What are the partnerships to respond to climate impacts?
11. Likert scale 1-5: In the management of the reefs of the FKNMS, experimentation of new management options is possible due to climate change? A. Strongly agree, B. Agree, C. Neutral, D. Disagree, E. Strongly disagree
12. Can you explain how experimentation is possible due to climate change?