ASSESSMENT OF REEF AND FISHERIES MANAGEMENT IN BELIZE USING A SOCIAL-ECOLOGICAL SYSTEMS APPROACH

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ABSTRACT

CATHERINE LAWRENCE ALVES: Assessment of reef and fisheries management in Belize using a social-ecological systems approach
(Under the direction of John F. Bruno)

Commercial and subsistence fisheries provide livelihoods and fish protein to nearly three billion people annually. This demand has led to overfishing, which disrupts marine ecosystem functioning and threatens fisheries sustainability. Fisheries are some of the most challenging common-pool resource systems (CPRS) for which to develop effective management strategies because they are easily sub-tractable and non-excludable. Without effective institutions to regulate the extraction of the marine species, users are inclined to overharvest resources. Territorial User Rights for Fishing (TURFs) have recently emerged to encourage environmental stewardship in coastal communities by providing effective ownership of fish stocks, further incentivizing sustainable fishing practices. These such community-based fisheries management (CBFM) strategies grant fishers rights to fish in designated areas in exchange for reporting their catch. Belize became the first country in the Caribbean to implement a nationwide TURF system–known as Managed Access (MA)–in 2016, resulting from long-term collaborations between governmental and international fisheries agencies.

In this dissertation, I applied Ostrom's social-ecological systems (SES) framework to understanding and evaluating over forty years of marine resource management in Belize. Using mixed methods, I determined that marine resource management in Belize is institutionally robust (e.g. contains nested and decentralize enterprises), which could lead to the overcoming of

collective action problems often found in CPR systems. Next, I described coral reef benthic community structure from 21 sites across the Belize Mesoamerican Barrier Reef (BMBR) following several major disturbances (bleaching, storms, and disease), and attributed them to ocean warming and local human impacts, from 1997-2016. I found two ecologically distinct assemblages between early and late sampling years, significant declines in mean coral cover, and significant increases in macroalgae cover over ~20 years. Lastly, I conducted quantitative interviews of fishers from 10 communities in southern Belize in 2019 and compared their knowledge, attitudes and perceptions to fishers from 2014. I discovered that respondents from both years understand the requirements for getting and renewing MA licenses, yet perceive lack of enforcement as an issue to success. The results of my dissertation provide holistic, science-based advice for sustaining fishers' livelihoods while preserving coral reef ecosystems in a changing world.

To Mitch, my mom, my Gram, and my sister, for being my biggest supporters.

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LIST OF ABBREVIATIONS

AIC	Akaike Information Criterion
ANOVA	Analysis of Variance
BAHA	Belize Agricultural Health Authority
BAS	Belize Audubon Society
BELTRAIDE	Belize Trade and Investment Development Service
BFD	Belize Fisheries Department
BFF	Belize Federation of Fishers
BHA	Belize Hotel Association
BMBR	Belize Mesoamerican Barrier Reef
BTB	Belize Tourism Board
BTIA	Belize Tourism Industry Association
CBFM	Community-Based Fisheries Management
CBWS	Corozal Bay Wildlife Sanctuary
CCA	Crustose Coralline Algae
CCRE	Caribbean Coral Reef Ecosystem
CDO	Climate Data Operator
CoRTAD	Coral Reef Temperature Anomaly Database
CPRS	Common-Pool Resource System
CPUE	Catch Per Unit Effort
CZM	Coastal Zone Management
CZMAI	Coastal Zone Management Authority and Institute
EDF	Environmental Defense Fund

EEZ	Exclusive Economic Zone
FoH	Fragments of Hope
FoN	Friends of Nature
FP	Fully Protected
GLMM	Generalized Linear Mixed Model
GSSCMR	Gladden Spit and Silk Cayes Marine Reserve
GRMR	Glover's Reef Marine Reserve
GU	General Use
GUZ	General Use Zone
HCMR	Hol Chan Marine Reserve
HII	Human Influence Index
ITQ	Individual Transferable Quota
KAP	Knowledge, Attitudes and Practices
LBNP	Laughing Bird National Park
MA	Managed Access
MATT	Managed Access Technical Team
MAWG	Managed Access Working Group
MBRS	Mesoamerican Barrier Reef System
MCCAP	Marine Conservation and Climate Adaptation Project
MPA	Marine Protected Area
MSR	Marine Scientific Research
MSY	Maximum Sustainable Yield
NEMO	National Emergency Management Organization

NGO	Non-Governmental Organization
NICH	National Institute of Culture and History
NMDS	Non-Metric Multidimensional Scaling
NPAS	National Protected Areas System
ODK	Open Data Kit
PACT	Protected Areas Conservation Trust
PHMR	Port Honduras Marine Reserve
PRZ	Preservation Zone
ResCA	Resilient Central America
RZ	Replenishment Zone
SACD	Sarteneja Alliance for Conservation and Development
SEA	Southern Environmental Association
SEDAC	Socioeconomic Data and Applications Center
SES	Social-Ecological System
SST	Sea Surface Temperature
TAC	Total Allowable Catch
TAMR	Turneffe Atoll Marine Reserve
TASA	Turneffe Atoll Sustainability Association
TASTE	Toledo Association for Sustainable Tourism and Empowerment
TIDE	Toledo Institute for Development and Environment
TNC	The Nature Conservancy
TSA	Thermal Stress Anomalies; the SST minus the maximum of weekly mean climatological SST calculated over the data range
TSA_Freq	Frequency of TSA; the number of instances TSA was over 1 °C

	over the previous 52 weeks
TSA_Freq_hist	Accumulative TSA; number of times since the beginning of the dataset (1982) to survey year that TSA was over 1 °C
TSA_Freq_btw_surveys	Frequency of TSA between survey years; the number of instances since the previous survey year that TSA was over 1 °C
TURF	Territorial User Rights for Fishing
UP	Unprotected
WCS	Wildlife Conservation Society
WWF	World-Wide Fund (formerly World Wildlife Fund)

CHAPTER 1: INTRODUCTION

Marine fisheries are some of the most challenging common-pool resource systems (CPRS) to manage. This is because the availability of resources — such as finfish, lobster, and conch — is subject to unregulated extraction and overuse by other users (Olson 1965, Ostrom 1990, Ostrom et al. 1999, Ostrom 2003). Further exacerbating this issue is the challenge of tracking and quantifying marine resource abundance across large and sometimes international oceanic boundaries (Cudney-Bueno and Basurto 2009, Urquhart et al. 2014, Levine and Richmond 2015). Overfishing of marine resources results from such un-checked extraction, leading to 80 – 95% reductions in large predatory fish biomass (Valdivia et al. 2015). This not only disrupts marine food web structure and ecosystem functioning, but also threatens invaluable commercial and subsistence fisheries that provide livelihoods and fish protein to nearly three billion people annually (FAO 2014).

The majority of present day small-scale multi-species fisheries management relies on local governance and stock assessments within territorial coastal waters, which include monitoring catch per unit effort (CPUE), reporting maximum sustainable yield (MSY), and setting catch limits on target species (Valdés-Pizzini et al. 2016). Rampant overfishing in these fisheries led resource managers to use a variety of gear-based management strategies and develop catch limits to decrease additional ecosystem impacts (Jackson et al. 2001, Valdés-Pizzini et al. 2016). Marine Protected Areas (MPAs) are a common fisheries management tool designed to protect fish populations and promote habitat resilience. MPAs are areas within which extractive fishing behaviors are restricted. Sometimes fish abundances and diversity are greater within well-managed, large (>100 km^2), old (>10 years) and isolated MPAs, and can often increase and spill over into adjacent non-protected areas (Gaines et al. 2010, Edgar et al. 2014, Chirico et al. 2017). Fishers can reap the benefits of increased fish size and abundance by fishing near MPAs, their access regulated via catch share programs and fishing licenses (Gaines et al. 2010, Anderson and Uchida 2014). However, poaching, lack of enforcement, limited spillover, and limited management resources often contribute to the failure of MPAs to achieve social and environmental objectives (Coelho 2007, Graham et al. 2008, Huntington et al. 2011, Edgar et al. 2014, Cox et al. 2017, Gill et al. 2017).

An established method of fisheries management, community-based fisheries management (CBFM), attempts to combat the aforementioned issues associated with MPAs. CBFM combines the understanding of fisheries – stocks, populations, and extraction methods – and the role of humans in shaping these techniques through culture, history, and social structure (Urquhart et al. 2014, Valdés-Pizzini et al. 2016). CBFM offers solutions to the common pool resource problems associated with fisheries because it provides a platform where fishers, managers, and communities collaborate to reach collective objectives. Another goal of CBFM is to protect the integrity and function of marine ecosystems while limiting and regulating fisheries extraction methods (Urquhart et al. 2014, Valdés-Pizzini et al. 2016). This can be done by limiting general-use access and implementing a licensing system, such as catch share programs for fishers (Foley et al. 2012, Barner et al. 2015). Catch share programs can provide a way for fishers to participate in local fisheries management by reporting their catch to associated fishing authorities while being granted “shares” of the total allowable catch (TAC) (Wiber et al. 2004, Islam and Yew

2013, Kittinger 2013, Alexander et al. 2015). Fisheries managers then use the data to develop more accurate catch limits and promote long-term sustainable fishing practices.

Belize was the first country in the Caribbean to establish a catch share program – known as Managed Access (MA) – which gives fishers rights to fish in select areas but requires them to report their catch to management officials. The particular catch share program implemented in Belize is an example of a territorial user rights for fishing (TURF) regime, where fishers were granted rights to fish in 1-2 areas paired with marine reserves, in exchange for reporting their catch and color-coding their vessel(s) (Foley 2015, Belize Fisheries Department 2015, Barner 2015, Fujita et al. 2017, Belize Fisheries Department 2019). MA was piloted in 2011 at the Port Honduras Marine Reserve (PHMR) and Glover's Reef Marine Reserve (GRMR), and later implemented nationwide in 2016, with six additional fishing sites added to Belize's territorial waters (Figure 1.1) (Foley 2015, Belize Fisheries Department 2015, Barner 2015, Fujita et al. 2017, Belize Fisheries Department 2019). This program built upon over four decades of evolving marine resource management in Belize and is the foundation of Belize's new Fisheries Resources Bill (Belize Fisheries Department 2019).

The purpose of my dissertation research was to apply Ostrom's social-ecological systems (SES) framework (Ostrom 2007, Brondizio et al. 2009) to understanding and evaluating over four decades of marine resource management in Belize (Figure 1.2). The SES framework provides a theoretical basis to examine the interactions and outcomes of social and ecological variables by defining four key components: (1) the Resource System, which outlines the natural resource system of habitats to be managed, (2) the Governance System, which describes all of the entities involved in setting the rules for access and extraction within the Resource System, (3) the Resource Units, which are the species extracted from the Resource System and managed by the Governance System, and (4) the Actors, who include the users of the Resource System and individuals in the Governance System (Figure 1.2) (Ostrom 2007, Brondizio et al. 2009).

The SES framework applied to marine resource management in Belize is very complex (Figure 1.2). The Resource System describes the Belize Mesoamerican Barrier Reef (BMBR) including the variety of marine ecosystems contained within that area (seagrass beds, mangroves, coral reefs, lagoons, cayes, and atolls). The Governance System in Belize includes the federal government, comprised of the Belize Fisheries Department (BFD), The Coast Guard, Port Authority, and Customs, the non-governmental organization (NGO) co-managers, including the MA committees (i.e., representatives from fishing communities, the NGOs and the Fisheries Department) and the MA Working Group (MAWG). The Resource Units refer to all species extracted from the Resource System by the Actors, and whose regulation is determined by those in the Governance System. In Belize, the Resource Units are primarily lobster, conch, and finfish species (including snapper, Goliath grouper, snook, grunts, and barracuda). The Actors, who participate in the Belize MA program, include natural resource managers at the governmental and NGO levels, commercial fishers, scientists and academics who seek to understand the action situation and collaborate with most actors, and representatives from the tourism and property sectors.

Each data chapter in this dissertation focuses on a different aspect of the SES framework. Chapter Two focuses on the Governance System of the SES framework by evaluating the robustness of the institutions involved in fisheries management in Belize. I first identified the institutional roles and structure, then examined the impact of that institutional structure on the decision-making power and implementation of the Managed Access program, and lastly determined that marine resource management in Belize exhibits Ostrom’s eight design principles for long-enduring CPRS (Ostrom 1990). Chapter Three focuses on the Resource System of the SES framework by describing changes in coral reef assemblages at 21 sites (roughly half of the sites within MPAs) across the Belize Mesoamerican Barrier Reef (BMBR) following several major disturbances (bleaching, storms, and disease) over a 20-year period (1997-2016). I identified potential drivers of reef changes, including local human impacts and ocean temperature, and described two unique ecological assemblages between early and late sampling years. Chapter Four focuses on the Actors of the SES framework, by comparing the knowledge, attitudes and practices of fishers towards the MA program between 2014 and 2019. Fishers in 10 communities in Southern Belize were interviewed in 2014 by the Belize Fisheries Department and again by me in 2019. I found that fishers overall know the rules to acquire and renew MA licenses, with significant increases in knowledge about the catch reporting process in 2019, but a lack of enforcement capacity hinders overall success.

By examining marine resource management in Belize from a social-ecological systems lens, this work contributes to the growing peer-reviewed literature about community-based fisheries management efficacy across the globe. Including fishers in the participatory process of fisheries management can lead to long-term sustainability goals for their livelihoods and the ecosystem on a whole (Fujita et al. 2017, Karr et al. 2017, Mcdonald et al. 2017). Lessons learned from this dissertation can be applied to improving small-scale fisheries management decisions in a changing world.

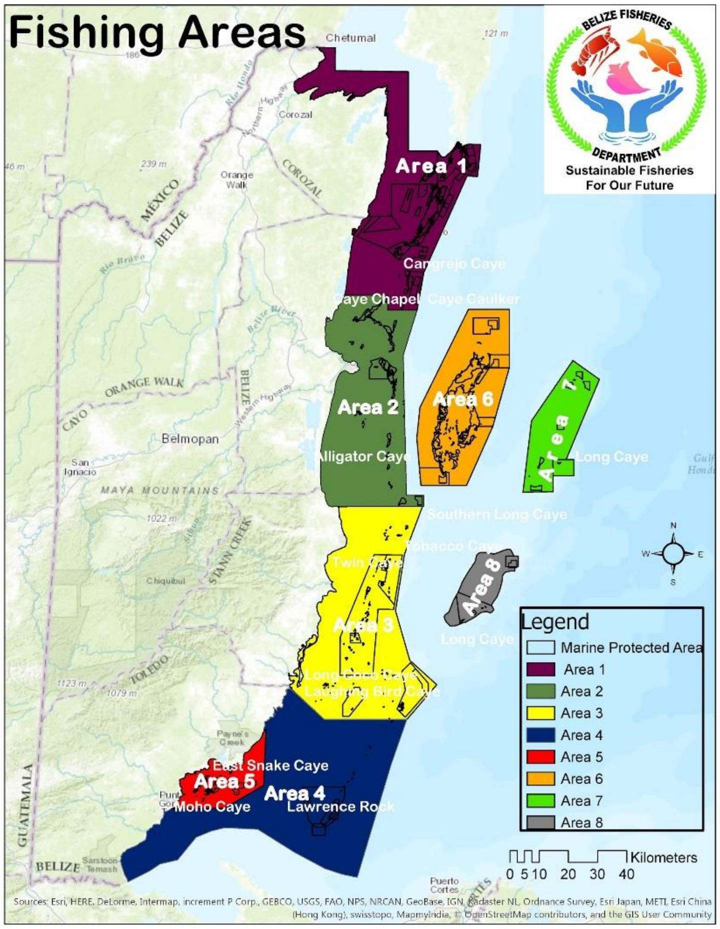

Figure 1. 1: Managed Access fishing areas in Belize. The polygons represent MPAs. The two pilot sites established in 2011 were: Area 5 (in red), the Port Honduras Marine Reserve (PHMR), and Area 8 (in grey), the Glovers Reef Marine Reserve (GRMR). The remaining Areas were established in 2016. Map from the Belize Fisheries Department 2019.

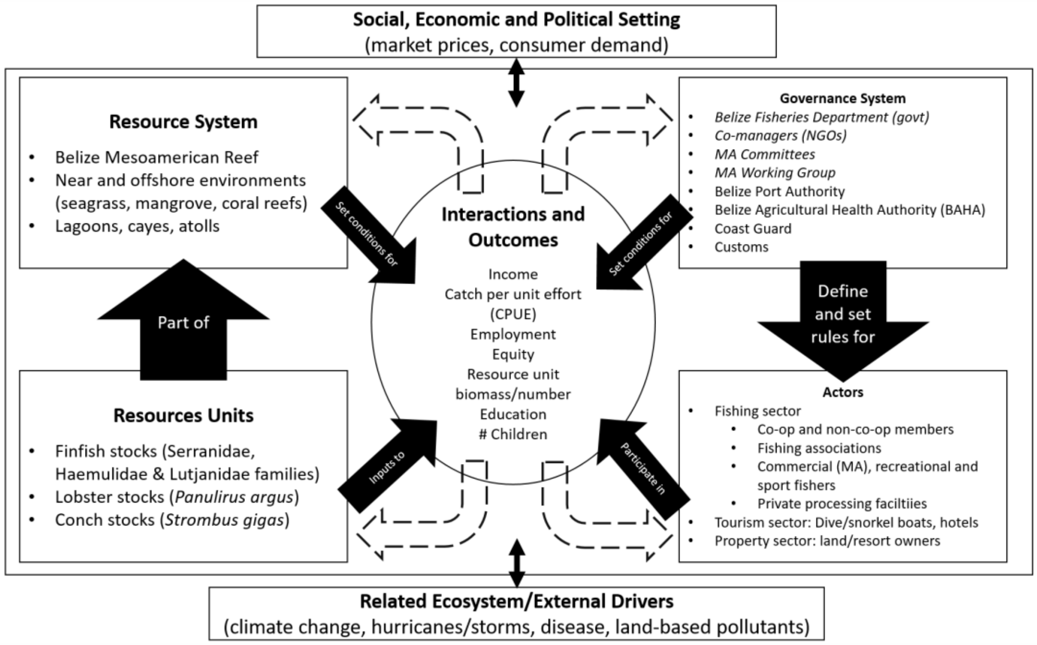

Figure 1. 2: Conceptual representation of marine resource management in Belize within the SES framework (Adapted from Ostrom 2007 and 2009, McGinnis and Ostrom 2014, Martone et al. 2017).

CHAPTER 2: MARINE RESOURCE MANAGEMET AND FISHERIES GOVERNANCE IN BELIZE: HISTORICAL ANALYSIS AND WAYS FORWARD[1]

Introduction

Forests and fisheries are often described as common pool resource systems (CPRS) because excluding resource unit (e.g. trees, land, and fish) extraction is challenging, and [over]consumption can contribute to the overall decline in resource availability to others (Olson 1965, Ostrom 1990, Ostrom et al. 1999, Ostrom 2003). Marine fish species are examples of common-pool resources because: 1) they are seemingly available for extraction (Anderson and Uchida 2014), 2) it is difficult to identify, track, and estimate their abundance (Levine and Richmond 2015), and 3) it is challenging to manage the access to the resource across large and sometimes international oceanic boundaries (Cudney-Bueno and Basurto 2009, Urquhart et al. 2014, Levine and Richmond 2015). Furthermore, the over-extraction of marine resources has implications for both environmental and livelihood outcomes. The overexploitation of marine systems and lack of effective management institutions manifests itself as overfishing, which leads to degradation of food webs and disruption of overall ecosystem functioning (Jackson et al. 2001).

Because subsistence and commercial fishing provide nearly three billion people with fish protein annually (FAO 2014), it is essential to develop management approaches to restore fish populations and maintain food security. The majority of present-day fisheries management relies

[1] A version of this chapter is in review in *Ocean and Coastal Management* as Alves, C. Marine resource management and fisheries governance in Belize: historical analysis and ways forward.

on local governance and stock assessments, which report catch per unit effort (CPUE) and estimate maximum sustainable yield (MSY) via population and ecosystem models (Costello et al. 2008). Small-scale fisheries in the tropics are often managed by targeting single-species and setting catch limits on the species of interest. To combat the threat of overfishing, there has been increased interest in establishing multi-species fisheries, enforcing the use of a variety of gear strategies, setting catch limits, and restricting fishing in select areas(Jackson et al. 2001, Gaines et al. 2010, Valdés-Pizzini et al. 2016).

Fisheries management measures, including formal licensing procedures and Marine Protected Areas (MPAs), have been the primary management response to overfishing. MPAs function by restricting fishing access to select offshore locations with the intention of increasing fish abundances and diversity within those areas, with fish spilling over to adjacent non-protected areas (Gaines et al. 2010). MPAs then may be coupled with specific restrictions on fishing, e.g. catch share programs and special licenses, ideally leading to increased fish size and abundance to participating fishers (Costello et al. 2008). However, MPAs often fall short of achieving ecological and social benefits due to lack of specified policy and goals (e.g. "paper parks"), enforcement capacity, poaching, limited spillover, as well as social conflict when fishers' livelihoods are negatively affected by MPAs (Huntington et al. 2011, Gill et al. 2017, Bruno et al. 2019). Common challenges to effective MPA governance also include confused goals, increased conflict, and unrealistic aims to scale-up beyond institutional capacity (Christie and White 2007), which demonstrate a need for improved MPA management.

One promising way to overcome these issues with CPRS in fisheries is to include fishers in the management of their fisheries by leveraging social capital (Brondizio et al. 2009) and inspiring collective action among community members (Olson 1965, Ostrom 1990, Ostrom et al.

1999, Ostrom 2003). Social capital refers to the value of trust established by networks of individuals and institutions who share common interests (Brondizio et al. 2009). The organization of those institutions has the potential to inspire collective action from communities, where individuals self-organize into groups to perform actions that lead to group benefits that would not be available to a non-group member ((“Olson 1965, Ostrom 1990, Ostrom et al. 1999, Ostrom 2003, Brondizio et al. 2009, Pinho et al. 2012)). To encourage collective action among individuals in a community, a common objective and behavior towards resource utilization must be identified, but this is no easy feat (Ostrom 2007, Brondizio et al. 2009, Pinho et al. 2012, Reddy et al. 2013). The success of such collective action depends on the networks of institutions involved, and the direction of motivation, which oftentimes begins on the local level and works up to the state- or country-wide level (Foley 2012, Catzim and Walker 2013, Barner 2015, Ayer et al. 2018).

Institutions for collective action in small-scale fisheries include fishing cooperatives and associations that advocate for fishers’ rights to management officials and that sometimes own shares of the total catch (Armitage et al. 2012, Basurto et al. 2013, Aceves-Bueno et al. 2017, Karr et al. 2017). These institutions provide a platform for fishers to become a part of community-based fisheries management (CBFM) by including them in the monitoring, enforcement, and overall decision-making processes involved in resource management in their communities (Wiber et al. 2004, Armitage et al. 2012, Pinho et al. 2012, Islam and Yew 2013, Urquhart et al. 2014, Valdés-Pizzini et al. 2016). Such participatory co-management may encourage environmental stewardship among fishers because they develop a sense of ownership of their fisheries, which provide additional incentives for sustainable fishing practices and continued collective action (Wiber et al. 2004, Cudney-Bueno and Basurto 2009). The overall polycentric governance structure of CBFM contributes to broad stakeholder involvement, increased policy freedom at local levels, improved spatial fits between knowledge and action, and ultimately better responses to complex changes facing fisheries in the future (Cvitanovic et al. 2018). These benefits can lead to long-term sustainability of conservation measures.

Scholars interested in CPRS institutions have identified several design principles that enhance probability of success. For instance, Ostrom identified eight design principles of long-enduring CPRS institutions that have been identified as potential means to solve collective action problems (Ostrom 1990). These principles can act as a means to empirically analyze the robustness of institutions in securing environmental and livelihood outcomes because they can be more directly measured. The principles include: 1) clearly defined boundaries (such as a coastal region), 2) connection between local conditions and provisioning rules, 3) collective-choice arrangements, where the users participating in operational rules also have collective-choice rights, 4) monitoring of the resource system by the users, 5) graduated sanctions in place, 6) conflict-resolution mechanisms between all actors, 7) minimal recognition of rights to organize. where external government authorities do not challenge the rights of appropriators to make their own institutions, and 8) nested enterprises (Ostrom 1990). Such design principles can offer a method for determining the potential for the proper management of CPRS well into the future (Cinner et al. 2009, Levine and Richmond 2015).

The purpose of this study was to assess the robustness of institutions involved in fisheries management in Belize by answering the following questions: 1) What are the institutions involved in fisheries management in Belize, what are their roles, and how are they structured? 2) How does the structure of enforcement and monitoring of Belize's Managed Access program affect decision-making power and implementation of the program? 3) Does marine resource management in Belize exhibit Ostrom's eight design principles for long-enduring CPRS (Ostrom 1990) and what implications does that have for the sustainability of the Managed Access program? I am defining "institutional robustness" by the presence of nested and decentralized institutions, as they are more resilient to shocks (Ostrom et al. 2010). To answer these questions, I used a mixed methods approach that combined review of secondary data, semi-structured interviews with key informants, and participant observation. As of late 2019, a new Fisheries Resources Bill was approved by the government of Belize, introducing many institutional changes to fisheries management across the country. This provides an opportunity to review the history of fisheries management in Belize and look critically into the future. My results suggest that Belize has the institutions in place to potentially be a long-enduring CPRS and overcome collective action problems (Ostrom 1990, Ostrom 2003) . However, certain challenges exist to the program being fully considered "participatory" in practice and in theory.

Case Study Context

Belize geography and marine ecology

Belize is located in Central America. Natural resources are an important contributor to the national economy, including commercial fisheries, eco-tourism (marine and terrestrial), and logging (Karlsson and Bryceson 2016). Belize is home to the second longest barrier coral reef in the world – the Belize Mesoamerican Barrier Reef (BMBR). The Belize Barrier Reef is part of the larger Mesoamerican Barrier Reef System (MBRS), which traces the coasts of Belize, Mexico, and Honduras. The reef system incorporates the diverse marine habitats of mangroves, seagrass beds, fringing and patch coral reefs, and several offshore atolls. Because of this rich biodiversity, ecotourism and fishing are two of the most prevalent livelihood strategies among

Belizeans (Gopal et al. 2015). Lobster, conch, snapper, and grouper are the primary fishery species across Belize (Catzim and Walker 2013).

Evolving coastal zone management in Belize

Belize has a rich history of relying on natural resources (e.g. forest and marine products) for economic, political, and social benefit (Karlsson and Bryceson 2016), stemming from the colonial occupation of the British until Belize independence in 1973 (Wainwright 2009). Over the last 40+ years, tremendous changes in coastal zone management and fisheries policies have occurred in Belize (Figure 2.1). Throughout this timeline, NGOs were formed, which are now some of the key stakeholders and regional co-managers of the marine reserves. The first marine reserve, Hol Chan Marine Reserve (HCMR), was formed in 1987, which started a precedent for future marine protection. Shortly after, in 1989, the first International Coastal Resources Management Workshop was held, focusing on sustainably managing the use and development of coastal ecosystems for the benefit of future generations. In 1996, seven protected areas within the BMBR became designated as a part of a UNESCO World Heritage Site. In 1997, the Toledo Institute for Development and Environment (TIDE) was formed, pioneering the way for other community-based conservation organizations throughout Belize.

In 2000, the Port Honduras Marine Reserve (PHMR) and Gladden Spit and Silk Cayes Marine Reserve (GSSCMR) were developed. TIDE soon became a co-manager of PHMR with the Belize Fisheries Department. In the early 2000s, additional NGOs began to form throughout Belize, including Healthy Reefs for Healthy People in 2003, the Sarteneja Alliance for Conservation and Development (SACD) in 2007, and the Southern Environmental Association (SEA) formed in 2008 from the merging of Friends of Nature (FoN) and the Toledo Association for Sustainable Tourism and Empowerment (TASTE). In 2011, a rights-based fishery known as Managed Access (MA) was piloted at the Port Honduras Marine Reserve (PHMR) and Glover's Reef Marine Reserve (GRMR) (Foley 2012, Belize Fisheries Department 2015, Belize Fisheries Department 2019). This rights-based fishery granted commercial fishers rights to fish in select areas while requiring them to report their catch to management officials. Piloting MA was the first step toward eliminating the “race to fish” associated with Belize’s open access fishery regime. After reported decreases in illegal fishing and increased catch by fishers (Catzim and Walker 2013), the MA program was implemented nationwide in 2016, with seven additional sites added to Belize’s territorial waters (Figure 2.2) (Foley 2012, Belize Fisheries Department 2015, Belize Fisheries Department 2019). Belize currently contains a network of marine reserves with varying levels of access/extraction of marine resources. Within the marine reserves are General Use Zones (GUZ,) where regulated extractive activities are allowed, Replenishment Zones (RZ), where non-extractive activities are permitted, and Preservation Zones (PRZ), which are open to research activities only (Belize Fisheries Department 2015, Belize Fisheries Department 2019).

Most of the marine reserves are co-managed by an NGO and/or the Belize Fisheries Department. As of late 2019, a new Fisheries Resource Bill was approved by the Cabinet, after nearly 10 years of deliberation by the federal government, scientists, fishers, and NGO co-managers. Included in this bill is the development of a Fisheries Council, with representatives from diverse sectors, increased enforcement and monitoring guidelines, and ways to improve fisheries management for sustainability and economic development (Belize Fisheries Department 2019).

Methods

This study used a mixed methods approach that combined reviewing secondary data, semi-structured interviews with key informants and participant observation. The review of secondary data was ongoing throughout the process of this study, and included published and unpublished governmental and non-governmental reports, academic publications (thorough literature searches), and online resources. Semi-structured interviews with key informants and participant observation occurred in June and September 2017, and from April - June 2019.

Key informants included individuals in leadership positions and natural resource managers in the governmental (n = 8) and non-governmental sectors (n = 26) within Belize. Key informants were also fishers (n = 23), some of whom were leaders in their communities (e.g. served on committees, fisher associations), while others were vocal about voicing their opinions about several fisheries-related topics. Participant observation included: attendance at fisher forums, meetings, and presentations by natural resource managers, and various formal and informal gatherings within the communities. Such community gatherings included the fish and produce markets and the Chocolate Festival in Punta Gorda, the Mango Festival in Hopkins, the Lobster Festival in Placencia, and the fish market in Dangriga. All respondents remained anonymous throughout this process.

Results

What are the institutions involved in fisheries management in Belize, what are their roles, and how are they structured?

Here, I describe the complex, polycentric, nested, and decentralized structure (Ostrom et al. 2010) of the institutions involved in fisheries management in Belize. The government, tourism sector, NGOs, and fishers sectors represent the type of institutions involved in the fisheries decision-making process (Figure 2.3). The key informant interviews and participant observations revealed that for many sectors, including the governmental and fishers' sector, institutions are nested within each other, providing for enhanced information transfer, collaboration, and decision-making power. In the NGO, tourism, and fishers sector, many institutions are also decentralized, representing the local community and protected area at regional and national levels.

Government Sector

The first institutional sector involved in fisheries management in Belize represents the federal government. Because coastal resource management in Belize involves the extraction of natural resources, use of Belize's territorial waters, and the trade and exporting of marine products, many governmental institutions are involved. The participant observation, key informant interviews and review of secondary literature revealed six ministries in the governmental sector, within which the different governing institutions reside (Figure 2.4). These nested institutions (McCabe and Feiock 2005a, Ostrom et al. 2010, Ostrom 2012) set rules for domestic and international trade, economic development, natural resource management, national security and enforcement of governmental policies.

Within the Ministry of Economic Development, Petroleum, Investment, Trade and Commerce is the Belize Trade and Investment Development Service (BELTRAIDE, Government of Belize 2019). BELTRAIDE promotes and enables socio-economic development. The Belize Port Authority and Belize Customs and Excise are two institutions within the Ministry of Transport and National Emergency Management. The Belize Port Authority is led by the Ports Commissioner (a.k.a. Harbour Master) and is responsible for regulating and developing

Belize’s ports, harbors and shipping as well as ensuring the safety of all vessels navigating within Belize’s territorial waters (Belize Port Authority 2019). Belize Customs and Excise develops and implements policies to ensure increased safety/security and develop the effective platforms for effective trade and revenue collection (Belize Customs and Excise 2018). International trade policies are developed by the Belize Customs and Excise, which are essential to the export of lobster and conch as the primary marine products exported from Belize (Belize Customs and Excise 2018).

The Belize Tourism Board (BTB), and the National Institute of Culture and History (NICH) are within the Ministry of Tourism, Civil Aviation, and Culture (Ministry of Tourism and Civil Aviation 2019). The BTB is a partner between the government and the private (tourism) sector in Belize, working closely with four tourism stakeholder groups (hotels, tour operators, tour guides, and the cruise industry (Belize Tourism Board 2020)). The role of BTB in natural resource management will be explained in the subsequent section. NICH is a statutory body that preserves and shares Belize’s historic and ethnic roots (National Institute of Culture and History 2020).

The Belize Coast Guard (Belize Ministry of National Security 2016a), Belize Police Department (Devex 2020), Belize Defence Force (Belize Defence Force 2020) and National Emergency Management Organization (NEMO, National Emergency Management Organization 2020) are housed within the Ministry of National Security (Belize Ministry of National Security 2016b) as entities all responsible for ensuring the safety and security of those in Belize. The Belize Coast Guard and Belize Defence Force are part of the professional military with soldiers trained in ensuring the safety and security of those in Belize. The Belize Coast Guard enforces maritime laws and protects Belize’s territorial waters (Belize Ministry of National Security

2016a), while the Belize Defence Force is more focused on the defense of Belize and supporting the Civil Authorities in maintaining order in Belize (Belize Defence Force 2020). The Belize Police Department works on more local levels to preserve law and order across the country, with three police for every 1000 inhabitants (Devex 2020). NEMO is responsible for providing citizens with information regarding emergency preparedness, storm tracking, and natural disasters (National Emergency Management Organization 2020).

The Belize Agricultural Health Authority (BAHA, Belize Agricultural Health Authority 2020) and the Belize Department of Cooperatives (Ministry of Food, Agriculture, and Immigration 2017a) is housed within the Ministry of Food, Agriculture, and Immigration (Ministry of Food, Agriculture, and Immigration 2017b). The BAHA oversees animal health, plant health, quarantine and food safety services that prioritize the health and wellness of those it serves while strengthening national food security and facilitating trade/commerce. BAHA is directly involved in the production, management, and trade of the marine products (lobster, conch, finfish) that are sold domestically and internationally (Belize Agricultural Health Authority 2020). The Department of Cooperatives provides regulatory services for entrepreneurial development programs related to the cooperative sector in Belize. The fisheries cooperatives (explained below) are regulated by this department (Ministry of Food, Agriculture, and Immigration 2017a).

The Forest Department (The Forest Department 2019), Department of the Environment (The Department of the Environment 2020), Fisheries Department (The Belize Fisheries Department 2013), Protected Areas Conservation Trust (PACT, Protected Areas Conservation Trust 2019) and Coastal Zone Management Authority and Institute (CZMAI, Coastal Zone Management Authority 2019) are all housed within the Ministry of Agriculture, Fisheries, Forestry, the Environment, and Sustainable Development (Government of Belize 2020). The Forest Department enforces the policies and regulations for the sustainable management of Belize's forested ecosystems (The Forest Department 2019). The Department of the Environment focuses on establishing, recommending and enforcing policies that improve environmental quality, limit pollution, and promote public engagement (The Department of the Environment 2020).

The Fisheries Department is responsible for the development and enforcement of management policies surrounding aquatic and fisheries resources, with a focus on sustainability for present and future generations. They are the primary government agency involved in fisheries management policies across Belize, working closely with the tourism and NGO sectors (The Belize Fisheries Department 2013). PACT is a national conservation trust which manages Belize's National Protected Areas System (NPAS) through strategic partnerships and investment opportunities (Protected Areas Conservation Trust 2019). CZMAI is a statutory body within the government responsible for the development and implementation of coastal zone management (CZM) strategies in Belize (Coastal Zone Management Authority and Institute 2019).

Tourism Sector

The key informant interviews, participant observation and review of secondary data revealed three main tourism sector institutions involved in fisheries management in Belize: The Belize Tourism Board (BTB, Belize Tourism Board 2020), the Belize Tourism Industry Association (BTIA, Belize Tourism Industry Association 2020) and the Belize Hotel Association (BHA, Belize Hotel Association 2020, Figure 2.5). The tourism sector is included in this paper for a variety of reasons: A) fishers sell their catch to restaurants, resorts and hotels, B) many fishers are also tour guides (they even take tourists out to go recreational fishing, thereby relying on “healthy” marine ecosystems for guests), and C) they are a big economic and decision-making stakeholder in determining, expanding, and enforcing marine protected areas.

Both the BTB and BTIA act as connections between the private and public sectors of the tourism industry. As previously stated, the BTB is a statutory body within the Ministry of Tourism (government sector) that acts as a strategic partner between the government and the private tourism sector. It develops, markets and implements tourism programs to fulfill the emerging needs of local and international tourism markets. The organizational structure of BTB includes branches such as Marketing and Industry Relations, Destination Planning and Cruise, Information Technology, and Finance (Belize Tourism Board 2020). The BTIA is an umbrella organization for the tourism industry’s private sector because it has representation on almost every government, legislative, advisory and consultative committee. BTIA is governed by a president and board of directors while the management of everyday operations is led by an executive director and secretariat (Belize Tourism Industry Association 2020).

The BTB and BTIA represent dive shops, cultural vendors and experiences, tour operator associations, tour operators, tour guide associations, tour guides, and hotels. All tour guides and tour operators do not have to be members of their respective associations, but they need to be registered with the BTB. The cruise industry is only represented by the BTB while sports fishing guides are only represented by the BTIA. The BTIA also has local chapters based on the destination, including (but not limited to) those in San Pedro, Caye Caulker, Cayo, and Corozol (Belize Tourism Industry Association 2020b). Lastly, the BHA is a non-profit, NGO and Belize’s oldest private sector tourism organization. It supports the sustainable growth of member hotels and the tourism industry in Belize via marketing initiatives, inter-and intra-sector partnerships and training services. Its membership includes educational facilities, resorts, lodges, condominiums, homestays and hotels (Belize Hotel Association 2020).

Environmental Non-Governmental Organization (NGO) Sector

The NGOs included in this paper focus on the environment and sustainability, and are not exhaustive of all NGOs in Belize. However, since the early 1990s, local and international NGOs have been working in Belize to promote the environmental conservation and sustainability of natural resources (Figures 2.1 and 2.6). Some NGOs are also co-managers of marine reserves with the Belize Fisheries Department. For the purpose of this paper, I divided the NGOs into those that are international with a local Belize chapter, and those that are local to a community or region within Belize. Making that distinction is important when considering the institutional stability, resources, and governance potential of all of these NGOs. Through many semi-structured interviews with key informants, participant observation and detailed review of secondary data, I describe all NGOs involved in coastal resource management and conservation in Belize (Figure 2.6).

Many of the NGOs local to a community focus on particular regions, marine reserves or a combination of the two. Many combine research, environmental monitoring, enforcement of fisheries policies, environmental outreach, and community development. The NGOs are led by a suite of full-time staff members, and overseen by boards of directors, which consist of community members, and representatives from the tourism and fisher sectors. The Southern Environmental Association (SEA) is based in Placencia, Belize, and is a co-manager of the Gladden Spit and Silk Cayes Marine Reserve (GSSCMR) and Laughing Bird National Park (LBNP, Yello Belize 2020). The Belize Federation of Fishers (BFF) is an umbrella organization that represents many individual fishers and fisher associations, but not all of them. Membership to BFF is voluntary. The BFF is led by an executive managing committee of 16 community representatives, many of whom are in leadership positions in their communities/fisher associations. The BFF was registered as a fisher community-focused conservation organization for commercial fishers in 2011, and incorporated in 2013 (BFFishers 2015). The Toledo Institute for Development and Environment (TIDE) is based in Punta Gorda, Belize, and works primarily in the Maya Mountain Marine Corridor of southern Belize. TIDE co-manages the Port Honduras Marine Reserve (PHMR) with the Fisheries Department, co-manages Payne's Creek National Park, and manages TIDE Private Protected Lands (TIDE 2020).

The Sarteneja Alliance for Conservation and Development (SACD) is based in Sarteneja, Belize, and serves the stakeholder communities of the Corozal Bay Wildlife Sanctuary (CBWS, SACD Belize 2020). The Belize Audubon Society (BAS) is another NGO co-manager of Lighthouse Reef Atoll, where the Belize Blue Hole and Half Moon Caye are located. BAS is headquartered in Belize City and is the oldest environmental NGO in Belize, having been founded in 1969 (Belize Audubon Society 2015). The Turneffe Atoll Sustainability Association (TASA) is also located in Belize City, and it co-manages the Turneffe Atoll Marine Reserve (TAMR, Turneffe Atoll Marine Reserve 2020). The Coalition for Sustainable Fisheries was formed in 2018 primarily to advocate for a gillnet ban throughout Belize and consists of conservation organizations, tourism operators, and sports and commercial fisherfolk (The Coalition for Sustainable Fisheries 2020). Fragments of Hope (FoH) is another NGO local to Belize, which focuses on coral restoration projects and sustainable management of coastal habitats (Fragments of Hope, Belize Ltd. 2015).

On the other hand, international environmental NGOs with chapters in Belize focus on a variety of environmental issues, both marine and terrestrial, and their international status enables them to leverage broader resources. Many of these international organizations combine science-based conservation work with stakeholder engagement and community development. They often collaborate with many of the Belizean-based NGOs, fisher communities and government agencies to meet common conservation goals. One such environmental NGO is Healthy Reefs for Healthy People, with projects across the entire Mesoamerican Barrier Reef System (MBRS), in Mexico, Belize, Guatemala and Honduras (Healthy Reefs 2020). Healthy Reefs collaborates with NGOs and government agencies to co-produce annual ecological monitoring "Report Cards" on the status of the MBRS. MarAlliance is another international NGO, based in Sarteneja, Belize, which focuses on improving the conservation of threatened marine species and their habitats, most notably sharks and rays. They have other projects across the MBRS as well as in Cabo Verde and Micronesia (MarAlliance 2020). Oceana is another international NGO with projects in Belize. Oceana was established in 1999 in the United States as an ocean advocacy group dedicated to protecting and restoring the world's oceans. Their work in Belize includes the passing of legislation banning offshore oil drilling, decreasing ocean plastic pollution and most recently, petitioning for the elimination of gill net use by fishers (Oceana 2020). Blue Ventures also works Belize on grassroots marine conservation initiatives (Blue Ventures Conservation 2020).

Headquartered on Carrie Bow Caye is a Smithsonian Institution Field Station for their Caribbean Coral Reef Ecosystems (CCRE) Program. The Carrie Bow Field Station includes a scientific laboratory, housing for visiting scholars, SCUBA facilities, and other resources for long-term monitoring of the Belize Barrier Reef System. The World-Wide Fund (WWF, formerly World Wildlife Fund) is another international organization that has been working in Central America since 1987. They were instrumental in the establishment of Belize's first MPA, the Hol Chan Marine Reserve. Since then, they have been involved in developing a season for spiny lobster, developing the Turneffe Atoll as an MPA and in the completion of Belize's National Integrated Coastal Zone Management Plan (World Wide Fund for Nature 2020). The Wildlife Conservation Society (WCS) has also been working in Belize for several decades, with projects including improved enforcement of fishing regulations, education and outreach programs, and spawning aggregations research. WCS is also the only international organization that serves as a co-manager of the Glover's Reef Marine Reserve (GRMR) with the Belize Fisheries Department (Wildlife Conservation Society 2020).

The Nature Conservancy (TNC) has been working in Belize since 1991, on projects ranging from seaweed aquaculture to seafood traceability in cooperatives (The Nature Conservancy 2020). They are working closely with Resilient Central America (ResCA) to improve seafood traceability at the National Fishermen Cooperative in Belize City (The Nature Conservancy 2019, 2020). The Environmental Defense Fund (EDF), and Rare collaborated with the government, NGOs, and fisher communities to transition fisheries management from an open-access regime to the rights-based/TURF program Managed Access from 2009-2017. They have also been integral in the development of the new Fisheries Resources Bill of 2020 (Environmental Defense Fund 2020, Rare 2020).

Fishers Sector

From key informant interviews and participant observation, I divided the fishers sector into three broad categories with unique license requirements: sport, recreational, and commercial

(Figure 2.7). Sport fishers are required to have a specific license to participate in catch-and-release of these species: tarpon, permit, bonefish, and snook. Recreational fishers do not need licenses. As of July 2016, all commercial fishers are required to obtain a Managed Access license, which grants them rights to fish in 1-2 of the areas outlined in Figure 2.2 (Belize Fisheries Department 2015, Belize Fisheries Department 2019). All fishers are required to abide by the coastal zone management rules and follow guidelines for marine reserves (i.e. they are not allowed to extract marine products where it is prohibited). All three of these groups of fishers can economically benefit from their fishing activities, because commercial fishers sell their marine product to formal and informal markets within Belize, and the sport and recreational fishers often rely on income related to the tourism sector (source: key informant interviews and participant observation).

Commercial fishers include individual fishers, fishers' associations (of which many are a part), Rainforest Seafoods, Ltd., cooperatives, and the Belize Federation of Fishers (BFF). The Belize Federation of Fishers was previously described. Many fishers are members of – and therefore sell their product to – one or all of the following fishing cooperatives: National Fisherman Cooperative (in Belize City), the Northern Fishermen Cooperative (in Independence/Mango Creek and Belize City), and the Placencia Produces Cooperative. These three cooperatives fall under the governing body, the Belize Department of Cooperatives. National and Northern Fishermen Cooperatives purchase only lobster and conch, primarily for export, while Placencia Produces Cooperative purchases lobster, conch and finfish. For fishers to be members of these cooperatives, they must pay an annual membership fee. Fishers benefit from cooperative membership by not only getting competitive prices for marine products, but also opportunities for small grants, raffles, and professional development. Fishers can also choose to sell lobster and conch to Rainforest Seafoods, which has collection facilities in Mango Creek/Independence and Dangriga, Belize, and exports the product internationally (Rainforest Seafoods 2020).

Providing the most direct opportunities/benefits for fishers is membership/participation in a fisher association. Most of the fishers' associations across Belize represent the commercial fishers of individual coastal fishing communities at regional and national scales. A complete list of the fishers associations can be found in Figure 2.7. Several communities have representation by multiple fisher associations. For instance, fishers engaged in aquaculture activities in Sarteneja can be represented by the Sarteneja Tilapia Growers and Development Association, and if they are also commercial fishers, be represented by the Sarteneja United Local Fishermen Association. Similarly, Dangriga has two fishers' associations: the Wabafu Fisherman Association ("Wabafu" is a Garifuna word meaning "people power") and the Belizean Chairmen of Fishers. In the Toledo District, and around Punta Gorda Town, fishers are represented by the Toledo Fishermen Association, and the Southern Fisherfolk Alliance Association. To be a functioning fisher association, there needs to be regular fee-paying membership, annual meetings, and meetings throughout the year. Executive meetings must also be held where records/minutes of the meetings are maintained and shared with the membership (source: key informant interviews).

Individual fishers may be members of one fisher association, 1-2 cooperatives, and the BFF (by way of their fisher association), any combination, or not represented by any of these organizations. Membership to a fisher association and/or cooperative is voluntary, and not all individual fishers are members/represented by any fisher-oriented organization. This provides a challenge when considering the equitable representation of fisher's needs at local, regional, and national scales (i.e. some voices and viewpoints will be excluded due to this structure).

Synthesis

Overall, the governmental, tourism, NGO, and fishers sectors involved in fisheries management in Belize demonstrate highly polycentric, nested, and decentralized institutions. In total, there are 16 governmental institutions housed within six ministries all involved in the rulemaking, enforcement, and oversight of different aspects of fisheries management in Belize. The tourism sector is represented by three primary institutions, but they represent the breadth of actors involved in tourism at local and national scales. The NGO sector is vast, with international (n = 11) and local (n = 8) agencies invested in environmental and fisheries sustainability in Belize. Because many of the NGOs are involved in their local communities, a decentralized structure is represented by these entities. Lastly, the fishers sector represents a complex arrangement of cooperatives, fisher associations, and individual interest groups, which demonstrates the varying degrees of self-organization and collective action potential of the actors here.

<u>How does the structure of enforcement and monitoring of Belize's Managed Access program affect decision-making power and implementation of the program?</u>

From 2017-present, I conducted 57 key informant interviews to describe and understand the institutional framework for the enforcement and monitoring of the Managed Access program, which is highly decentralized (Figure 2.8) (Ostrom 1990, Dietz 2003, Chuenpagdee and Jentoft 2018). In Figure 2.8, the Belize Fisheries Department (BFD) is depicted as the highest governing body because the BFD sets the rules and regulations for the licensing process, logbook reporting, and enforcement of MA (Belize Fisheries Department 2015, Belize Fisheries Department 2019). The individuals representing the BFD in this depiction include the Fisheries Administrator (Beverly Wade), who oversees the entire BFD. Working closely with her are the Marine Scientific Research (MSR) Permit Officer (Mauro Gongora), and the Managed Access Liaison Officers in Belize City (Isabel Martinez) and Punta Gorda. The decentralized structure represented in Figure 2.8 leads to a division of decision-making power from the Belize Fisheries Department, a centralized governing body, down to the local, community-level, where each MA area is represented by its own committee. These MA committees consist of representatives from many of the sectors described in previous sections. The basis for the MA program was to pair marine reserves with the territorial user rights for fishing (TURF) areas, so each of the eight MA areas has a marine reserve paired with it. As such, each area is [co-]managed by a government and/or NGO agency (Belize Fisheries Department 2015, Belize Fisheries Department 2019).

Because MA implementation was driven by a partnership between the Environmental Defense Fund (EDF) and the Belize Government, there are representatives from EDF and BFD on the Managed Access Technical Team (MATT). From 2014-2017 the MATT was an extension of the BFD and was responsible for implementing MA on a national level. Members of the MATT provided leadership, advice, and knowledge to those on the Managed Access Working Group (MAWG). The MAWG consists of the members of the MATT, but also the leadership (Executive Directors) of the co-manager NGOs, representatives from the Forest Department, individuals from the fisher communities, and academic partners. The role of the MAWG was to develop, implement, and oversee Managed Access (Belize Fisheries Department 2019). From 2013-15, the MAWG and BFD underwent an extensive consultation process with key stakeholders of the fishing industry to develop the framework and plan for MA implementation nationwide. The MAWG provides a link between each MA area and the BFD by providing information transfer, and resources for enforcement, licensing and logbook reporting (source: key informant interviews). The governance of each of the eight MA areas (excluding Area 9: deep water) involves diverse stakeholder groups (Figure 2.8). The primary management institution for each MA area is the MA Committees, which consist of elected persons from the fishing communities, and representatives from the BFD and co-managers. The purpose of the MA Committees is to provide community leadership, scrutinize license applications, improve transparency in the license granting process, inform their communities about program updates, and assist with improved data collection/reporting (Foley 2012, Belize Fisheries Department 2015, Belize Fisheries Department 2019).

Area 1 is co-managed by the Sarteneja Alliance for Conservation and Development (SACD), the Forest Department, and the BFD. SACD collaborates with the Forest Department to manage the Corozal Bay Wildlife Sanctuary. Area 1 encompasses these three marine reserves, which are all managed by the BFD: Bacalar Chico, Hol Chan and Caye Caulker. The fisher communities who mostly use Area 1 are Sarteneja, Chunox, Copper Bank, Caye Caulker, and San Pedro. Area 2 is managed by the BFD and is the only MA area that does not consist of a marine reserve. The fishing communities who mostly use Area 2 are the same as Area 1, but may also include Belize City. Area 3 is co-managed by the Southern Environmental Association (SEA), the Forest Department and the BFD. SEA manages the Gladden Spit and Silk Cayes Marine Reserve and works with the Forest Department to manage the Laughing Bird Caye National Park. BFD manages South Water Caye, and the parts of Area 3 that are not managed by SEA or the Forest Department. The fishers that mostly use Area 3 come from these communities: Dangriga, Hopkins, Riversdale, Seine Bight, Independence, Placencia, and Monkey River.

Area 4 includes the Sapodilla Cayes Marine Reserve, which is managed by the BFD. The fisher communities that mostly use Area 4 are from Monkey River, Punta Negra, Punta Gorda, and Barranco. Area 5 is the entirety of the Port Honduras Marine Reserve (PHMR), which is managed by the Toledo Institute for Development and Environment (TIDE). TIDE works closely with the BFD to issue licenses to fishers and to improve enforcement of the area. There are general use areas of the marine reserve where fishing is allowed, but also conservation and replenishment zones, where fishing is restricted. The fishing communities who mostly use Area 5 are Monkey River, Punta Negra, Punta Gorda and Barranco. Like Area 5, Area 6 is also a marine reserve. Area 6 is the Turneffe Atoll Marine Reserve (TAMR), which is co-managed by the Turneffe Atoll Sustainability Association (TASA). The fishing communities who mostly use Area 6 are Belize City, Chunox, Caye Caulker, San Pedro.

Area 7 comprises the Lighthouse Reef Atoll, which is home to the Half Moon Caye and Blue Hole National Monuments. These sites are co-managed by the Belize Audubon Society (BAS) and the BFD. The fishers who mostly use Area 7 are from these communities: Belize City, Chunox, Caye Caulker, San Pedro, Copper Bank and Sarteneja. Area 8 is the Glover's Reef Marine Reserve (GRMR), which is co-managed by the Wildlife Conservation Society (WCS). The fisher communities who mostly use Area 8 are from Dangriga, Riversdale, Hopkins, Seine Bight, Placencia, and Independence. Area 9 is the only area that does not have a formal Managed Access Committee, and is where all fishers are allowed to fish. Area 9 is mostly deep slope fishing, which is very gear/resource-intensive, so not many fishers go there. It is, however, being explored as a new fishery option (Belize Fisheries Department 2019).

In summary, the enforcement and monitoring of the Managed Access program in Belize is highly decentralized (Ostrom 1990, Dietz 2003, Chuenpagdee and Jentoft 2018). This structure has implications for how decisions are made and implemented from the national levels down to the individual fisher communities. The presence of fishers, NGO leaders, and governmental representatives on each MA committee provides for improved information transfer and implementation between the local and national levels. Furthermore, having each MA area overseen by a committee enables for more equitable representation of the users of each area.

Does marine resource management in Belize exhibit Ostrom's eight design principles for long-enduring CPRs (Ostrom 1990) and what implications does that have for the sustainability of the Managed Access program?

The results in this section suggest that fisheries management in Belize exhibits all eight of Ostrom's design principles for long-enduring CPRs (Ostrom 1990, Table 2.1), but some are more established than others. This leads to an imbalance of governing power and areas of improvement for the program in the long run. For instance, the MA fishing areas within Belize's exclusive economic zone (EEZ) represent the clearly defined boundaries of the resource system (Foley 2012, Belize Fisheries Department 2015, Fujita et al. 2017, Belize Fisheries Department 2019), for which the provisioning rules of the actors apply. MA committees not only connect the local conditions to provisioning rules but they also give collective-choice arrangements to the fishers because they are platforms for fishers to represent the interests of their communities to natural resource managers (Belize Fisheries Department 2015, Belize Fisheries Department 2019, key informant interviews). The local community-based NGOs as co-managers of marine reserves provide further connection between the local context and provisioning rule development at the national level (Belize Fisheries Department 2015, Belize Fisheries Department 2019, key informant interviews). The NGOs, in collaboration with the BFD, do the majority of the monitoring and enforcement of the resource system, which takes the responsibility of monitoring away from the users (fishers). However, fishers are quite aware of transboundary and non-licensed users in their area, leading to a potential increase in fisher-led monitoring efforts in the future (sources: key informant interviews and participant observation). If users are found breaking the provisioning rules, then there are graduated sanctions in place. Currently, the BFD observes a three-strike rule; first a verbal warning, second a written warning, and third is arrest managers (Catzim and Walker 2013, Belize Fisheries Department 2015, Belize Fisheries Department 2019, key informant interviews). However, the new Fisheries Resource Bill is much stricter and involves a multi-step process for citing infractions, providing evidence, charging, and then serving time in jail managers (Belize Fisheries Department 2019, key informant interviews). If a fisher receives an infraction, the MA committee may decide to deny them their commercial license in the following year managers (Belize Fisheries Department 2015, Belize Fisheries Department 2019, key informant interviews).

To resolve any conflicts, certain mechanisms are in place, including fisher forums and outreach to fishers by co-managers. Through my participant observation at several fisher forums, they occur at least once a year between all marine stakeholders of the eight MA areas, and offer a place of information-sharing. However, not all fishers are in attendance, very few have the opportunity to speak, the few who do are occasionally cut short, and they do not prefer to be shown graphs of data from the co-managers. In Belize, there is minimal recognition of rights to organize as the government recognizes and does not challenge the rights of the users to self-organize by way of active fishers' organizations, the BFF, and cooperatives managers (Belize Fisheries Department 2015, Belize Fisheries Department 2019, key informant interviews, participant observation).

The final design principle for long-enduring CPRs that Belize fisheries management exhibits is nested enterprises (Ostrom 1990, Table 2.1). Excellent examples of nested institutions can be found in Figures 2.4 and 2.8, where Figure 2.4 depicts each governmental agency nested within a Ministry, and Figure 2.8 demonstrates that the governance of each MA area is nested within the Managed Access Working Group, the Managed Access Technical Team, and all overseen by the Belize Fisheries Department. Furthermore, in the near future, a Fisheries Council will be formed, consisting of representatives from the government, tourism, fisheries and NGO sectors, an expert in fisheries science, and the Fisheries Administrator. These entities will be nested under the umbrella of the Fisheries Council, which will be an established advisory body to make recommendations to the Minister of Agriculture, Fisheries, Forestry, the Environment and Sustainable Development (Belize Fisheries Department 2019).

In summary, fisheries management in Belize demonstrates all eight components of a long-enduring CPR system, as defined by Ostrom (Ostrom 1990), suggesting the actors have the potential to overcome collective action problems in the long run. There are (1) clearly defined boundaries of the resource system, (2) a connection between local conditions and provisioning rules, (3) collective-choice arrangements by the fishers on MA committees, (4) monitoring of the resource system by the users, (5) graduated sanctions in place for rule infractions, (6) conflict-resolution mechanisms, (7) minimal recognition of rights to organize by the government, and (8) nested enterprises (Ostrom 1990, Table 2.1). While the MA program in Belize is less than a decade-old in action, the presence of all eight CPR design principles suggests it will be a sustainable program well into the future.

Discussion

Belize’s fisheries management policies demonstrate institutional robustness

Through extensive review of primary and secondary literature, semi-structured interviews with key informants, and participant observation, this study examines the institutional robustness of Belize’s fisheries management strategies. The results indicate that the institutions are robust and resilient to future shocks due to their polycentric, decentralized, and nested governance structure (Chuenpagdee and Jentoft 2018). For example, fisheries management in Belize demonstrates polycentric governance because the governmental, NGO, tourism, and fishers sectors each represent the many centers of decision-making that often function independently of one another (Ostrom et al. 1961, Ostrom 2010). In the case of Belize, these various sectors each play an important role in the monitoring, decision-making, enforcement and provisioning rules in the common pool resource system (Ostrom 2010). Polycentric fisheries governance has been found to overcome several limitations found in other systems because it promotes broad levels of stakeholder engagement, increases policy freedom at local levels and ensures governance responses are implemented at appropriate scales (Cvitanovic et al. 2018).

However, the institutions involved in fisheries management in Belize also function in a decentralized way because the decision-making power is distributed to those at the local community level (Ostrom 1990, Dietz 2003). For example, TIDE co-manages the PHMR in southern Belize by working closely with fishers from several communities (Punta Gorda, Punta Negra, Monkey River, and Barranco). As an institution, TIDE builds trust with the fishers while also communicating their needs to the Belize Fisheries Department. Decentralization has been found to be a very effective tool in effective governance of natural resources because it takes the strain off of centralized forms of governance while granting the decision-making power to the users of the system (Ostrom 1990, Dietz 2003, Wright et al. 2016).

Further contributing to institutional robustness is the nested nature of several key institutions involved in fisheries management in Belize (McCabe and Feiock 2005b, Ostrom et al. 2010). Like previously described, each government agency is nested within a Ministry, which oversees multiple agencies with similar objectives and provides for linkages between such agencies. The fishers' sector is another nested enterprise where individual fishers can be represented by fishers associations local to their community, and then several fishers associations are a part of the Belize Federation of Fishers (BFF), which represents fishers at the national level. This nesting can lead to improved stability in the face of global change and ongoing stresses (Chuenpagdee and Jentoft 2018). Overall, the polycentric, decentralized and nested governance structure of the institutions involved in fisheries management in Belize contributes to overall institutional robustness and resilience to shocks in the future (Chuenpagdee and Jentoft 2018).

Belize has potential to be a long-enduring common pool resource system

This study demonstrates that Belize contains the necessary institutions in places to become a long-enduring CPRS and potentially overcome obstacles to collective action. While fisheries management policies in Belize represent all eight of Ostrom's design principles for long-enduring CPRS (Ostrom 1990), these three components could be improved upon to achieve further institutional stability: the monitoring of the resource system by the users, conflict-resolution mechanisms, and minimal recognition of rights to organize. This could be because more time is needed to fully implement these components of community-based management in Belize.

For example, in a comparison of Hawaii's community-based subsistence fisheries area legislation to that of American Samoa, the program in American Samoa comprised more of the design principles, primarily due to the successful implementation of its program (Levine and Richmond 2015). The Hawaii program has the potential to consist of the common-pool resource design principles, but only if effective institutions are in place (Levine and Richmond 2015). My study demonstrates that Belize has a variety of institutions and a diverse governance structure to ensure the design principles endure in the long-term. In two additional co-managed fisheries, one in Kenya and one in Madagascar, Cinner et al. (2009) found their systems to also be lacking several design principles to overcome CPR problems. Monitoring of resources and surveillance were two of the missing components of these co-management regimes, while clearly defined geographic boundaries, collective choice arrangements, graduated sanctions and nested enterprises were partially implemented (Cinner et al. 2009). Like in Belize, monitoring and surveillance were two components in Kenya and Madagascar co-managed fisheries needing improvement, demonstrating the challenge of encouraging users to become more involved in the monitoring and surveillance of the resource system.

<u>Fisher associations are mechanisms for collective action</u>

The fishers' associations in Belize and other small-scale fisheries contexts are platforms for fishers to engage in collective action. They are self-organizing, where several motivated individuals recognize a need for increased representation at the local, community-level (Ostrom 2003). Because Belize has a wide range of fishers' associations, ranging geographically across the country, the likelihood of fisher representation at local levels is much higher than if there were very few associations (Partelow et al. 2020). However, not all commercial fishers are members of fisher associations, leading to discrepancies in equity/inclusivity/representation. Therefore, some voices are lost while others are amplified. The inequitable representation of fishers by fisher associations can also lead to corruption (Hanich and Tsamenyi 2009, Cross 2016, Nunan et al. 2018) and biases in the decision-making processes (Semitiel-García and Noguera-Méndez 2019).

Fisher associations provide a platform for individual fishers to build social capital and trust within their communities and advocate for them at the national level, particularly with the NGO and governmental sectors. In a freshwater fishery in the Amazon, fishers identified a need for regulating their fisheries when the state failed to provide them with effective institutions to do so. Over time, this decentralized, community-based management led to protection of freshwater fish populations and stabilized livelihoods (Pinho et al. 2012). Similarly, in the Scotia-Fundy region of coastal Canada, fishers became more involved in the management and monitoring of marine resources by participating in fisher's association (Wiber et al. 2004). Furthermore, inland fishers in Bangladesh who participated in a community-based fisheries management (CBFM) regime had greater access to fisheries resources and improved livelihoods compared to non-CBFM participating fishers (Islam and Yew 2013), demonstrating the livelihood benefits of participatory fisheries management.

Complexity in information transfer and collaboration between institutions

However promising Ostrom's CPR design principles are in Belize, there is incredible complexity in information transfer and collaboration between institutions, which has implications on management, economy, environment, and institutional stability. Often, different sectors work together and act as nested enterprises (McCabe and Feiock 2005b, Ostrom et al. 2010). One example of that is The Nature Conservancy working closely with ResCa (both NGOs) to improve the seafood market traceability of the fishers who sell their product at the National Fishermen Cooperative. They are maximizing on the economic incentive of fishers to accurately report their catch. Through this, they are making up for shortcomings in the logbook reporting process by the Belize Fisheries Department. This is an example of smaller scale institutions (the NGOs and cooperatives) filling the gaps that exist in the government's capacity to accurately conduct stock assessments. It is therefore imperative for policymakers to receive accurate numbers of catch per unit effort (CPUE) by fishers so they may set feasible and data-driven catch limits (Schiermeir 2002, Reddy et al. 2013, Carruthers et al. 2014).

The membership of the Belize Federation of Fishers (BFF) is another example of complex institutional cross-over and information transfer. Those who serve on the leadership board of BFF are also in positions of power in the fisher associations and serve on the MA committees. They are therefore in charge of deciding who gets commercial licenses for their areas and are involved in advocating for their communities on a national level. By nature of this design, there is exclusion from the benefits of BFF organization. Fishers who are not members of fisher associations and fisher associations not members of BFF are excluded from the advocacy benefits provided by BFF. Furthermore, there are certain costs and benefits to having the same individuals serving on BFF for multiple years. Having the same individuals involved provides the benefits of improved information transfer, maintained trust, and not many changes in the structure, e.g., shocks (Wiber et al. 2004, Foley 2012, Wade et al. 2019). On the other hand, having the same individuals in these positions excludes others from the chance of being involved, therefore leading to uneven representation, exclusion, and missing voices (Bodwitch 2017). It could also increase the likelihood of corruption and biases in decision-making, as the same individuals making the decisions could be advancing their own agenda(s) rather than advancing the needs of the collective "group" they represent (Hanich and Tsamenyi 2009, Cross 2016, Nunan et al. 2018, Semitiel-García and Noguera-Méndez 2019).

There is also a connection between fishers, the tourism industry, and the government, because many fishers, particularly those in southern Belize, are also tour guides. By becoming tour guides, fishers become stewards of their local environment, sharing their knowledge of the marine system with others (Bennett et al. 2018). However, such opportunities are highly location-specific and not available for all commercial fishers across Belize. This discrepancy leads to conflict among fishers in the same or neighboring communities (sources: key informant interviews, participant observation). Furthermore, to work as tour guides, fishers must attend training sessions and receive their license from the Belize Tourism Board (BTB) and the Belize Tourism Industry Association (BTIA). The license and training are also pretty costly, and require annual fees to be renewed. These policies demonstrate the integration between the governmental, tourism and fisheries sectors, but also that becoming a fisher-tour guide has its own slew of complexities in policies and agency.

Conclusion

This case study demonstrates that over 40 years, Belize has developed polycentric, decentralized and nested institutions to sustainably manage its fisheries and coastal resources. This variety in governance structure can potentially lead to Belize overcoming the collective action problems associated with its fisheries being a common pool resource system (Olson 1965, Ostrom 1990, Ostrom et al. 1999, Ostrom 2003, Levine and Richmond 2015). The partnerships across scale between local NGOs, fishers' associations, and the federal government are examples of cross-scale linkages that contribute to overall institutional stability, robustness, and improved information transfer across scale (Cudney-Bueno and Basurto 2009). All actors of this resource system are encouraged to engage in collective action to reach shared sustainability goals (Urquhart et al. 2014, Valdés-pizzini et al. 2016). However, due to the lack of widespread and equitable representation of fishers in the management process of the MA program, I cannot conclude that the program is an example of participatory management. An additional challenge to sustainable fisheries management in Belize is the implementation of the new Fisheries Resources Bill in the coming years, which will require long-term buy-in by the fisherfolk and improved inclusion of them in management processes.

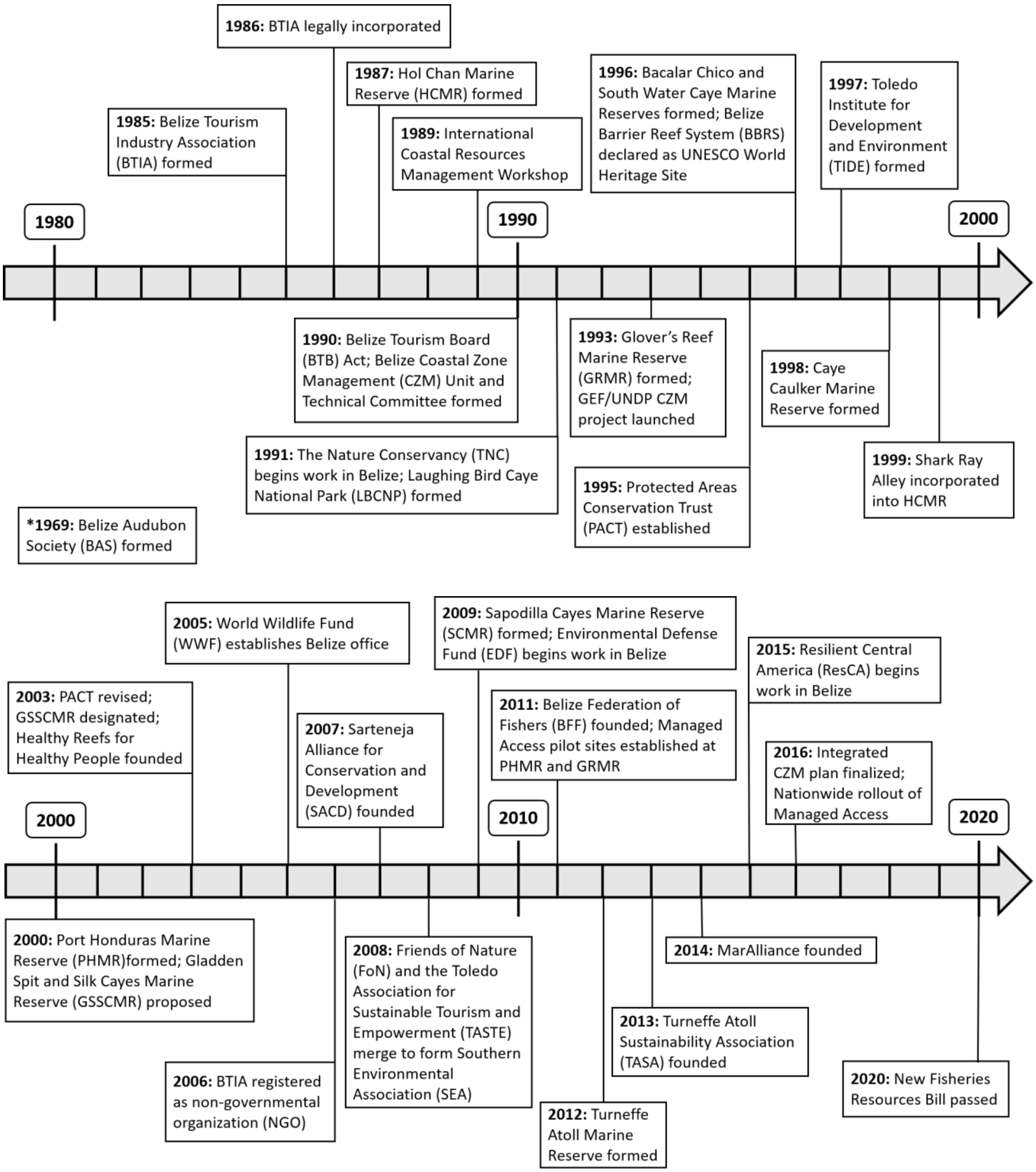

Figure 2. 1: Timeline of significant milestones in coastal zone/fisheries management in Belize from 1980 to present. Top panel shows 1980-2000 while the bottom panel shows 2000-2020. Source: key informant interviews and review of secondary literature.

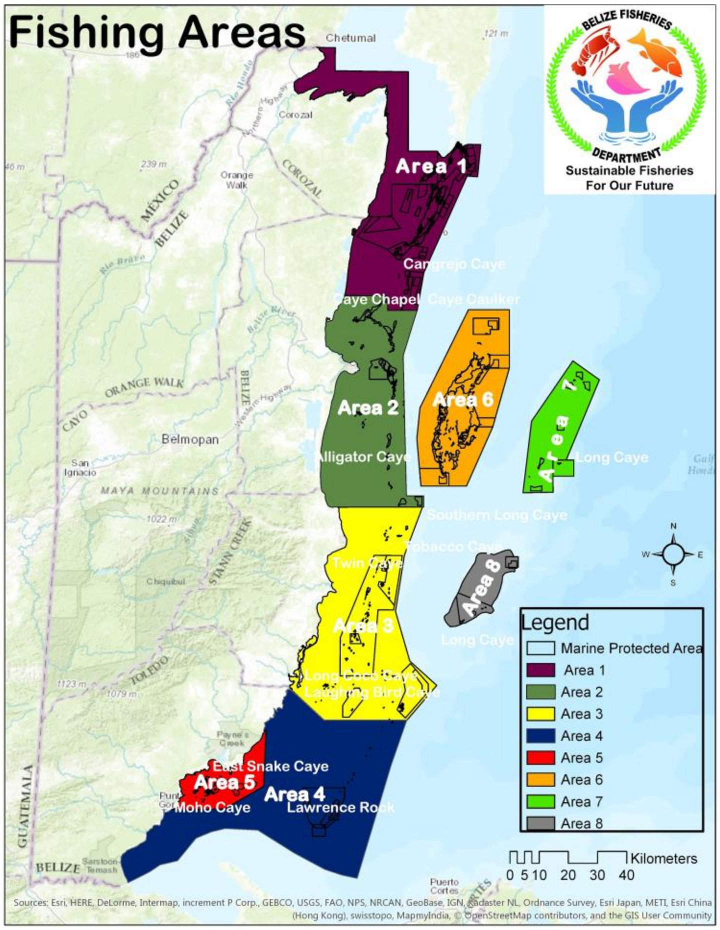

Figure 2. 2: Managed Access fishing areas in Belize. The polygons represent MPAs. The two pilot sites established in 2011 were: Area 5 (in red), the Port Honduras Marine Reserve (PHMR), and Area 8 (in grey), the Glovers Reef Marine Reserve (GRMR). The remaining Areas were established in 2016. Map from the Belize Fisheries Department 2019.

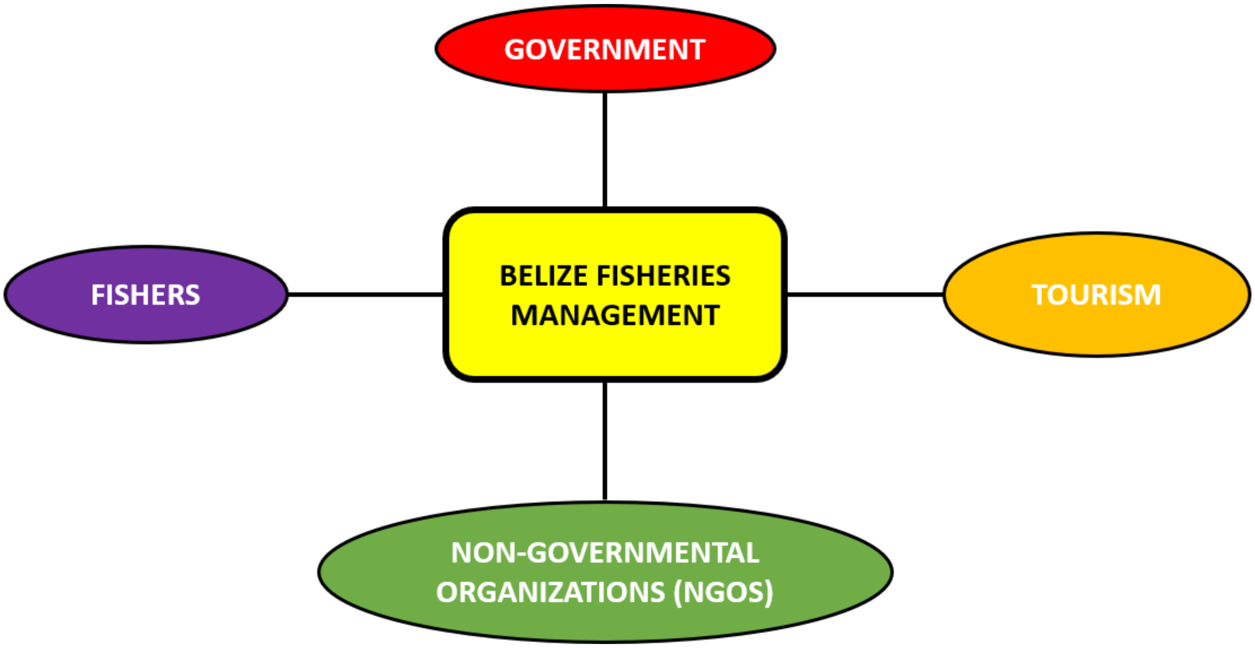

Figure 2. 3: Visual depiction of the different sectors involved in fisheries management in Belize. Sources: key informant interviews, participant observations and review of secondary data.

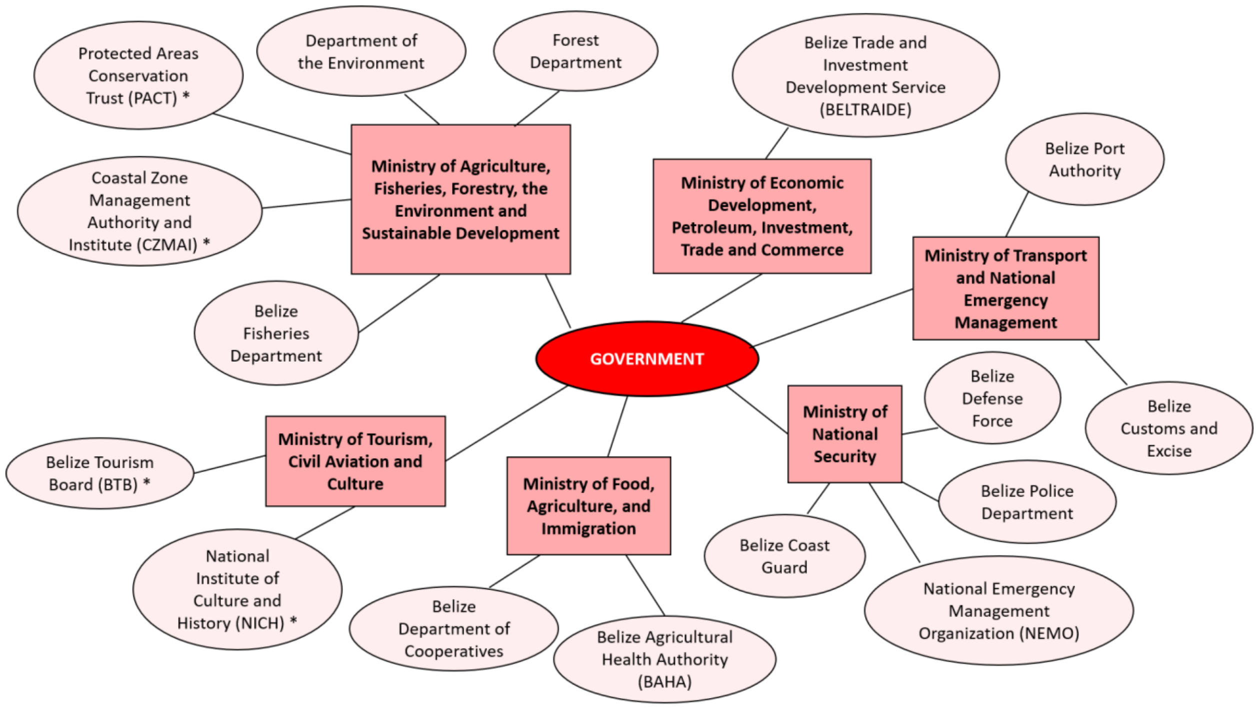

Figure 2. 4: Visual depiction of the governmental agencies involved in fisheries management in Belize. Each governmental organization is nested within a Ministry. The Belize Tourism Board (BTB) is also represented in the tourism sector. Asterisk indicates statutory body. Sources: key informant interviews, participant observations and review of secondary data.

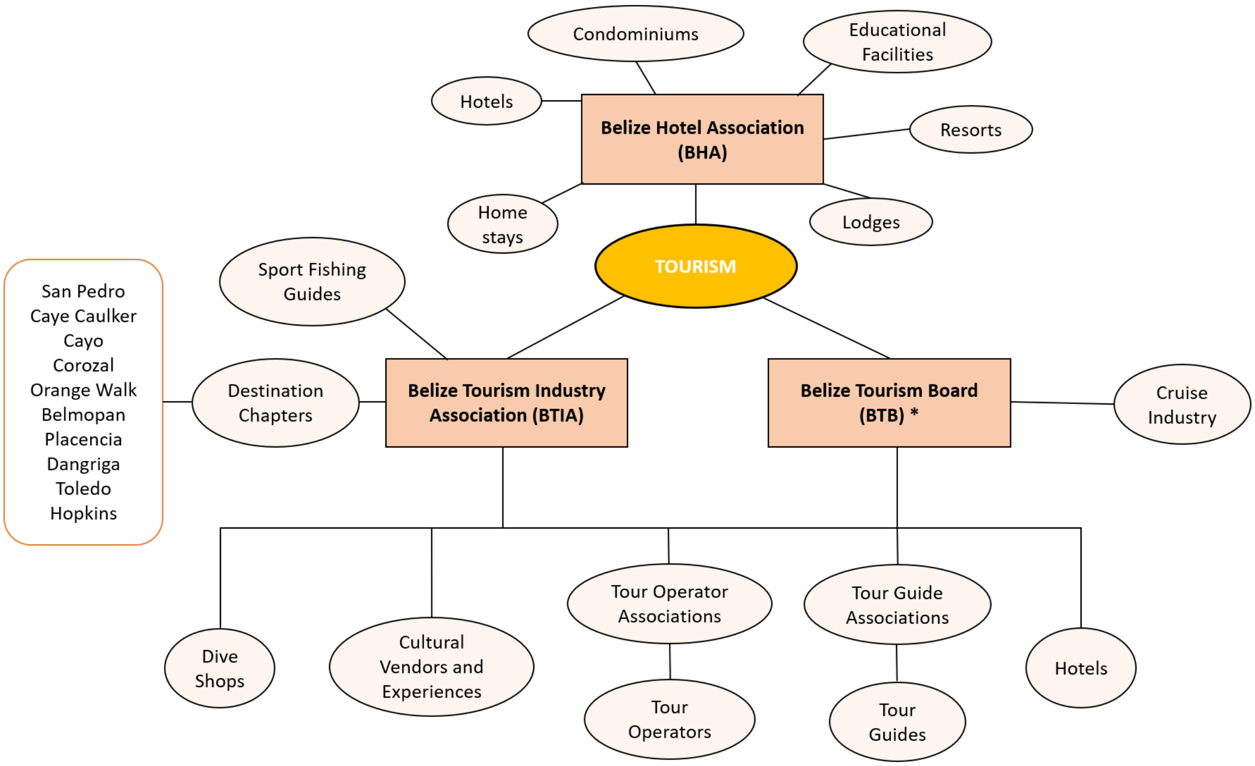

Figure 2. 5: Visual depiction of the tourism institutions involved in fisheries in Belize. Asterisk indicates statutory body in the government sector. Sources: key informant interviews, participant observations and review of secondary data.

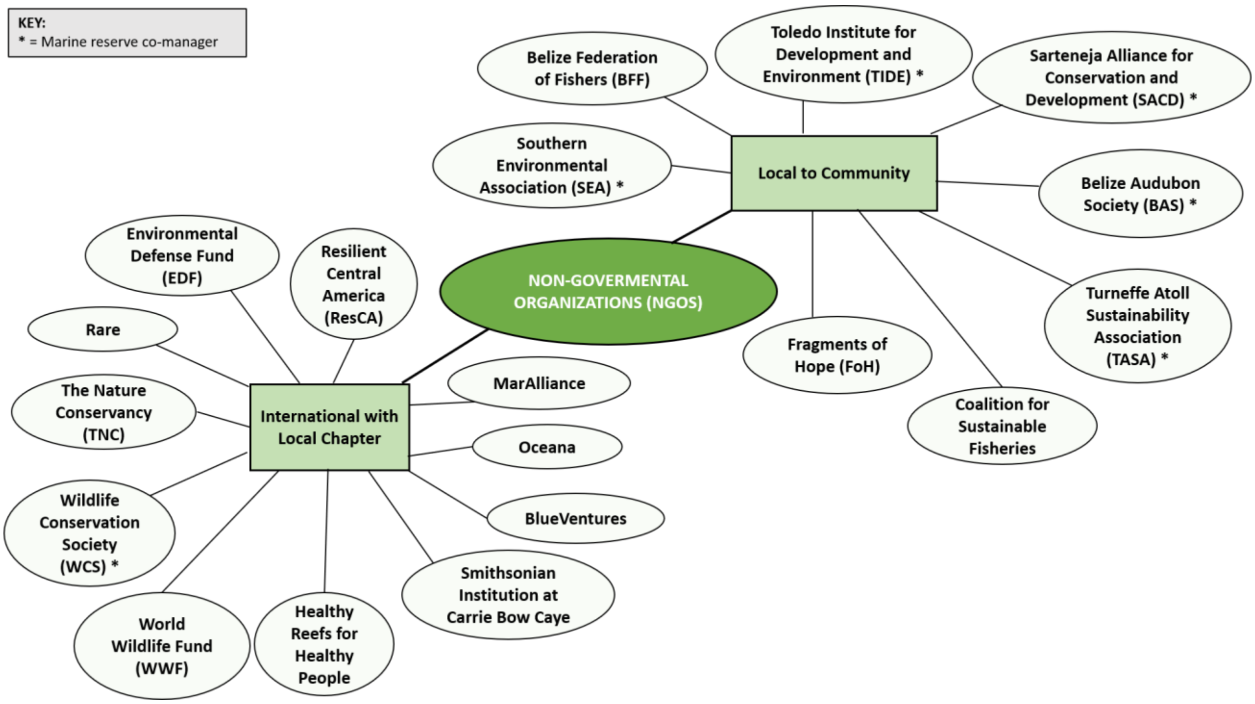

Figure 2. 6: Visual depiction of the environmental non-governmental organizations (NGOs) involved in fisheries management in Belize. About half of them are local to a community in Belize, while the other half are international organizations with local chapters. Asterisk indicates an organization is a co-manager of a marine reserve (with the Belize Fisheries Department). Sources: key informant interviews, participant observations and review of secondary data.

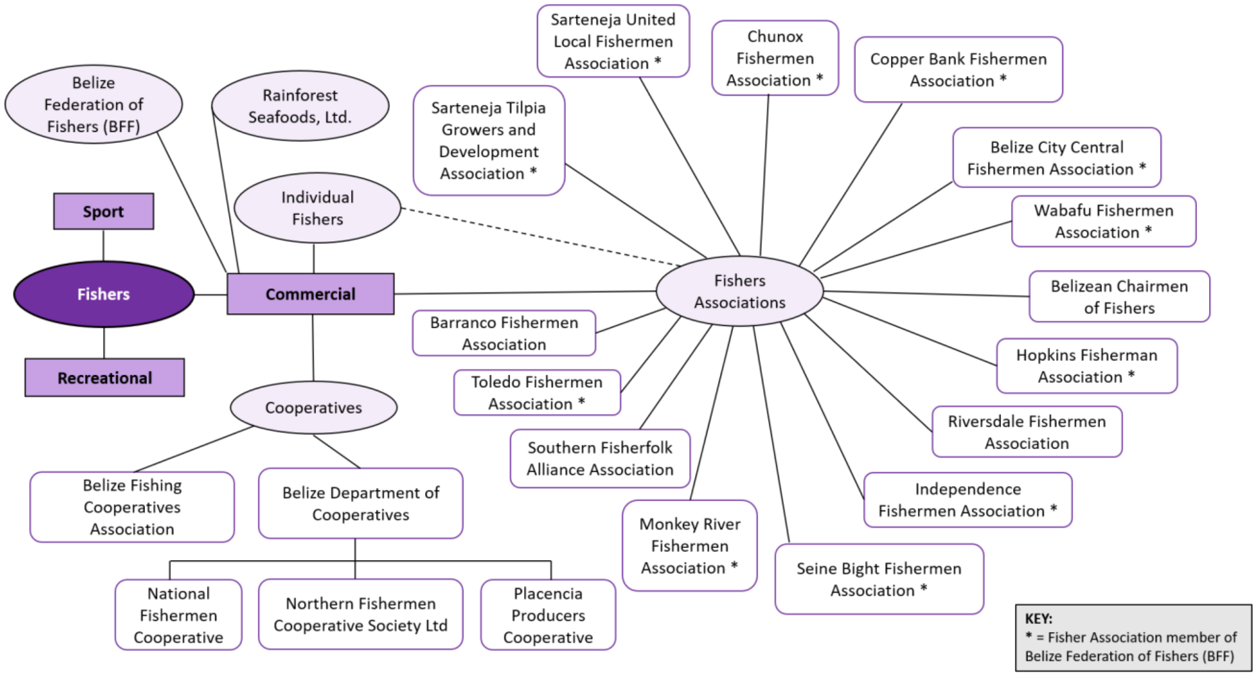

Figure 2. 7: Visual depiction of the fishers' organizations in fisheries management in Belize. Note this figure primarily focuses on the commercial fishing sector. Asterisk indicates Fisher Associations as members of the Belize Federation of Fishers (BFF). Sources: key informant interviews, participant observations and review of secondary data.

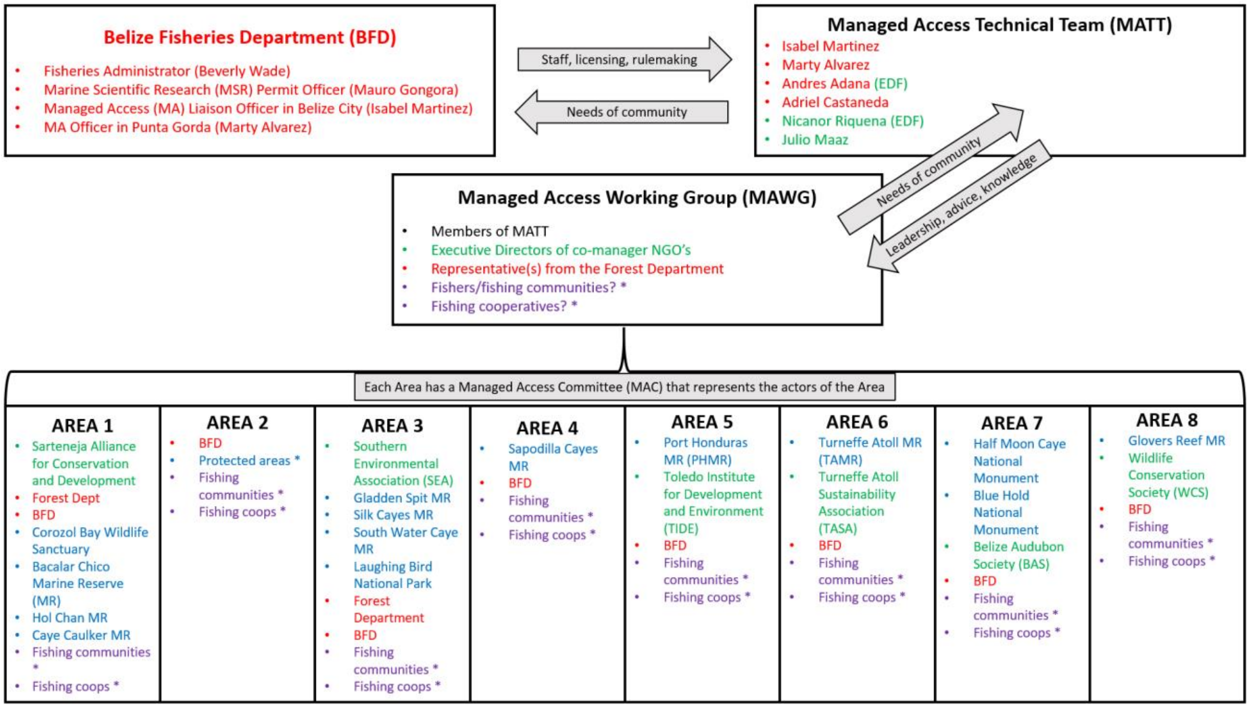

Figure 2. 8: Depiction of the institutions (and individuals) involved in the co-management of the Managed Access program in Belize. Red indicates the governmental sector. Blue represents marine reserves and/or protected areas. Green represents the NGO sector. Purple represents the fishers' sector. Arrows indicate the roles and information transfer between the levels. Sources: key informant interviews, participant observations and review of secondary data.

Table 2. 1: Ostrom's design principles for long-enduring CPRs applied to Belize's marine resource governance context

	Design Principle	Belize Context	Source(s)
1	Clearly defined boundaries	Belize's exclusive economic zone (EEZ) and the eight distinct MA areas where commercial fishers are granted access/ownership rights.	Foley et al. 2012, Fujita et al. 2017, Belize Fisheries Department 2015 & 2019
2	Connection between local conditions and provisioning rules	The existence of MA committees, where fishers can serve and represent the interests of their communities. Local, community-based NGOs are co-managers of marine reserves. Fishers organizations and BFF represent the interests of fishers on local and national scales.	Belize Fisheries Department 2015 & 2019, key informant interviews
3	Collective-choice arrangement s	Fishers serving on MA committees can provide input about who gets MA license in subsequent years. Fishers also consulted during the development of MA and rewriting of the Fisheries Resources Bill. However, BFD has final say about how the resource units get accessed and used.	Belize Fisheries Department 2015 & 2019, key informant interviews
4	Monitoring of resource system by users	Majority of the monitoring and enforcement are done by Fisheries Officers at BFD and NGOs. But, fishers are pretty aware of transboundary fishers/notice a non-licensed user in their area. Potential for fishers to increase monitoring of areas in future.	Belize Fisheries Department 2015 & 2019, participant observation
5	Graduated sanctions	Currently, there is a 3-strike rule by BFD (first is a verbal warning, second is a written warning, and third is an arrest). However, the Fisheries Resource Bill is much stricter (infractions, evidence, being charged, possible jail time). If a fisher has an infraction, they may not be able to get commercial license next year (as decided by MA committee)	Belize Fisheries Department 2015 & 2019, key informant interviews
6	Conflict-resolution mechanisms	Fisher forums, which occur at least once a year between all marine stakeholders of each MA area, offer a place for information sharing between co-managers and fishers. However, from my participant observation, not all fishers attend, only a few vocal fishers voice concerns, sometimes fishers don't have enough time to speak, and they don't like seeing graphs/data.	Belize Fisheries Department 2015 & 2019, participant observation
7	Minimal recognition of rights to	Government recognizes active fishers' organizations, BFF and cooperatives and does not challenge the rights of the users to make their own institutions.	Belize Fisheries Department 2015 & 2019,

	organize		participant observation, key informant interviews
8	Nested enterprises	Figure 8 depicts highly nested enterprises involved in governing the MA program. Fishers from local communities are often represented by fishers' associations, which advocate for them at regional and national levels. NGOs are local to villages and regions, but often serve on national committees. Included in the 2019 Fisheries Resources Bill is the development of a Fisheries Council, which will be an advisory body consisting of individuals representing the governmental, tourism, fisheries and NGO sectors, as well as someone with expertise in fisheries science and the Fisheries Administrator.	Belize Fisheries Department 2015 & 2019, participant observation, key informant interviews

CHAPTER 3: TWENTY YEARS OF BENTHIC COMMUNITY CHANGES ACROSS THE BELIZE MESOAMERICAN BARRIER REEF [2]

Introduction

Coral reefs worldwide have experienced remarkable changes over the past 50 years, including the loss of reef-building corals and large predatory fishes (Gardner et al. 2003, Bruno and Selig 2007, Mora 2008, Schutte et al. 2010, Valdivia et al. 2017) This has caused a reduction in or effective loss of essential ecological functions including reef accretion (Perry et al. 2013, Cramer et al. 2017), and the provisioning of habitat and fishery production (Kuffner and Toth 2016). Given the substantial economic and cultural value of healthy reefs (Spalding et al. 2017), this degradation is affecting coastal human communities that depend on reefs for food, income, and protection from storms (Ferrario et al. 2014).

Numerous factors are responsible for the well-documented degradation of Caribbean reefs. Acroporid corals, that dominated Caribbean reefs for millions of years, experienced 90-95% mortality due to white-band disease in the 1980s (Aronson & Precht 2001). This disease, likely exacerbated by ocean warming (Randall and Van Woesik 2015), coupled with increased hurricane frequency and intensity (Webster et al. 2005, Elsner et al. 2008, Emanuel 2013), reduced the habitat complexity, or rugosity, of Caribbean reefs (Alvarez-Filip et al. 2009). Other disease syndromes have greatly reduced the cover of other coral taxa, including yellow band

[2] A version of this chapter is in review in *Marine Ecology Progress Series* as Alves, C., N. Bood, K. Castillo, C. Cox, C. Fieseler, Z. Locklear, M. McField, L. Mudge, J. Umbanhowar, A. Valdivia, R. Aronson, J. Bruno. Twenty years of benthic community changes across the Belize Mesoamerican Barrier Reef.

disease (*Orbicella* spp.) and stony coral tissue loss disease (*Dendrogyra cylindrus, Pseudodiploria strigosa, Meandrina meandrites, Eusmilia fastigiate, Siderastrea sidereal* and *Diploria labyrinthiformis*, (Alvarez-Filip et al. 2019). Coral bleaching and other manifestations of ocean warming (including increased disease severity) are also a primary cause of Caribbean coral loss (Aronson et al. 2002b, Eakin et al. 2010). On a local scale, eutrophication via nutrient input and increased sedimentation from coastal development affect coral reefs by increasing turbidity, which contributes to coral smothering and loss of light (Gil 2013, Silbiger et al. 2018). Finally, centuries of fishing have caused an 80-95% reduction in large predatory fish biomass across the Caribbean (Valdivia et al. 2017). Secondary drivers include factors that enabled the observed increase in macroalgae (fleshy seaweeds), including the removal of competitively dominant Scleractinian corals, the subsequent freeing up of space and other resources, and the loss of reef herbivores, particularly the sea urchin *Diadema antillarum* (Carpenter 1988), and herbivorous fishes due to overfishing in some locations.

The primary management response to reef degradation has been the implementation of marine protected areas (MPAs) (Gaines et al. 2010, Mumby and Harborne 2010, Selig and Bruno 2010, Lamb et al. 2015). MPAs and MPA networks designate areas where extractive fishing behaviors are regulated via fishing closures or gear restrictions. Within those MPAs, fish abundances and diversity often increase, and in some cases, spill over into adjacent non-protected areas (Gaines et al. 2010, Chirico et al. 2017). Fishers reap the benefits of increased fish size and abundance via catch-share programs, access rights and fishing licenses, oftentimes fishing in the areas near or within the MPAs (Gaines et al. 2010, Anderson and Uchida 2014). However, poaching, lack of enforcement, inadequate fishing regulations, and limited spillover often contribute to the failure of MPAs to protect fish populations (Coelho 2007, Graham et al. 2008, Huntington et al. 2011, Cox et al. 2017, Gill et al. 2017, Bruno et al. 2019).

The purpose of this study was to measure changes to benthic communities within the Belize Mesoamerican Barrier Reef (BMBR) from 1997 to 2016 and determine whether such changes were related to reef-site protection status, local human impacts, and ocean temperatures anomalies. We compiled data from benthic surveys conducted in 1997, 1999, 2005, 2009 and 2016 (McField et al. 2001, Bood 2006, Cox et al. 2017) to describe how reef benthic communities in the BMBR have changed over time and identify the drivers of those changes. Our results indicate shifts in benthic community state between early and late sampling years, highlighting the shortcomings of MPA networks in the BMBR in mitigating coral loss and maintaining ecosystem function following disturbances.

Methods

Study Area

Scientists have tracked coral reef community composition across Belize for the last 60 years, mostly through short-term longitudinal studies (Stoddart 1969, 1974, 1961, Aronson & Precht 1997, 2001, McClanahan and Muthiga 1998, McField et al. 2001, Aronson et al. 2002a, 2005, 2012, Huntington et al. 2011, Rodríguez-Martínez et al. 2014, Cox et al. 2017). Belize has an extensive 30-plus-year-old MPA network (Cox et al. 2017) and a history of disturbances (Table 3.1). Belize also hosts 55% of the reef area of the Mesoamerican Barrier Reef System (MBRS), the second-largest barrier reef in the world.

We surveyed fore-reef benthic communities (15–18 m depth) at 21 sites along the BMBR system during the summer months in 1997, 1999, 2005, 2009, and 2016 (Figure 3.1; Table

A3.1). This reef zone was surveyed because it has been widely studied in Belize and is fairly convenient: surveys are not affected by wave action, it is not so deep that surveys are limited by dive time, and similar spur-and-grove zones are found across the barrier-reef system. Study sites were selected to maximize spatial heterogeneity and include a range of protection or management zones (McField et al. 2001, Bood 2006, Cox et al. 2017). These management protections include (1) fully protected zones where only non-extractive activities were permitted (FP), (2) general-use zones with restrictions placed on certain gear types and other fishing regulations (GU), and (3) non-protected zones (NP) where fishing is not restricted (Cox et al. 2017). Because of logistical constraints we did not survey all sites each year, except for three of the 21 sites (Bacalar Chico, Middle Caye, and Tacklebox; Table A3.1). We removed data from study sites that were sampled only once.

<u>Benthic surveys</u>

Benthic surveys were conducted by video-transecting or photography. At each site, dive teams laid out 25 m x 2 m belt transects along the individual spurs. The transects usually began on or near the shoulders of the spurs in 13–17 m depth, shoreward of the drop-off. Between four and 10 transects were sampled per site per year. Divers worked in buddy pairs, where one diver laid out the transect tape and the other used a digital camera in an underwater housing to obtain videos and still-frames of the benthos. At each site, we photographed or videotaped the belt transects at a standard distance of 25 cm above the benthos using a horizontal bar projected from the front of the camera housing (Aronson et al. 1994, Murdoch and Aronson 1999, McField et al. 2001, Bood 2006). In all sampling years except 2016, we obtained underwater videos along the belt transects and extracted still frames from those videos (outlined below). In 2016, we photographed the transects using a GoPro Hero4 by swimming at a rate of 5–7 minutes/30 m and taking a photograph every five seconds.

Image extraction and analysis

We used several techniques to extract and analyze the benthic images from the underwater transects over the course of this study, primarily due to changes in imaging technology and analysis software. For sampling years 1997, 1999 and 2005, we obtained Hi-8 video footage from each transect, using two 30-watt ultrabright lights for illumination. From the video footage, we randomly frame-grabbed, processed (de-interlaced, sharpened, enhanced) and saved onto a CD-ROM 50 images per transect (McField et al. 2001, Bood 2006). In 2009, we obtained video footage from underwater transects using a digital camera in an underwater housing. Years later, we extracted the images from the video footage at a rate of 1-fps using Adobe Premiere Pro CC 2014. We ran the images through the Automator program on OS-X software to select every third, fifth or seventh image, depending on the length (in time) of the transect. We analyzed 15 images/transect/site for 2009 and 2016 sampling years because we could still obtain a similar level of inference about community composition with 15 images rather than the 50 recommended by Aronson et al. (1994; J. Bruno, pers. comm.). To select 15 images per transect/site from 2009 and 2016, we automated the process using a code in R version 3.6.3 (RStudio Team 2016), to randomly chose, copy and paste 15 images into a new folder from our source folder of all images.

We analyzed the benthic cover of images from 1997–2005 using the Coral Point Count software (Kohler & Gill 2006), and from 2009 and 2016 using CoralNet (Beijbom et al. 2012, 2015). We manually input species-level benthic identifications for each of 10 random points overlaid on all images. When species-level identifications were not possible, benthic components were identified to genus or family. All benthic component identified were pooled into six key benthic categories (crustose coralline algae, CCA; *Halimeda*, a genus of calcareous green algae; hard coral; macroalgae; soft coral, and sponges). *Orbicella annularis, O. favelota,* and *O. franksii* were pooled as *Orbicella* spp. because the species distinction did not occur during 1997 and 1999 data collection. In all instances, image-level point-count data were converted to percent-cover estimates, and we calculated overall mean percent covers for each site and year.

<u>Identifying potential drivers of benthic community dynamics</u>

We estimated local human impacts using the global Human Influence Index (HII) data from NASA's Socioeconomic Data and Applications Center (SEDAC) database (WCS and CIESIN 2005). We extracted sea surface temperature (SST) metrics obtained from NOAA's Coral Reef Temperature Anomaly Database (CoRTAD) (Selig et al. 2010). We extracted HII data for the Mesoamerican Barrier Reef Region (Figure A3.1) to estimate local anthropogenic stress to the BMBR. The HII is a global dataset of 1-km grid cells aggregated from 1995–2004 quantifying an index for human influence by estimating human population pressure, human land use and infrastructure, and human access. Higher values represent higher Human Influence Indices, and therefore can be used as a proxy for local human impacts on coral reefs. We downloaded the HII global dataset from SEDAC for the MBRS (WCS and CIESIN 2005). Then, we extracted accumulative HII data (sum of data per pixel) within several buffers (10, 25, 50, 75, 100 km) from the center-coordinates of each study site (Table A3.1, Figure A3.1).

The CoRTAD dataset contains approximately 4-km-resolution SST data on a weekly time scale from 1982 to 2017. We examined four metrics of thermal-stress anomalies (TSA) from Version 6 of the CoRTAD database to determine the impact of temperature on benthic communities along the BMBR: (1) TSA, the SST minus the maximum of weekly mean climatological SST calculated over the data range, (2) frequency of TSA ("TSA_Freq"), defined by the number of instances TSA was over 1 °C over the previous 52 weeks, (3) the frequency of TSA between survey years ("TSA_Freq_btw_surveys"), defined as the number of instances since the previous survey year that TSA was over 1 °C, and (4) the accumulative TSA ("TSA_Freq_hist"), represented by the number of times since the beginning of the dataset (1982) to survey year that TSA was over 1 °C (Table A3.2, Figure A3.2). Because the CoRTAD TSA dataset was very large, we used a shell script to run the Climate Data Operator (CDO) command to extract all raster data layers within a geographic boundary around Belize (from -85 to -89° longitude, and 15 to 19° latitude). We then extracted TSA, TSA_Freq, TSA_Freq_btw_surveys, and TSA_Freq_hist for our study sites using the following R packages: raster (Hijmans 2019), ncdf4 (Pierce 2019), maptools (Bivand & Lewin-Koh 2019) and formatR (Xie 2019).

Statistical analysis

To examine benthic community compositional changes over temporal and spatial scales and identify potential drivers of such changes, we constructed six generalized linear mixed models (GLMM) using the lme4 package (Bates et al. 2015). The response variables were the logit-transformed percent cover of the six key benthic categories of interest. The final models had survey year, protection level (protected = FP, and unprotected = UP), HII at 50-km buffer, and TSA_Freq as fixed effects, and site as a random effect. All predictor variables were additive, and the maximum likelihood estimation was used to fit to the data. We chose to pool NP and GU into an "unprotected" category because we were most interested in seeing the impact of full closures (fishing not allowed) on benthic community structure, and because there is minimal operational difference between GU and NP areas in Belize. Prior to fitting models, we rescaled and centered all fixed effects to optimize comparisons among variables.

We performed several exploratory tests to find the best-model fit. The models we compared each had different metrics for cumulative thermal stress (TSA_Freq, TSA_Freq_btw_surveys, and TSA_Freq_hist), and HII at 50 km and 100 km. We evaluated competing models by comparing Akaike information criterion (AIC) values (Table 3), and ultimately chose the TSA_Freq model, as it was the most parsimonious model with the lowest AIC. Other studies have found that TSA_Freq is a significant predictor of coral-cover loss and coral-disease prevalence (Bruno and Selig 2007, Selig et al. 2010, Maina et al. 2011). The HII at 50 km was included because all sites and years had HII at that buffer, and because it is understood that most fishers and tour operators are less likely to travel past 50 km from a coastal town in a day trip (Mora 2008). We tested for homoscedasticity (equal variance across predictor variables) by plotting residuals versus fitted values. Observations were normally distributed with no evidence of heteroscedasticity. Comparing fitted and residual values showed that our linear models were reasonable models of the means. We also examined the marginal and conditional R-squared values of the model(s). An example of the final model for hard coral is below.

$$\text{Logit (coral cover)}_{ij} = \alpha + \beta 1_j * \text{Year}_{ij} + \beta 2_j * \text{Protection}_{ij} + \beta 3_j * \text{HII}_{ij} + \beta 4_j * \text{TSA\_Freq}_{ij} + \alpha_i + e_{ij}$$

Where α = intercept, α_i = random intercept (Site), e_{ij} = error term and $\beta\ 1_j$ – $\beta\ 4_j$ are the coefficient estimates for covariates. The logit-transformed coral cover is modeled as an intercept (α), plus a linear year effect, protection level effect, HII effect, TSA_Freq effect, and a random intercept (α_i) for site, that is assumed to be normally distributed with a mean of 0 and variance $\sigma\alpha^2$, and an error (e_{ij}). The index *i* refers to sites ($i = 1, \ldots, 16$) and *j* to the year of survey ($j = 1997, \ldots, 2016$). The term e_{ij} is the within-site variance of coral cover, and is assumed to be independently normally distributed with mean of 0 and a variance of σ^2.

We also used analysis of variance (ANOVA) to determine if the mean percent cover of coral genera varied significantly over time. To examine further the changes in community composition of all benthic species – not just coral genera – within sites and across years, we constructed non-metric multidimensional scaling (NMDS) ordinations using the vegan package in R (Oksanen et al. 2019). We used the Bray–Curtis dissimilarity matrix to calculate distances among species-level cover data because it handles large quantities of zeros (or absences) commonly found in ecological data and does not consider shared absences as being similar (Legendre and Legendre 2012). To determine significant differences among groups, we ran the Adonis test, a statistical test of dissimilarity between observational groups at the site and year levels, using the vegan package (Oksanen et al. 2019). All predictor variables (HII at 50 km buffer, TSA_Freq, Year, and Protection level) were included in this function, which conducts a multivariate analysis of variance using distance matrices. All statistical analyses were done in R version 3.6.3 (RStudio Team 2016), and the code and raw data are available in GitHub.

Results

Overall loss of hard coral and increase in macroalgae

Among the six benthic groups of interest [crustose coralline algae (CCA), *Halimeda*, hard-coral, macroalgae, soft coral (gorgonians), and sponges], we identified a significant decline in hard-coral cover (Table 3.2, coefficient estimate = -0.551, $p < 0.001$) an increase in CCA

(Table 3.2, coefficient estimate = 0.221, $p = 0.034$), macroalgae (Table 3.2, coefficient estimate = 1.88, $p < 0.001$), and soft coral cover (Table 3.2, coefficient estimate = 0.447, $p < 0.001$) over the duration of the study (Figures 3.2–3.4, Table 3.2).

Role of protection status, frequency of Thermal Stress Anomalies, and Human Influence Index on benthic cover

There was no effect of protection level on the total mean percent cover of hard coral (Table 3.2, coefficient estimate = 0.099, $p = 0.562$) or macroalgae between fully protected ("FP") sites versus unprotected ("NP", UP and GU zones; Table 3.2, coefficient estimate = -0.016, $p = 0.946$). Even fully protected ("FP") areas experienced loss of hard coral cover and increased macroalgae cover (Figures 3.2–3.4).

We also found a strong, negative correlation between TSA_Freq and hard coral (Table 3.2, coefficient estimate = -0.464, $p < 0.001$), macroalgae (Table 3.2, estimate = -0.808, $p < 0.001$), soft coral (Table 3.2, coefficient estimate = -0.307, $p = 0.004$), and sponges (Table 3.2, coefficient estimate = -0.207, $p = 0.009$). Sites with high HII showed lower cover of soft coral (Table 3.2, coefficient estimate = -0.281, $p = 0.0213$) and sponges (Table 3.2, coefficient estimate = -0.161, $p = 0.0396$). None of our environmental predictors were associated with observed changes in *Halimeda* cover (Table 3.2, Figures 3.2–3.4).

Distinct benthic assemblages between early and late sampling years

There were species-specific compositional shifts in the dominant benthic assemblages between 1997 and 2016, as indicated by the non-metric multidimensional scaling (NMDS; Figures 3.5 and A3.3). Every study site sampled in multiple years expressed shifts in the dominant benthic communities over time (Figure A3.3). Among all explanatory variables (HII at 50 km buffer, TSA_Freq, Year, and Protection level) included in the statistical test of dissimilarity between treatment/observational groups (Adonis test), Year was the only significant predictor of shift in community composition ($R^2 = 0.31295$, $F=15.0654$, $p < 0.001$). The NMDS plot revealed a significant difference in species composition between earlier sampling years (1997–2005) on the right along MDS1, and our later sampling years (2009 and 2016) on the left, spread across MDS2 (Figure 3.5). For instance, *Acropora* and *Orbicella* corals were more-often present and more dominant in early sampling years, as opposed to turf algae, *Pseudodiploria clivosa*, and *Dictyota* macroalgae in later sampling years (Figure 3.5).

Trends of coral species over time

Throughout the two decades of this study, we documented significant decline of the hard-coral genus *Orbicella* — including *O. annularis, O. franksi* and *O. faveolata*, grouped together as "*Orbicella* complex" — with mean cover at 4.24 % (± 0.0051) in 1997 to 0.75 % (± 0.0020) in 2016 (Figure 3.6, Table 3.4, $F = 18.80, p < 0.001$). The mean cover of *Agaricia grahamae* significantly increased from zero in 1997 to 0.21 % (± 0.0026) in 2016 (Figure 3.6, Table 4, $F = 7.35, p = 0.0096$), likely due to improved survey identification. Trends in the cover of other coral species remained relatively stable throughout this study (Figure 3.6, Table 3.4).

Discussion

Our findings demonstrate an overall shortcoming of the BMBR MPA network in mitigating the degradation of benthic reef assemblages following the disturbances that occurred before and after 1997. We document a statistically significant decline in hard-coral cover, and an increase in macroalgae and soft corals, regardless of management regime. Even the oldest and most protected sites (where fishing is fully restricted) experienced hard-coral loss and macroalgal increase. This conclusion is concordant with a majority of studies that have found MPAs to be ineffective at mitigating the decline of corals in response to large-scale disturbances including disease, bleaching, and storms (McClanahan et al. 2001, Coelho 2007, Graham et al. 2008, McClanahan 2008, Huntington et al. 2011, Toth et al. 2014, de Bakker et al. 2017). Our study contributes to the growing body of literature indicating that MPAs provide little protection to coral populations, even if they are successful in increasing fish populations. Although we did not examine fish biomass across sites in this study, Cox et al. (2017) found no effect of fisheries restrictions on preventing loss of coral cover nor promoting reef fish biomass from 2009–2013 along the BMBR MPA network.

We found ecologically distinct benthic assemblages between early (1997, 1999, 2005) and late sampling years (2009, 2016). Time (year) was statistically significantly related (Table 3.3) to observed changes in benthic composition (unlike protection level, HII, and TSA_Freq which were not). For instance, *Acropora* and *Orbicella* corals were more-often present and more dominant in the early sampling years, as opposed to turf algae, the fleshy brown macroalga *Dictyota*, and the hard-coral *P. clivosa* in later sampling years. In contrast, living cover of "weedy" coral taxa such as *Porites* and *Agaricia* spp. remained relatively consistent throughout the course of the study. The decline in *Orbicella* spp. was likely due to mortality from coral bleaching in 1998 (Aronson et al. 2002a, 2002b, 2005, Miller et al. 2009, Eakin et al. 2010, Villamizar et al. 2014, Neal et al. 2017) and yellow band disease in the early 2000s. The ecological extinction of the two once-dominant BMBR coral genera (*Acropora* and *Orbicella*) has dramatically changed the structure and functioning of this unique regional ecosystem.

Our results are concordant with previous studies in Belize that documented shifts in hard-coral and macroalgal abundance from the 1970s to 1996 (McClanahan and Muthiga 1998). The patch reefs of Glovers Reef atoll had 80% hard coral and 20% algae cover in 1970–1971 but phase-shifted to 20% hard coral and 80% algae cover by 1996–1997 (McClanahan and Muthiga 1998). This was due to declines in the reef-building corals *A. cervicornis*, *A. palmata*, and *O. annularis* (formerly *Montastrea annularis*), as well as reductions in herbivores and spongivores (Pawlik et al. 2018). Prior to the beginning of our study, Acroporid abundance declined in Belize (Aronson and Precht 2001, Rodríguez-Martínez et al. 2014), thus we did not document some of the earlier, and likely more dramatic community shifts. At Channel Cay shoal, Belize, for example, *A. cervicornis* was replaced mostly by *Agaricia tenuifolia* (Aronson & Precht 1997), but then subsequently by sponges following the 1998 mass-bleaching event (Aronson et al. 2002b). A longitudinal study of *A. palmata* along the Mexican part of the Mesoamerican Barrier Reef System also indicated declines in acroporids with *A. palmata* decreasing from 7.7% in 1985 to 2.9% in 2012 (Rodríguez-Martínez et al. 2014). We documented the decline of *O. annularis*, and the failure of the formerly dominant acroporid species to recover post-disease, even after 20 years. The observed increase in macroalgae is concordant with other studies in the late 1990s and early 2000s in Belize, which also documented macroalgal increases, principally by the genus *Lobophora* (McClanahan & Muthiga 1998).

Similar shifts in the dominant benthic assemblages have been documented across the Caribbean, followed by the failure of the reefs to recover following disturbances (Gardner et al. 2003, Bruno et al. 2009, Schutte et al. 2010, Toth et al. 2014, Hughes et al. 2018b, 2018a, Steneck et al. 2019). Across seven subregions in the Caribbean, Schutte et al. (2010) found significant declines in hard-coral cover and increases in macroalgal cover from 1970–2005. In the Florida Keys (Toth et al. 2014), and in the U.S. Virgin Islands (Edmunds & Elahi 2007), stony corals failed to recover, with declines associated with the decline in *O. annularis* following the 1999 and 2000 El Niño events. The coral reefs in Bonaire exhibited similar trends over 15 years of bleaching, storms, and diseases, with a 22% decline in coral cover and an 18% increase in macroalgal cover by 2017 (Steneck et al. 2019). These trends were also apparent in our study.

We measured the potential effects of several putative drivers of the observed compositional shifts, including local human impacts estimated using the Human Influence Index (HII) and the frequencies of Thermal Stress Anomalies (TSA_Freq). HII was variable across the BMBR (Table A3.1, Figure A3.1), suggesting variability in local human pressure. TSA_Freq differentially affected in space and time throughout the study (Table A3.1, Figure A3.2). We found that soft-coral and sponge cover were significantly lower on sites where HII was higher, suggesting that these taxa may be more susceptible to local human stressors than CCA, *Halimeda*, macroalgae, and hard corals (Mora 2008). TSA_Freq was significantly negatively associated with the cover of hard corals, macroalgae, soft corals, and sponges. These findings are concordant with other studies that have documented coral mortalities and subsequent declines in coral cover following the temperature-induced bleaching events in 1998 (Peter J. Mumby 1999, McField et al. 2001, Aronson et al. 2002b) and 2005 (Miller et al. 2009, Eakin et al. 2010, Villamizar et al. 2014, Neal et al. 2017).

Several major disturbances have impacted coral reefs across the BMBR since 1997, including two mass bleaching events, three hurricanes, and a reef-damaging earthquake (Table 3.1). We suggest that these disturbances accelerated the temporal shifts in community types we observed between 2005 and 2009. In the summer of 1998, corals across the globe experienced bleaching caused by widespread thermal anomalies due to ocean warming (Bruno et al. 2001, Aronson et al. 2002b). Not long after the summer 1998 bleaching event, three major storms—Hurricane Mitch in October 1998, Hurricane Keith in October 2000, and tropical cyclone Iris in October 2001 (Aronson et al. 2002b, 2005) —struck Belize's coastline, resulting in additional damage to the already-impacted reef system. In 2005, another temperature-induced mass bleaching event occurred across the Caribbean (Eakin et al. 2010), resulting in disease and mortality of *Orbicella* spp. (Miller et al. 2009), a lack of recovery by many species in some locations (Neal et al. 2017), and further shifts in the benthic communities (Villamizar et al. 2014). Then, in August 2007, Hurricane Dean struck the coast of Mexico, bringing strong winds and impacts to the Belizean coast (San Pedro Sun 2007). To round out the decade, Belize experienced an earthquake in May 2009, which resulted in the avalanching and fracturing of reefs in the shelf-lagoon (Aronson et al. 2012). The aftermath of the earthquake was marked by an increase in sediment cover and declines of already low hard coral cover.

Our study documents a shift in the dominant benthic communities across the Belize Barrier Reef following decades of disturbances and demonstrates an overall shortcoming of MPAs at mitigating those impacts. Although we began sampling after a majority of the recent disturbances to Caribbean coral reefs, we documented a decline in *Orbicella* spp., which drove increases in macroalgal and soft-coral cover and distinguished the benthic assemblages of 1997–2005 from those of 2009–2016. The benthic communities along the BMBR have experienced local, regional, and global impacts, which contributed to the reef assemblages we see today. Our study provides insight into extent of influence of local and regional stressors at a time of rapid climate change, which will help managers improve their decision-making strategies. We are optimistic that scientists can work with natural-resource managers to develop actionable recommendations to improve the governance and enforcement of well-designed networks of

MPAs. We recommend continued research using long-term monitoring data to identify patterns in community composition across temporal and spatial scales. These longitudinal studies can identify taxa and functional groups that persist through disturbances and, therefore, could be a focus of future management efforts. We encourage adaptive management strategies at local scales to extend past managers working closely with scientists and include more widespread participation by fishers and local users to ensure long-term sustainability. Finally, we recommend global mitigation of carbon emissions to improve the health of reef communities across Belize and elsewhere.

Table 3. 1: Timeline of disturbances to the Belize Mesoamerican Barrier Reef

Year	**Disturbance**	**References**
1980s	*Acroporid*-specific white band disease	Aronson & Precht 2001
1980	*Diadema*-specific disease	Carpenter 1988, Edmunds & Carpenter 2001, Mumby 2009
1998	Temperature-induced coral bleaching	Aronson et al. 2002a, Aronson et al. 2002b
1998	Hurricane Mitch	Jackson et al. 2014
2001	Tropical Cyclone Iris	Aronson et al. 2005
2005	Temperature-induced coral bleaching	Miller et al. 2009, Eakin et al. 2010, Villamizar et al. 2014, Neal et al. 2017
2007	Hurricane Dean	San Pedro Sun 2007
2009	Earthquake	Aronson et al. 2012

Table 3. 2: Estimated regression parameters, standard error, F statistic, and p-value from the final generalized linear mixed models for each benthic group of interest. Significance codes: 0; ***, 0.001; **, 0.01, *, 0.05; 0.1; 1.

Benthic Group and Fixed Effects	Estimate	Standard error	F statistic	p-value
CCA				
(Intercept)	-3.41			**<0.001*** **
Year	0.221	0.110	2.02	**0.043 ***
Protected vs. Not Protected	-0.023	0.113	-0.207	0.836
Hii at 50 km	-0.028	0.112	-0.252	0.801
TSA_Freq	0.057	0.111	0.516	0.606
Marginal R^2 =0.090; Conditional R^2 = NA				
Halimeda				
(Intercept)	-3.33			**<0.001*** **
Year	0.222	0.122	1.83	0.068
Protected vs. Not Protected	0.202	0.126	1.61	0.108
Hii at 50 km	0.225	0.124	1.81	0.071
TSA_Freq	0.053	0.123	0.427	0.670
Marginal R^2 = 0.215; Conditional R^2 = NA				
Hard Coral				
(Intercept)	-1.78			**<0.001*** **
Year	-0.551	0.095	-5.78	**7.55E-09 *** **
Protected vs. Not Protected	0.099	0.171	0.580	0.562
Hii at 50 km	0.238	0.166	1.43	0.153
TSA_Freq	-0.464	0.103	-4.50	**6.94E-06 *** **
Marginal R^2 = 0.472; Conditional R^2 = 0.669				
Macroalgae				
(Intercept)	-1.51			**<0.001*** **
Year	1.88	0.232	8.10	**5.65E-16 *** **
Protected vs. Not Protected	-0.016	0.240	-0.068	0.946
Hii at 50 km	0.331	0.237	1.40	0.162
TSA_Freq	-0.808	0.238	-3.39	**0.000688 *** **
Marginal R^2 = 0.589; Conditional R^2 = NA				
Soft Coral				
(Intercept)	-2.41			**<0.001*** **

Year	0.447	0.103	4.36	**1.33E-05 *** **
Protected vs. Not Protected	0.242	0.125	1.94	0.0519
Hii at 50 km	-0.281	0.122	-2.30	**0.0213 ***
TSA_Freq	-0.307	0.108	-2.85	**0.00441 ****
Marginal R^2 = 0.387; Conditional R^2 = 0.447				
Sponge				
(Intercept)	-3.16			**<0.001*****
Year	0.028	0.077	0.360	0.718
Protected vs. Not Protected	0.063	0.080	0.787	0.432
Hii at 50 km	-0.161	0.078	-2.06	**0.0396 ***
TSA_Freq	-0.207	0.079	-2.62	**0.00866 ****
Marginal R^2 = 0.210; Conditional R^2 = NA				

Table 3. 3: Summary of model comparisons. For each linear mixed-effect model, the model terms, degrees of freedom, Akaike Information Criterion (AIC), Bayesian Information Criterion (BIC), log likelihood (LogLik) and deviance are reported.

Approach and Model Terms	**df**	**AIC**	**BIC**	**LogLik**	**Deviance**
CCA					
Model 1: Year + Protection + HII.50 + TSA_Freq_btw_surveys + (1|Site)	45	50.7	63.4	-18.4	36.7
Model 2: Year + Protection + HII.50 + TSA_Freq_Hist + (1|Site)	45	50.2	62.9	-18.1	36.2
Final Model (3): Year + Protection + HII.50 + TSA_Freq + (1|Site)	45	50.7	63.3	-18.3	36.7
Halimeda					
Model 1: Year + Protection + HII.50 + TSA_Freq_btw_surveys + (1|Site)	45	59.6	72.2	-22.8	45.6
Model 2: Year + Protection + HII.50 + TSA_Freq_Hist + (1|Site)	45	60.0	72.6	-23.0	46.0
Final Model (3): Year + Protection + HII.50 + TSA_Freq + (1|Site)	45	60.1	72.7	-23.0	46.1
Hard Coral					
Model 1: Year + Protection + HII.50 + TSA_Freq_btw_surveys + (1|Site)	45	75.8	89.5	-30.9	61.8
Model 2: Year + Protection + HII.50 + TSA_Freq_Hist + (1|Site)	45	79.0	92.7	-32.5	65.0
Final Model (3): Year + Protection + HII.50 + TSA_Freq + (1|Site)	45	63.3	77.0	-24.7	49.3
Macroalgae					
Model 1: Year + Protection + HII.50 + TSA_Freq_btw_surveys + (1|Site)	45	153.3	167.0	-69.7	139.3
Model 2: Year + Protection + HII.50 + TSA_Freq_Hist + (1|Site)	45	153.3	166.9	-69.6	139.3
Final Model (3): Year + Protection + HII.50 + TSA_Freq + (1|Site)	45	142.9	156.6	-64.5	128.9
Soft Coral					
Model 1: Year + Protection + HII.50 + TSA_Freq_btw_surveys + (1|Site)	45	68.4	82.1	-27.2	54.4
Model 2: Year + Protection + HII.50 + TSA_Freq_Hist + (1|Site)	45	65.9	79.5	-25.0	51.9
Final Model (3): Year + Protection + HII.50 + TSA_Freq + (1|Site)	45	61.5	75.2	-23.8	47.5
Sponge					
Model 1: Year + Protection + HII.50 + TSA_Freq_btw_surveys + (1|Site)	45	34.5	48.2	-10.3	20.5

Model 2: Year + Protection + HII.50 + TSA_Freq_Hist + (1|Site)	45	34.5	48.1	-10.2	20.5
Final Model (3): Year + Protection + HII.50 + TSA_Freq + (1|Site)	45	28.1	41.7	-7.0	14.1

Table 3. 4: Output from analysis of variance tests (ANOVA) testing if mean percent cover of hard coral species representing six major genera (Acropora, Agaricia, [Pseudo-]Diploria, Orbicella, Porites, and Siderastrea) varied significantly over time. Significance codes: 0; ***, 0.001; **, 0.01, *, 0.05; 0.1; 1.

Coral Species and Parameters	Df	Sum Sq	Mean Sq	F value	p-value
A. agaricites					
Year	1	0.746	0.746	0.858	0.359
Residuals	43	37.355	0.869		
A. cervicornis					
Year	1	0.246	0.246	3.59	0.065
Residuals	43	2.954	0.069		
A. grahamae					
Year	1	0.191	0.191	7.36	**0.009** **
Residuals	43	1.117	0.026		
A. lamarcki					
Year	1	0.001	0.001	0.195	0.661
Residuals	43	0.300	0.007		
A. tenuifolia					
Year	1	0.168	0.168	0.465	0.499
Residuals	43	15.50	0.361		
D. labyrinthiformis					
Year	1	0.048	0.048	0.509	0.479
Residuals	43	4.050	0.094		
***Orbicella* complex**					
Year	1	36.26	36.26	18.80	**8.59e-05*** **
Residuals	43	82.91	1.93		
***P. porites* complex**					
Year	1	0.001	0.001	0.001	0.974
Residuals	178	109.9	0.618		
P. strigosa					
Year	1	0.306	0.306	0.403	0.529
Residuals	43	32.70	0.760		
***Siderastrea* spp.**					
Year	1	0.041	0.041	1.023	0.317
Residuals	43	1.731	0.040		

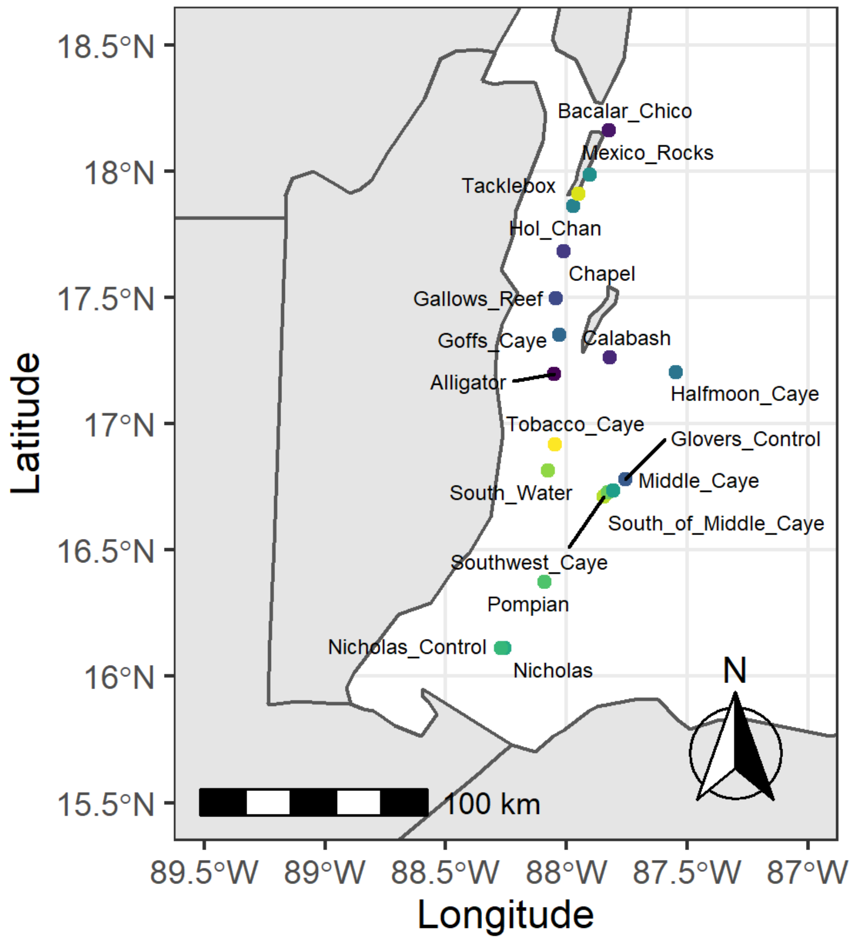

Figure 3. 1: Study sites along the Belize Mesoamerican Barrier Reef system.

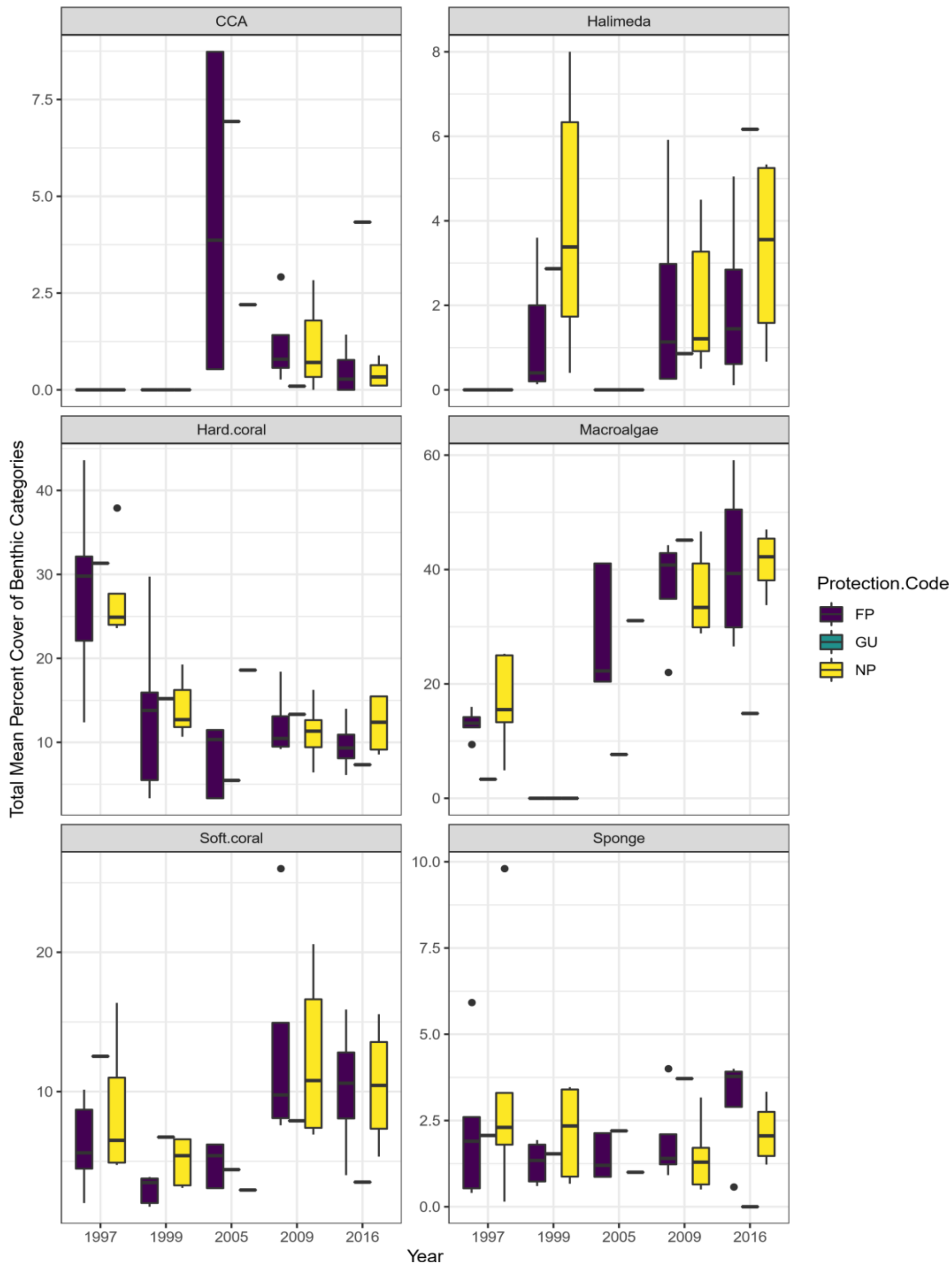

Figure 3. 2: Mean percent cover of six benthic categories over time (Year) and across management regime (Protection.Code). The "Protection.Code" categories are: (1) fully protected zones where only non-extractive activities were permitted (FP), (2) general-use zones with restrictions placed on certain gear types (GU), and (3) non-protected zones (NP) where fishing is not restricted. Categories with percent cover close to zero indicate a lack of data for those years.

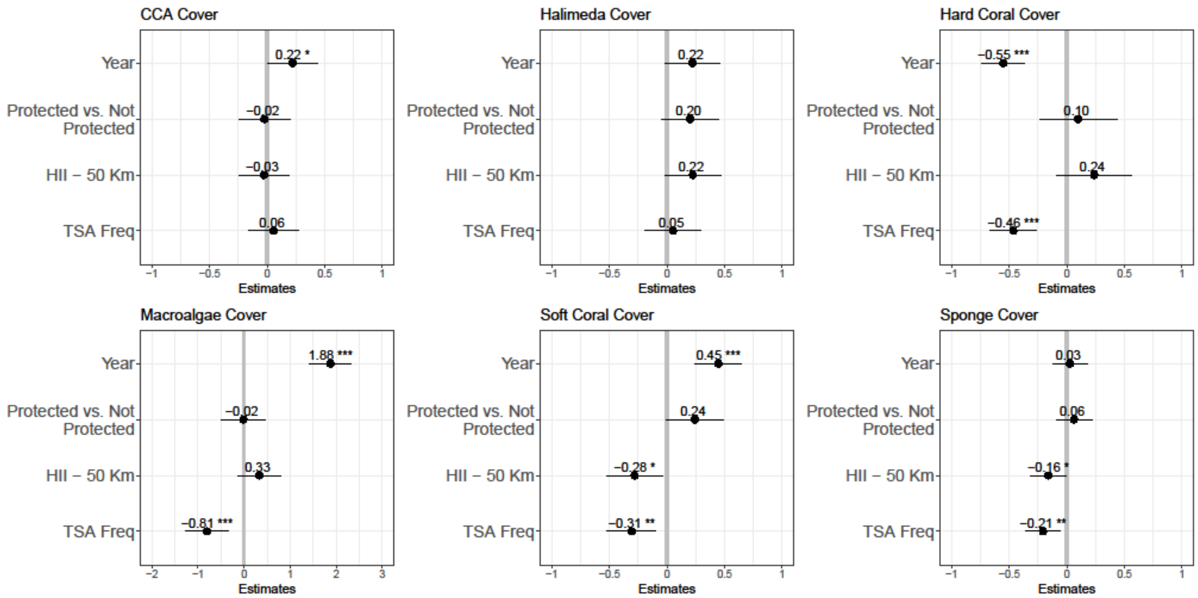

Figure 3. 3: Effect sizes (+ 95% CI) from the GLMMs of all covariates on the six benthic categories of interest. Asterisk indicates statistically significant (< 0.05) p value. Vertical grey line represents an effect size of zero.

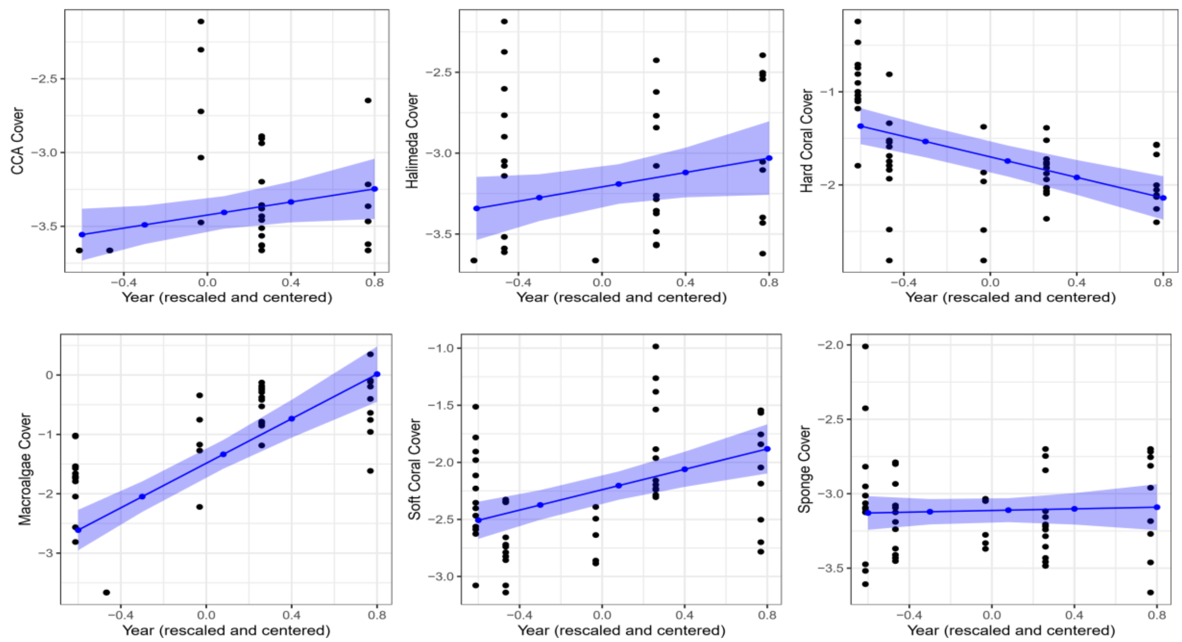

Figure 3. 4: Relationship between logit-transformed percent cover and time. Blue dots and lines represent GLMM model estimates over time (continuous), while black dots represent the logit-transformed percent cover of the six benthic categories plot for each year of the study (discrete). Blue shading indicates 95% CI. Time was a significant predictor of changes in the cover of: hard coral ($p < 0.001$), macroalgae ($p < 0.001$), and soft coral ($p < 0.001$) (Table 3.2).

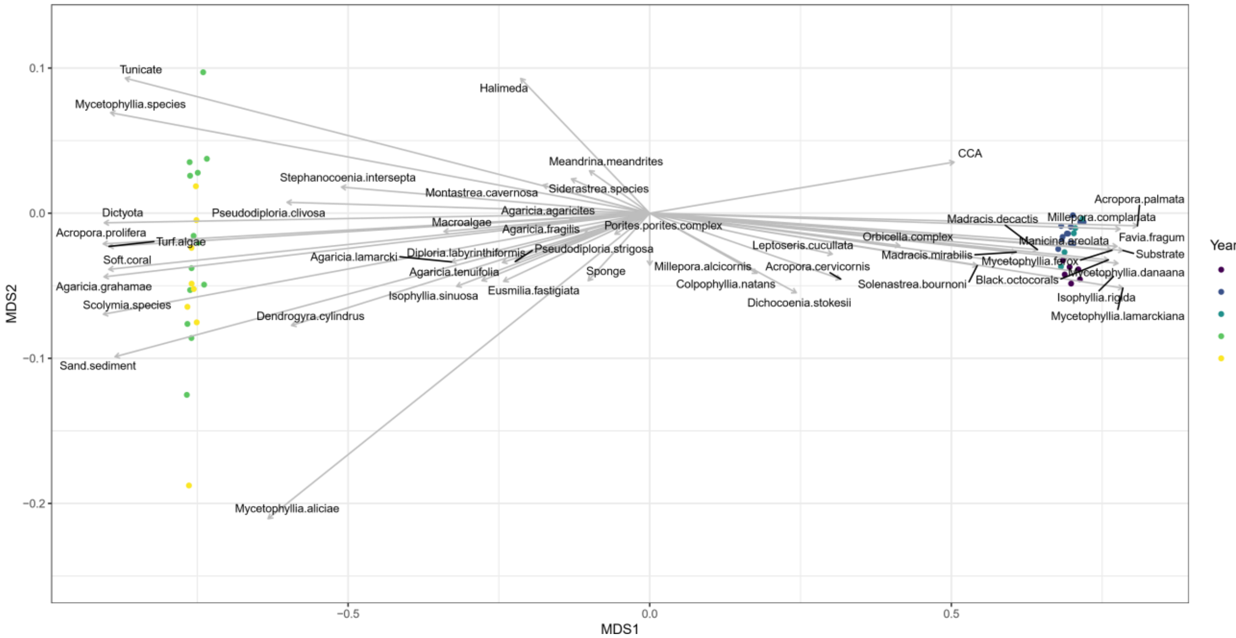

Figure 3. 5: Multi-dimensional scaling (MDS) plot depicting species (ID)-level data colored by year. Points represent individual sites, arrows and IDs represent the MDS loadings. The Bray-Curtis dissimilarity matrix was used and the stress value is 0.029. Zoanthid (MDS1 = -0.20, MDS2 = 1.5) and Rubble (MDS1 = -0.70, MDS2 = 0.41) were removed from the Figure as they distorted the MDS2 axis. Years are colored and labeled in chronological order at the right as follows: 1997, 1999, 2005, 2009, and 2016.

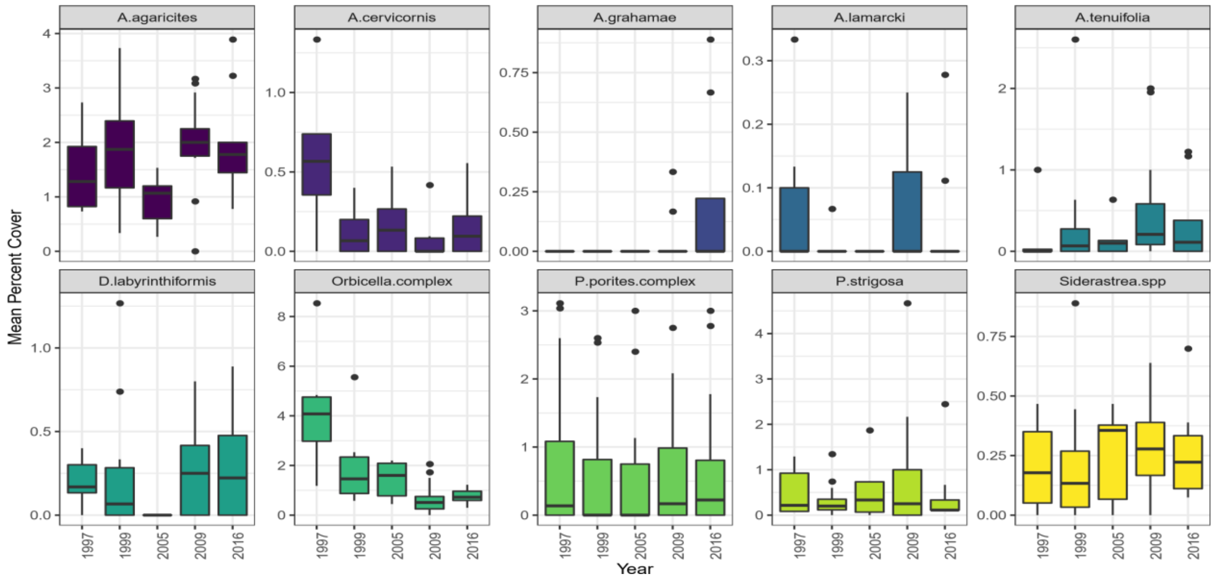

Figure 3. 6: Mean percent cover of hard coral species across six major genera: *Acropora, Agaricia, [Pseudo-]Diploria, Orbicella, Porites,* and *Siderastrea.*

CHAPTER 4: ASSESSING FISHER PERCEPTIONS OF THE TERRITORIAL USER RIGHTS FOR FISHING (TURF) PROGRAM: A CASE STUDY IN SOUTHERN BELIZE[3]

Introduction

Commercial and subsistence fisheries provide livelihoods and fish protein to nearly three billion people annually (FAO 2014). This demand has led to overfishing of marine ecosystems, which disrupts ecosystem functioning and threatens fisheries sustainability (Jackson et al. 2001, Valdivia et al. 2015). As a result, fisheries science is becoming increasingly interdisciplinary to develop innovative management strategies to mitigate common-pool resource system (CPRS) problems (Dietz 2003, Cudney-Bueno and Basurto 2009). Fisheries are some of the most challenging CPRS for which to develop effective management strategies because they are easily sub-tractable and non-excludable (Ostrom 1990). Without effective institutions (i.e. rules and enforcement mechanisms) to regulate the extraction of the marine species, users will be inclined to overharvest these CPRS (Ostrom 1990 and 2003, Gibson et al. 2005). Sustainable fisheries management requires all actors involved to engage in collective action to reach shared sustainability objectives for current and future generations (Ostrom 1990, Urquhart et al. 2014, Valdés-Pizzini et al. 2016). This puts even more emphasis on the importance of compliance by fishers to govern and manage their fisheries for ultimate success (Gibson et al. 2005).

Community-based fisheries management (CBFM) has emerged as a promising solution to the challenges associated with governing the coastal commons by providing a platform where

[3] A version of this chapter is in prep for *Marine Policy* as Alves, C., R. Kramer. Assessing fisher perceptions of the territorial user rights for fishing (TURF) program: A case study in Southern Belize.

fishers, managers, and communities collaborate to meet collective objectives (Armitage et al. 2012, Urquhart et al. 2014, Valdés-Pizzini et al. 2016). Ideally, CBFM combines understanding fisheries – stocks, populations and extraction methods – and the role humans play in shaping these through culture, history, and social structure (Armitage et al. 2012, Urquhart et al. 2014, Valdés-Pizzini et al. 2016). This strategy can provide fishers an opportunity to get involved in local fisheries governance through participatory management, where fishers report their catch to fishing authorities and are included in the decision-making process (Wiber et al. 2004, Islam and Yew 2013, Kittinger 2013, Alexander et al. 2015). CBFM must address the current needs of society, while not jeopardizing the potential of future generations to benefit from the services provided from marine ecosystems. Sustainable fisheries management, therefore seeks to preserve the history, livelihoods, economic growth and development and the environment.

Catch share programs are an example of CBFM strategies that are increasingly common in small scale fisheries contexts across the globe (Costello et al. 2008, Birkenbach et al. 2017, Karr et al. 2017, White and Costello 2017). They may include territorial user rights for fishing (TURFs), where fishers are granted use and access rights to fish in designated areas (Barner et al. 2015). They may also include an individual transferable quota (ITQ) system where a share of the scientifically determined total catch is divided up to fishers, cooperatives, or communities (Costello et al. 2008, Harford et al. 2016, Mcdonald et al. 2017, White and Costello 2017). Assigning catch shares to fishers can prevent the “race to fish” paradigm because fishers are sharing a portion of the total catch between members of their community (Birkenbach et al. 2017). Catch share programs can also inspire collective action, leading fishers to become stewards of their environment. These initiatives may lead to decreased poaching in restricted areas and gradual recovery of fish populations (Foley 2012, Catzim and Walker 2013, Barner 2015, Valdés-pizzini et al. 2016, Mcdonald et al. 2017).

Despite the promise of catch share programs, like TURFs, several challenges exist to their overall success. One such challenge is establishing international governance policies between countries that share a resource system, like in the Caribbean (Christie and White 2007, Matias et al. 2013). Another obstacle presents itself by way of "roving bandits," which are fishing fleets that enter a fishery from outside the community and exploit the marine resources (Cudney-Bueno and Basurto 2009). Furthermore, ecological (i.e. commercial species density) and socioeconomic (i.e. fisher income) outcomes often take a long time (>10 years) to improve following TURF implementation (Villaseñor-Derbez et al. 2019), despite the desire for immediate improvements. However, it is important to evaluate how TURF programs impact the livelihoods and perceptions of the users to determine gaps in their effectiveness in the short- and long-term.

TURFs have been implemented in small scale fisheries contexts worldwide through partnerships with diverse stakeholders at the academic, government, and non-government organization (NGO) levels. For example, benthic fisheries in Chile are currently managed by a TURF system, which is proving effective at increasing species richness and encouraging collective action among fishers (Gelcich et al. 2012a, 2012b, Gelcich 2014). In Baja California and along the Yucatan Peninsula in Mexico, several small TURF programs have emerged, which often pair with pre-existing fisher cooperatives and marine reserves (Basurto et al. 2013, Aceves-Bueno et al. 2017, Villaseñor-Derbez et al. 2019). Many of these have not been in place long enough for social and ecological benefits to come to fruition. In the Caribbean, the first TURFs emerged in Belize in 2011, with two pilot sites established at the Glover's Reef and Port

Honduras Marine Reserves, and seven additional sites added in 2016 (Foley 2012, Catzim and Walker 2013, Belize Fisheries Department 2015, Fujita et al. 2017, Karr et al. 2017, McDonald et al. 2017, Belize Fisheries Department 2019), but there has been no formal evaluation of the program since its inception.

This study is the first to evaluate the community perceptions of Belize's TURF program - known as Managed Access (MA). The purpose of this study was to evaluate the impact of MA participation on the knowledge, attitudes and practices (KAP) of fishers from southern Belize. KAP studies provide enhanced understanding of management effectiveness by asking respondents about their perceptions towards management rules, attributes, and policies at the individual and community level (Gupta et al. 2015, Heinen et al. 2016). For this study, fishers from 10 communities in Southern Belize were interviewed in 2014 by the Belize Fisheries Department (Belize Fisheries Department 2015) — two years before the national implementation of MA — and again by me in 2019. We compared the responses from fishers in 2014 to those in 2019, and conducted 2019-specific analyses to understand fisher perceptions towards several program-related components (logbook process, enforcement, and support). Because fishers are key stakeholders of the Managed Access program, it is essential to understand what they know, understand and perceive about the program. This is because fisher buy-in is critical for the long-term sustainability of fisheries management policies. From their perceptions, we can interpret if the MA program is meeting its objectives, which focus on increased fisher income, catch per unit effort, and decreased illegal fishing – all in line with fishers' goals. Insights from this study can inform other projects evaluating community perceptions of CBFM in other small-scale fisheries contexts.

Methods

Study area

Belize is in Central America, and is home to the second longest barrier coral reef in the world – the Belize Barrier Reef (BBR) – which spans over 300 kilometers (Figure 4.1). Seven protected areas within the BBR have been a part of a UNESCO World Heritage Site since 1996 (UNESCO 2019). The Belize Barrier Reef is part of the larger Mesoamerican Barrier Reef System, which traces the coasts of Belize, Mexico, and Honduras. The reef system incorporates the diverse marine habitats of mangroves, seagrass beds, fringing and patch coral reefs, and several offshore atolls. Because of this rich biodiversity, ecotourism and fishing are two of the most prevalent livelihood strategies among Belizeans (Gopal et al. 2015).

Lobster, conch, snapper and grouper are the primary fishery species across Belize (Catzim and Walker 2013). Lobster season goes from June 15 until February 14, while conch season is from October 1 - April 30. Lobster traps, shades, and free-diving are the primary methods fisherfolk target lobster and conch (Fujita et al. 2017). Finfish can be harvested anytime, and there are currently no quotas on finfish species except parrotfish, Nassau grouper, tarpon, bonefish and permit, which are prohibited from extraction. However, special licenses are granted for fishers to target lane snapper spawning aggregations (Belize Fisheries Department 2019). Nearshore finfish are harvested by handlines, spear guns and traps (Fujita et al. 2017). The fishing industry is male-dominated (~95% male), although they find women approachable and many fisheries managers/NGO leaders are women (Catzim and Walker 2013).

Coastal resource management structure and history

In the early 1980s, the first marine protected areas (MPAs) were established in Belize, restricting fishing from distinct offshore locations and demonstrating a commitment to marine resource sustainability by the government (Alves, *in review*). During that time, fishers were not regularly included in marine resource management decisions, until 2009, when Belize began reforming fisheries practices. In 2011, Belize became the first country in the Caribbean to implement Managed Access (MA) – a Territorial User Rights for Fishing (TURF) regime that grants fishers rights to fish in select areas in exchange for reporting their catch and color-coding their vessel(s) (Foley 2012, Belize Fisheries Department 2015, Barner 2015, Fujita et al. 2017, McDonald et al. 2017, Belize Fisheries Department 2019). The MA program was the result of over a decade of planning between the Belize government, the Environmental Defense Fund (EDF), and Belizean non-governmental organizations (NGOs) (Foley 2012, Catzim and Walker 2013, Belize Fisheries Department 2015, Fujita et al. 2017, McDonald et al. 2017, Belize Fisheries Department 2019). Many NGOs act as co-managers of the marine reserves (and fishing areas) with the Belize Fisheries Department to enforce MA rules, issue logbooks, and provide resources to fishers. Two pilot MA sites were established in 2011, one of which paired with the Port Honduras Marine Reserve (PHMR, established in 2000), while the other was incorporated into the Glover's Reef Marine Reserve (GHMR, established 1998). In a 2013 assessment of the pilot sites by Catzim and Walker (2013), illegal fishing had decreased and reported catches had increased among fishers in the pilot sites.

This encouraged the Belize government and partner NGOs to begin a nationwide campaign in 2014 to educate fishers and the public about the proposed national expansion of MA. Paired with this educational campaign was a survey across Belizean coastal fishing communities to measure the knowledge, attitudes and practices (KAP) of respondents towards the proposed national expansion of MA (Belize Fisheries Department 2015). The 2014 KAP survey was coordinated by the Marine Conservation and Climate Adaptation Project (MCCAP) within the Belize Fisheries Department (Belize Fisheries Department 2015). Then, in 2016, the Managed Access program was implemented nationwide across Belize, adding six fishing areas to the pre-existing two pilot sites.

This study is the first to explore the impact of program participation on the knowledge, attitudes, and practices of fishers in Belize. Due to funding and logistical constraints, this project was a case study that targeted users of four MA areas (3, 4, 5 8), representing 10 communities in southern Belize (Figure 4.1). The 2019 sampling methodology, survey design and data collection were based off of the 2014 survey methodology.

Sampling design and methodology

The target population for both the 2014 and 2019 surveys were licensed commercial fishers who were over 18 years old. Respondents for the 2014 survey were selected through a stratified random sampling methodology based off of a list of all licensed commercial fishers from the Belize Fisheries Department (Belize Fisheries Department 2015 and 2019). Because of logistical constraints, the 2019 survey targeted fishers only in Southern Belize. We used a stratified random sampling methodology to select fishers from the following southern communities: Dangriga, Hopkins, Riversdale, Seine Bight, Placencia, Independence, Monkey River, Punta Negra, Punta Gorda, and Barranco. For the sake of comparison, Forest Home, Cattle Landing and Punta Gorda surveys were combined in 2014 to be compared to Punta Gorda surveys in 2019. The three communities are adjacent to one another and the town center is Punta

Gorda. Table 4.1 expresses the number of respondents and percent of the population surveyed in each community and year.

To identify and recruit participants for the 2019 survey, we accessed a list of fisher's names, telephone numbers and addresses from local NGO partners (the Toledo Institute for Development and Environment, TIDE and the Southern Environmental Association, SEA). The difference in fishers surveyed in each community is due to variance in number of licensed fishers per community (i.e. lower numbers reflect communities with fewer fishers) and difficulty in fisher recruitment across communities (i.e. fishers in some communities were easier to recruit than others). Within those communities, we visited neighborhoods and villages, and some fishers' homes.

To decrease the likelihood of bias in both 2014 and 2019, a variety of recruitment methods were used in the different communities. Snowball sampling was employed where identified key informants and previous participants led us to other respondents (Coleman 1959, Goodman 1961). Respondent-driven convenience sampling was also used, where participants were selected based on the level of access (time, place, and willingness to participate) (Heckathorn 1997). We held scheduled and random household visits, called fishers on the telephone to set up household visits, intercepted fishers while at fish markets, and scheduled meetings at community centers with a small refreshment. To recruit fishers to participate in the community meetings, we reached out to fishers who were leaders in their communities (e.g. head of fisher associations) and asked that they help us advertise to the fishers in their communities. We also distributed flyers to public places that included a brief statement of informed consent; the date, time and location of the community meetings; the name and contact information of the primary author, and a statement requiring proof of valid commercial fishing license. We understand that there still might be some selection bias as we used key informants of some communities to help us organize meetings with fishers; also, those who consented to survey might be more/less supportive of MA, and may have less survey fatigue than those who declined.

Designing and pre-testing the survey questionnaire

To thoroughly investigate the knowledge, attitudes, perceptions and behaviors of fishers, both the 2014 and 2019 surveys were designed using the peer-reviewed literature focusing on measuring livelihoods and environmental dependence and the knowledge, attitudes, and practices of common-pool resource users towards management decisions (Appendix B). We also drew upon consultations with key agency and community informants. Because the purpose of this study was to examine the impact of MA program participation on the knowledge, attitudes, and practices of fishers from 2014-2019, the 2019 survey was modified from the 2014 KAP survey (Belize Fisheries Department 2015). This provides a basis for comparison among key responses, however several differences exist between the 2014 survey and the one we implemented. For instance, the 2019 survey included demographic questions at the end of the survey to eliminate survey fatigue at the more important livelihood and perceptions questions. The 2019 survey included MA-specific questions from the 2014 survey as well as more MA-program questions involving fishing methods, the typical catch in a fishing trip, perceptions about enforcement, insights into accurate logbook reporting, and use of alternative livelihood strategies. The 2019 survey was also shortened to ensure it could be easily completed within 20-30 minutes, and therefore reduce respondent fatigue.

Respondents were asked a series of questions related to their fishing behavior, knowledge, and attitudes towards the MA program and demographic information (Tables 4.2-

4.4). To measure knowledge, attitudes, and practices towards the MA program components, respondents were asked to rank their responses using either Yes/No/Not Sure or by using a 5-point Likert scale (1 = Strongly disagree, 2 = Disagree, 3= Neither agree nor disagree, 4 = Agree, 5= Strongly agree). Non-responses were removed from the sample while those who did not know/did not have an opinion were reported separately from the sample. Additional questions were asked of respondents in 2019 to examine the perceptions of fishers towards Managed Access program-specific components (Table 4.4). Such responses were broken into the following categories: (A) enforcement and rule following, (B) logbook reporting, (C) support for the MA program in general. Prior to survey implementation, the survey instrument was pre-tested with enumerators and managers at the partner NGOs. Language clarity improved, additional marine species caught were added, and a list of alternative livelihood strategies was updated. Pre-testing was an important component of the survey planning process because it ensured the questionnaire was clear and not too long.

Enumerator hiring and training

For both survey years, individuals experienced in marine resource management were hired and trained as enumerators to conduct the interviews. In 2014 they were recruited from local NGOs and from the Belize Fisheries Department staff (Belize Fisheries Department 2015). In 2019, enumerators were recruited from the group of community researchers at TIDE and SEA, due to their in-depth knowledge of the communities served by the two organizations. Enumerator training occurred prior to survey implementation and during the course of one week. Training included presentations on the purpose of the research study, the proposed methods and fieldwork schedule, instructions on how to use the Open Data Kit (ODK) software (Hartung et al., 2010), tablets, and associated passwords (for 2019), practice interviewing and being interviewed, and familiarity with the survey instrument. Enumerator training also covered best practices for conducting social science interviews, which emphasized the importance of confidentiality and anonymity with fishers, reading a statement of informed consent at the beginning of each survey, translating the survey to local languages on spot from English, and how to handle difficult situations (respondent refuses to answer question, gets confused or angry, etc.).

Data collection

In 2014, survey implementation occurred in May, while in 2019 it occurred in May and the first half of June. In 2014, 60 close-ended questions were asked of respondents using paper surveys (Belize Fisheries Department 2015). In 2019, 50 close-ended questions were asked of respondents on tablets using the Open Data Kit software and associated open-source resources on Android tablets (Hartung et al. 2010). When respondents were particularly interested in the research subject, we encouraged them to provide additional information in a semi-structured interview format. Often these key informants were fishers who were leaders in their communities, representing their fisher organizations and coastal communities. In 2019, semi-structured interviews with key informants (n = 20) occurred in these communities: Punta Gorda, Monkey River, Punta Negra, Hopkins, Seine Bight, Riversdale, and Dangriga. In 2019, the primary author also was a participant observer of the fisheries management process at a Fisher Forum representing MA areas 4 and 5 in Punta Gorda, on June 6. To assist with contextualizing the results of this study, the primary author regularly visited the local fish markets, docksides, produce markets, participated in town and village social events, and contributed to the local economies (e.g. patronage at restaurants, grocery stores, house rentals, and taxis).

Data entry, quality assurance, quality checking and analysis

At the end of each day of data collection for both survey years, the team meetings were held between project members to follow-up, input and backup data into spreadsheets on a secure computer drive. The primary author manually inspected each survey for quality assurance, quality checking and completion. To report the summary of the population sampled, we first calculated the number and percentage of respondents fitting seven demographic variables (Table 4.2: gender, age range, highest level of education, number of additional persons in household, cultural group, membership to fisheries organization(s), and percent daily catch kept for family).

To compare the knowledge, attitudes, and perceptions of fishers towards the Managed Access program rules and potential components between 2014 and 2019, and between respondents from 2019, we used the Likert package in R (Bryer and Speerschneider 2016). We divided up responses for comparison based on if they were Yes/No/Not Sure and then those that were asked on a 5-point Likert scale (Tables 4.3 and 4.4). To determine if statistically significant differences in response existed between 2014 and 2019 for the Yes/No/Not Sure questions, we conducted a Chi (χ)-square test on the count (number of responses) for each response type and year. Non-responses expressed as NA's and refusals to answer were dropped from the analysis. The R studio software version 3.6. was used to visualize and quantify trends among the data and variables of interest (R Core Team 2020). The code is available upon request to the corresponding author. The semi-structured interviews with key informants from 2019 ($n = 20$) were coded by hand, with specific themes identified and direct quotes identified in the results' section (Burbano et al. 2020).

Results

Demographic profile of respondents from 2014 and 2019

A total of 362 respondents were interviewed in 2014 while 123 were interviewed in 2019 (Table 4.2). In 2014, 6.35% of respondents were female, while the other 93.65% were male. The population surveyed in 2019 was very similar, with 5.69% of respondents reporting as female and 94.31% as male (Table 4.2). In 2014, the majority of respondents were between 21-50 years old, with the most respondents (26.80%) in the 31-40-year-old age range. On the other hand, in 2019, the majority (31.71%) of respondents were in the 41-50-year-old range (Table 4.2). For both survey years, most respondents' highest level of education was primary school, with 46.96% of respondents in 2014 and 53.66% of respondents from 2019. The next highest level of education completed by respondents of both years was secondary school/high school level (32.04% in 2014 and 33.33% in 2019, Table 4.2).

The surveyed populations of both years were also similar for the number of additional persons living in their household, with the most respondents of both years (~30%) sharing their household with more than five individuals (Table 4.2). The highest proportion of respondents from 2014 (41.44%) belonged to the Creole cultural group, with the next highest proportions representing Garifuna (29.01%) and Mestizo (15.47%). This breakdown is also reflected in the population from 2019 (Table 4.2). 41.71% of respondents in 2014 reported belonging to a fishing cooperative, while only 22.76% of respondents in 2019 were cooperative members (Table 4.2). The majority of respondents in both years reported keeping less than half of their daily catch for their families (71.55% in 2014 and 80.49% in 2019).

Comparison of the knowledge, attitudes, and perceptions of fishers towards MA rules and program components, between 2014 and 2019

Fishers' perceptions toward the Managed Access program rules and components varied between 2014 and 2019 (Table 4.3, Figures 4.2 and 4.3). The survey questionnaires gauged fishers' perceptions towards the eligibility rules for getting and renewing a Managed Access license as well as the rights-based and reporting components of the program (Table 4.3, Figures 4.2 and 4.3). There were statistically significant differences in the percentage of respondents who answered "Yes" versus "No" versus "Not sure" between 2014 (n = 362) and 2019 (n = 123) for the prompt "Fishers are required to record their catch" ($\chi^2 = 36.97$, df = 3, $p < 0.001$), with more respondents answering "Yes" in 2019 than 2014 (Table 4.3, Figure 4.2). There were not statistically significant differences in the responses to "I know the requirements to obtain a Managed Access license" between 2014 (n = 234) and 2019 (n = 123, $\chi^2 = 2.80$, df = 3, p = 0.423). In 2014, 65.81% of respondents answered "Yes", while in 2019 71.54% answered "Yes" (Table 4.3, Figure 4.2).

Similarly, for the prompt "I know the terms for Managed Access license renewal," there were not statistically significant differences in the responses between 2014 (n = 235) and 2019 (n = 123, $\chi^2 = 7.44$, df = 3, p = 0.059). Most respondents in 2014 (56.60%) and 2019 (69.91%) responded "Yes" to the prompt (Table 3, Figure 2). However, there were statistically significant differences in the responses to the prompt "There are benefits to having Managed Access rights" between respondents in 2014 (n = 360) and those in 2019 (n = 123, $\chi^2 = 11.84$, df = 3, p = 0.00). Significantly more respondents (56.91%) answered "Yes" to that prompt in 2019 than in 2014 (41.94%, Table 4.3, Figure 4.2). Lastly, to the prompt "There are benefits to reporting catch," there were no statistically significant differences in responses between respondents in 2014 (n = 361) and 2019 (n = 123, $\chi^2 = 6.17$, df = 3, p = 0.104). Most respondents in 2014 (52.53%) and

2019 (43.09%) said “Yes” to the prompt, while the proportion of respondents who answered “No” and “Not Sure” were more similarly distributed (Table 4.3, Figure 4.2).

Fishers’ perceptions towards the Managed Access program as measured on a 5-point Likert scale also differed between the two sampling years (Table 4.3, Figure 4.3). Most of the respondents in 2014 (71%) and 2019 (75%) agreed or strongly agreed with the prompt, “Fishers in my community can locate boundaries of marine reserves” (Table 4.3, Figure 4.3). In 2019, a higher proportion of respondents (55%) agreed or strongly agreed with the statement “MA rights have been fairly distributed to fishers,” compared to 39% in 2014 (Table 4.3, Figure 4.3). However, in 2014, 50% of respondents either disagreed or strongly disagreed with that statement (Table 4.3, Figure 4.3). Lastly, in response to the statement, “Most fishers in my community can be trusted,” most respondents from both 2014 (67%) and 2019 (75%) agreed or strongly agreed (Table 4.3, Figure 4.3).

Managed Access program-specific analyses (from 2019)

Survey Questionnaires

Respondents in 2019 (n = 81) were asked to state the level to which they agreed with several statements to gauge their perceptions towards several Managed Access program-specific components, separated into the following three categories: (A) enforcement and rule following, (B) logbook reporting, (C) support for the MA program in general (Table 4.4, Figure 4.4). In the enforcement and rule following category, the majority of respondents either agreed (61.73%) or strongly agreed (24.69%) with the statement, “Most fishers in my community follow the rules,” but 72% of respondents reported agreeing or strongly agreeing with the statement, “I have seen fishers fishing without a license” (Table 4.4, Figure 4.4). However, there is wide agreement by

84% of respondents that “Fishers in my community can manage our fishery” (Table 4.4, Figure 4.4). When asked if fishers “Trust the enforcement of MA,” 44.44% agree with the statement, while 13.58% strongly disagree and 25.93% disagree with the statement (Table 4.4, Figure 4.4). There was almost an even split between respondents who agree (49%) and disagree (47%) that “Illegal fishing in marine reserves has declined” (Table 4.4, Figure 4.4). Lastly, 49% of respondents disagreed or strongly disagreed with the statement “Enforcement has improved under MA” (Table 4.4, Figure 4.4).

In the logbook reporting category, 77% of respondents agreed (59.26%) or strongly agreed (17.28%) with the prompt, “Logbooks are easy to fill out” (Table 4.4, Figure 4.4). Similar viewpoints were expressed by respondents to the prompt, “I fill out my logbook accurately,” with 49.38% of respondents stating they agree with it, and 22.22% strongly agreeing (Table 4.4, Figure 4.4). In the category for support for the MA program in general, 68% of respondents agreed (49.38%) or strongly agreed (18.52%) with the statement, “I fully support MA in the long run” (Table 4.4, Figure 4.4). A similarly high proportion of respondents (67%) also agreed that “MA is improving the marine resources” (Table 4.4, Figure 4.4). When asked if “MA is benefiting my livelihood,” 56% of respondents agree (46.91%) or strongly agree (8.64%) while 32% disagree (18.52%) or strongly disagree (13.58%) with the statement (Table 4.4, Figure 4.4). Most (48%) respondents either disagree (39.51%) or strongly disagree (8.64%) with the statement “I spend less time fishing now,” while 41% of respondents agree (38.27%) or strongly agree (2.47%) with it (Table 4.4, Figure 4.4). Lastly, 47% of respondents either disagree (32.10%) or strongly disagree (14.81%) with the statement “My catch has improved under MA” while 40% agree (33.33%) or strongly agree (6.17%) with it (Table 4.4, Figure 4.4).

Themes from Semi-Structured Interviews

The themes that arose from the semi-structured interviews with key informants in 2019 (n = 20) were broken into the three categories from the 2019 quantitative surveys (enforcement and rule following, logbook reporting, and support for the MA program), as well as two additional categories: the importance of fishing to respondents' livelihoods and well-being, and the active role fishers can play in the MA process. One of the most common themes that arose was the need for increased enforcement. One fisher said, "*I have no problem breaking the rules because Fisheries [Department] isn't doing their job,*" while another said, "*Why make more rules if nobody is enforcing anything?*"

Another common theme with fishers was their criticism of the role of local NGOs in the enforcement of MA. One expressed that the local NGO co-manager of their fishing area is "*Managing, but not for us, but for them,*" while another said "*Our ideas aren't good because they go against their show*." One respondent stated that "*[Local NGO] only helps fishermen with mouth,*" not with action. Another fisher said, "*For who is [Local NGO] protecting this area? Not for the Belizeans, it's for the aliens*," demonstrating a concern with illegal, transboundary fishers also using their MA area. Several other fishers noted that some of the NGO rangers who patrol the MA areas won't report illegal fishing if they know the fishers or if they get paid off, highlighting a gap in enforcement effectiveness.

Statements about the inaccuracy of the logbook data were prevalent in the interviews. One fisher stated that the logbook reporting "*Is just a waste of a fisherman's time…They're [co-managers and the Fisheries Department] not getting the true information.*" Another fisher from a different community stated that logbooks, "*To me, they're a waste of time.*" One even said, "*None of the data are legitimate data; they're bulls***.*" At least one fisher admitted to the corresponding author, "*To be honest with you, I didn't fill out one logbook*." One respondent recognized that the inaccuracy of the data cannot be used for any management decisions, stating that managers "*Can't use the data 'cause it's not right*."

Respondents were also critical about the effectiveness of the Managed Access program. One fisher who had been fishing for over 40 years said, "*I thought the words would speak for themselves -- Managed Access -- but it has to be* managed." Others echoed similar sentiments, with one respondent stating, "*This Managed Access thing isn't working*" and another: "*I can't say it's positively benefitting us*." One respondent even said, "*If I could fish what I was getting before I'd say Managed Access is working*." Another fisher expressed additional concerns about if the program is meeting management goals, stating, "*Managed Access is not working how they wanted it to*." Lastly, a fisher stated that they felt they "*have no rights*" as members of Managed Access.

Another theme that arose in the semi-structured interviews was the importance of fishing to respondents' livelihoods and well-beings. Three separate individuals expressed that fishing and being at sea is their lifeblood. One stated, "*If I don't go to sea, I'm gonna die*," while another said, "*[If] I can't make a living fishing – I'd die*." The third individual stated, "*The sea is a part of me*," demonstrating how intertwined their identity is with fishing. Several respondents also expressed that they no longer fish as much as they used to, having turned to tourism or other alternative livelihood strategies to make ends meet. One fisher who now is a tour guide part-time said, "*When I am not fishing, I am helping the ocean,*" recognizing that they can make a living preserving marine life instead of extracting it. Another individual told us, "*I take my kids out every two weeks to show them what I used to do,*" carrying on the fishing tradition to younger generations but not needing it for their livelihood. The same fisher also called marine life "*Belize's heartbeat*."

The final theme prevalent throughout the key informant interviews was about the active role fishers can play in the MA process. One fisher stated in Creole, "*Make we protect dis ting for we self*," demonstrating their willingness to be involved in the monitoring and self-reporting aspect of Managed Access. Another fisher reflected on the changes in management, stating, "*If it were still up to us, I think we'd still have a good healthy reef*." One fisher recognized the importance of protecting marine resources for future generations when they said, "*We want to protect our stuff for our ancestors*." Another expressed interest in learning more about the logbook data collection and analysis process: "*What if you educate me more*."

Overall, the semi-structured interviews revealed that fishers are concerned about the effectiveness of Managed Access and the accuracy of the logbook data, but are willing to get more involved in the participatory monitoring process of the program. Their criticism of the NGO co-managers in the enforcement of Managed Access demonstrates room for improvement for the program moving forward.

Discussion

Summary of key findings

The purpose of this study was to evaluate the knowledge, attitudes, and perceptions of fishers from southern Belize towards the newly implemented TURF program known as Managed Access (MA). We compared the responses from fishers in 2014 – two years before the national implementation of MA – to those from 2019 and found that the surveyed populations shared some demographic characteristics. About 94% of both populations were male, the majority of respondents' highest level of education completed was primary school, most shared their household with more than five individuals, and most respondents were either in the Creole or Garifuna cultural groups. However, more respondents in 2014 were members of a fishing cooperative than those in 2019. The similar demographic information between the two sampled populations suggests similarities in the overall population characteristics, providing a basis for comparison of their knowledge, attitudes and perceptions of the MA program between the two years.

Overall, fishers from both years understood the requirements for acquiring and renewing their licenses, but in 2019, more fishers understood the requirement of logbook reporting and the benefits of having MA rights than those in 2014. These changes demonstrate that the increased education and outreach efforts of the co-managers that occurred throughout the MA implementation process (Belize Fisheries Department 2015 and 2019) could have potentially led to this shift in responses (D'agata et al. 2020). However, fishers in both 2014 and 2019 answered similarly to the prompt, "There are benefits to reporting catch," showcasing that even after three years of MA implementation, fishers' perception towards the logbook reporting process did not change. The semi-structured interviews with key informants supported these claims, with several respondents expressing that the data reported in logbooks are not accurate and are a waste of time to report. This dissatisfaction with the accuracy and benefit of the logbook reporting process highlights a potential avenue of focus for future educational outreach efforts, even if most (77%) respondents in 2019 agreed that logbooks are easy to fill out and that they (72%) fill out their logbook accurately.

67 – 75% of respondents surveyed in 2014 and 2019 agreed that their communities can locate boundaries of marine reserves and be trusted, demonstrating the potential for long-term

collective action and involvement in fisheries management (Armitage et al. 2012, Basurto et al. 2013, Aceves-Bueno et al. 2017, Karr et al. 2017, Alexander et al. 2018). This sentiment of confidence in one's fishing community was mirrored in several responses only asked of fishers in 2019, with 86% of respondents agreeing that fishers in their community follow the rules, and 84% of respondents agreeing that fishers in their community can manage our fishery. This suggests further potential for fisher empowerment in the participatory process of Managed Access, and certain room for improvement going forward. Involving fishers in the data-collection and reporting process is not a new concept to participatory fisheries management, but is one that requires institutional capacity, resources and fisher buy-in in the long run (Wiber et al. 2004, Lundquist and Granek 2005). In Belize, fishers are not involved in the management decisions or data-collection process as much as the program set out to achieve (Karr et al. 2017, Fujita et al. 2018), demonstrating a gap in the overall efficacy of Managed Access.

However, one of the biggest issues that arose in the 2019 was about non-licensed fishers and a lack of enforcement, with the finding that 72% of respondents reported seeing "fishers fishing without a license," 47% disagreeing with the statement that "Illegal fishing in marine reserves has declined," and 49% of respondents disagreeing that "Enforcement has improved under Managed Access." For those respondents who stated they have seen fishers fishing in areas without a license, this could be indicative of on-going conflicts of transboundary, non-licensed fishers fishing in Belize's territorial waters (source: key informant interviews). Similar sentiments were revealed through the semi-structured key informant interviews, with two respondents separately criticizing the enforcement measures by the Fisheries department, stating: "*I have no problem breaking the rules because Fisheries [Department] isn't doing their job,*" and, "*Why make more rules if nobody is enforcing anything?*" These responses indicate that enforcing the rules of MA is still an obstacle to the perceived success and legal adoption of the program. These findings are concordant with a recent study by Wade et a. (2019), which found that fishers negatively perceived the enforcement and illegal fishing activities, demonstrating an area of improvement for policymakers.

Belize context

As of late 2019, a new Fisheries Resource Bill was passed, which includes policies geared towards increased participation by diverse stakeholder groups and improved enforcement and monitoring guidelines (Belize Fisheries Department 2019). It is possible that the implementation of this new bill will resolve some of the present criticisms of the Managed Access program by fishers found in this study. Furthermore, Belize is a place where pre-existing governance structures exist to empower fisherfolk, encourage participatory co-management across stakeholder groups and adapt to new data-driven indicators of fisheries management effectiveness (Fujita et al. 2017, Karr et al. 2017, McDonald et al. 2017). However, fisher perceptions revealed criticism of the enforcement strategies of managers and a willingness to get more involved, suggesting room for improvement of the program in the long-run. This study demonstrates the importance of including fisher perceptions in the evaluation of fisheries policies, as their buy-in ensures long-term sustainability (Wiber et al. 2004, Cudney-Bueno and Basurto 2009).

Study limitations and suggested next steps

This was the first study to evaluate the knowledge, attitudes, and perceptions of fishers towards the implementation of the Managed Access program in Belize. However, due to logistical and financial constraints, we focused on a small scale, only interviewing fishers from 10 communities in southern Belize. Because of this, we are missing out on the feedback of northern fishers, who have different fishing strategies, and potentially cultural and behavioral differences as well, especially in regards to historic fishing practices and varied relationships with the co-manager NGOs (Perez 2009, key informant interviews). Therefore, the conclusions made in this study about fishers' knowledge, attitudes and practices related to MA is spatially constrained to the communities where we interviewed. Furthermore, the follow-up study in 2019 was conducted only three years after nationwide implementation of MA, which was likely not long enough to see the impact of the public policy change on the perceptions of users. Ecological and socioeconomic outcomes often take over 10 years to improve following TURF implementation (Villaseñor-Derbez et al. 2019) despite the desire for immediate improvements.

Due to the limited scope of this study, there are additional questions that could be asked of the data collected to further understand the intricacies of fisher perceptions towards the MA program. I am particularly interested in examining if differences in perceptions exist between fishers who are members of fisher associations or cooperatives, compared to those who do not belong to any organization. This would assist in answering questions about the role of fisher organizations in inspiring collective action and influencing the perceptions of the membership (Wiber et al. 2004, Partelow et al. 2020). Furthermore, additional analyzes should investigate the potential impact of socio-economic variables on fisher perceptions. Such variables could include percent income from fishing, alternative livelihood strategies, and/or assets owned by fishers, which were all obtained in the 2019 survey (Appendix B). These suggested analyzes contribute to enhanced interpretation of why including fisher perceptions is important to understanding the MA program on a whole.

Our conclusions are primarily based off of quantitative surveys, so we encourage future studies to be conducted across Belize and include more qualitative data collection methods such as in-depth focus groups, key informant interviews, and even experimental games. Additional studies should focus on the potential for continued collective action and monitoring of the MA areas by the fishers as way to fill in the gap in enforcement capacity by co-manager NGOs and the Fisheries Department that currently exists and was perceived by fishers in 2019. This would gather more information about the gaps in participatory management that currently exist in the MA program.

Recommendations for managers

We recommend natural resource managers conduct user surveys before and after public policy interventions like MA, spacing the interviews at least 10 years apart (Villaseñor-Derbez et al. 2019). However, even doing a post-implementation a post-implementation assessment like ours within five years can glean several important components to the overall efficacy of policy interventions. This study also demonstrates the importance of prioritizing effective enforcement activities by not only the Fisheries Officers at the co-manager NGOs and Fisheries Department, who are currently the primary ones responsible for enforcement, but also fishers. There is the potential for fishers to increase participation in collective action by monitoring/self-policing their areas (cite). Increasing the trainings and reporting responsibilities for fishers would also lead to much-needed support for pre-existing gaps in management capacity (Gill et al. 2017). This project would not have been possible without the willingness of natural resource managers in Belize to partner with us, demonstrating the importance of inter-institutional collaborations and the value placed on using science to inform policy decisions in Belize.

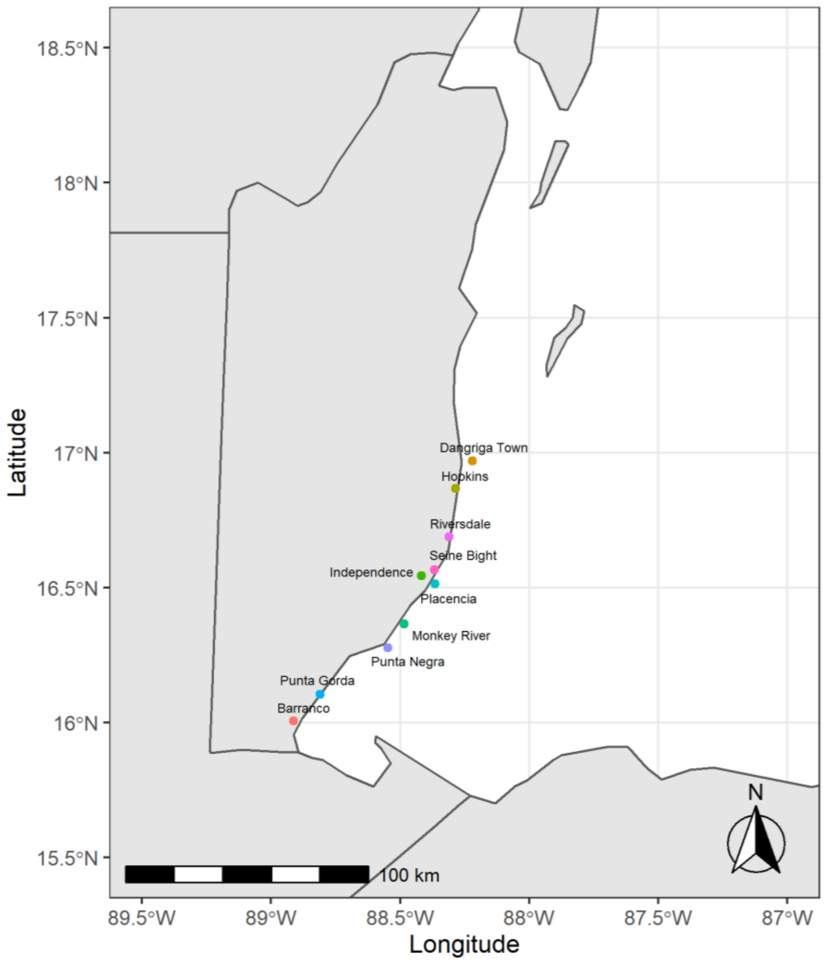

Figure 4. 1: Site map of 10 communities surveyed across southern Belize in both 2014 and 2019.

Table 4. 1: Number of respondents and percent of the population surveyed per community and year.

Community	# obs. 2014 (%) n = 362	# obs. 2019 (%) n = 123
Barranco	0 (0.00)	3 (2.44)
Cattle Landing	1 (0.28)	0 (0.00)
Dangriga Town	108 (29.83)	16 (13.01)
Forest Home	2 (0.55)	0 (0.00)
Hopkins	37 (10.22)	17 (13.82)
Independence	57 (15.75)	10 (8.13)
Monkey River	12 (3.31)	15 (12.20)
Placencia	52 (14.36)	15 (12.20)
Punta Gorda	72 (19.89)	28 (22.76)
Punta Negra	5 (1.38)	7 (5.69)
Riversdale	8 (2.21)	7 (5.69)
Seine Bight	8 (2.21)	5 (4.07)

Table 4. 2: Demographic summary statistics of fisherfolk surveys conducted in 2014 (n = 362) and 2019 (n = 123).

Variable	**Description of Responses**	**# obs. 2014 (%) n = 362**	**# obs. 2019 (%) n = 123**
Gender	Female	23 (6.35)	7 (5.69)
	Male	339 (93.65)	116 (94.31)
Age Range (years)	18 to 20	16 (4.42)	2 (1.63)
	21 to 30	89 (24.59)	23 (18.70)
	31 to 40	97 (26.80)	20 (16.26)
	41 to 50	79 (21.82)	39 (31.71)
	51 to 60	51 (12.09)	22 (17.89)
	61 or older	30 (8.29)	17 (13.82)
Highest Level of Education	No school completed	37 (10.22)	8 (6.50)
	Primary school level	170 (46.96)	66 (53.66)
	Secondary school/high school level	116 (32.04)	41 (33.33)
	Tertiary school/post-high school level	28 (7.73)	7 (5.69)
	Trade/Vocational course	9 (2.49)	1 (0.81)
	Other	2 (0.55)	0 (0.00)
Number of Additional Persons in Household	Zero	3 (0.83)	7 (5.69)
	One	35 (9.67)	11 (8.94)
	Two	33 (9.12)	11 (8.94)

	Three	47 (12.98)	14 (11.38)
	Four	61 (16.85)	21 (17.07)
	Five	69 (19.06)	22 (17.89)
	More than Five	112 (30.94)	37 (30.08)
	No Response	2 (0.55)	0 (0.00)
Cultural Group	Creole	150 (41.44)	42 (34.15)
	East Indian	27 (7.46)	9 (7.32)
	Garifuna	105 (29.01)	36 (29.27)
	Maya	4 (1.10)	3 (2.44)
	Mestizo	56 (15.47)	26 (21.14)
	Other	20 (5.52)	7 (5.69)
Membership to Fisheries Organization(s)	Cooperative	151 (41.71)	28 (22.76)
	Belize Fisherman Cooperative Association	18 (4.97)	5 (4.07)
	Fisheries Association	61 (16.85)	2 (1.63)
	None	131 (36.19)	37 (30.08)
	Other	0 (0.00)	51 (41.46)
	No Response	1 (0.28)	0 (0.00)
Percent Daily Catch Kept for Family	None	19 (5.25)	9 (7.32)
	Less than Half	259 (71.55)	99 (80.49)
	Half	24 (6.63)	8 (6.50)
	More than Half	22 (6.08)	1 (0.81)

	All	17 (4.70)	0 (0.00)
	Other	1 (0.28)	6 (4.88)
	Don't Know	16 (4.42)	0 (0.00)
	No Response	4 (1.10)	0 (0.00)

Table 4. 3: Reported responses to gauge fishers' knowledge, attitudes and practices related to the Managed Access program in both 2014 and 2019. Sample size varied by question type, as there was some non-response for certain questions.

Variable	**Description of Responses**	**# obs. 2014 (%) n = 362**	**# obs. 2019 (%) n = 123**
Fishers are required to report their catch	Yes	199 (54.97)	104 (84.55)
	No	108 (29.83)	11 (8.94)
	Not sure	55 (15.19)	8 (6.50)
		# obs. 2014 (%) n = 234	**# obs. 2019 (%) n = 123**
I know the requirements to obtain a MA license	Yes	154 (65.81)	88 (71.54)
	No	44 (18.80)	21 (17.07)
	Not sure	36 (15.38)	14 (11.38)
		# obs. 2014 (%) n = 235	**# obs. 2019 (%) n = 123**
I know the terms for MA license renewal	Yes	133 (56.60)	86 (69.91)
	No	74 (31.50)	26 (21.14)
	Not sure	28 (11.91)	11 (8.94)
		# obs. 2014 (%) n = 360	**# obs. 2019 (%) n = 123**
There are benefits to having MA rights	Yes	151 (41.94)	70 (56.91)
	No	109 (30.28)	32 (26.02)
	Not sure	100 (27.78)	21 (17.07)
		# obs. 2014 (%) n = 361	**# obs. 2019 (%) n = 123**

There are benefits to reporting catch	Yes	189 (52.35)	53 (43.09)
	No	96 (26.59)	42 (34.15)
	Not sure	76 (21.05)	28 (22.76)
		# obs. 2014 (%) n = 202	**# obs. 2019 (%) n = 91**
Fishers in my community can locate boundaries of marine reserves	Strongly disagree	4 (1.98)	5 (5.49)
	Disagree	43 (21.29)	18 (19.78)
	Neither agree nor disagree	12 (5.94)	0 (0.00)
	Agree	107 (52.97)	50 (54.95)
	Strongly agree	36 (17.82)	18 (19.78)
		# obs. 2014 (%) n = 202	**# obs. 2019 (%) n = 91**
MA rights have been fairly distributed to fishers	Strongly disagree	28 (13.86)	20 (21.98)
	Disagree	73 (36.14)	21 (23.08)
	Neither agree nor disagree	22 (10.89)	0 (0.00)
	Agree	67 (33.17)	42 (46.15)
	Strongly agree	12 (5.94)	8 (8.79)
		# obs. 2014 (%) n = 202	**# obs. 2019 (%) n = 91**
Most fishers in my community can be trusted	Strongly disagree	0 (0.00)	5 (5.49)
	Disagree	67 (33.17)	18 (19.78)
	Neither agree nor disagree	0 (0.00)	0 (0.00)

	Agree	101 (50.00)	50 (54.95)
	Strongly agree	34 (16.83)	18 (19.78)

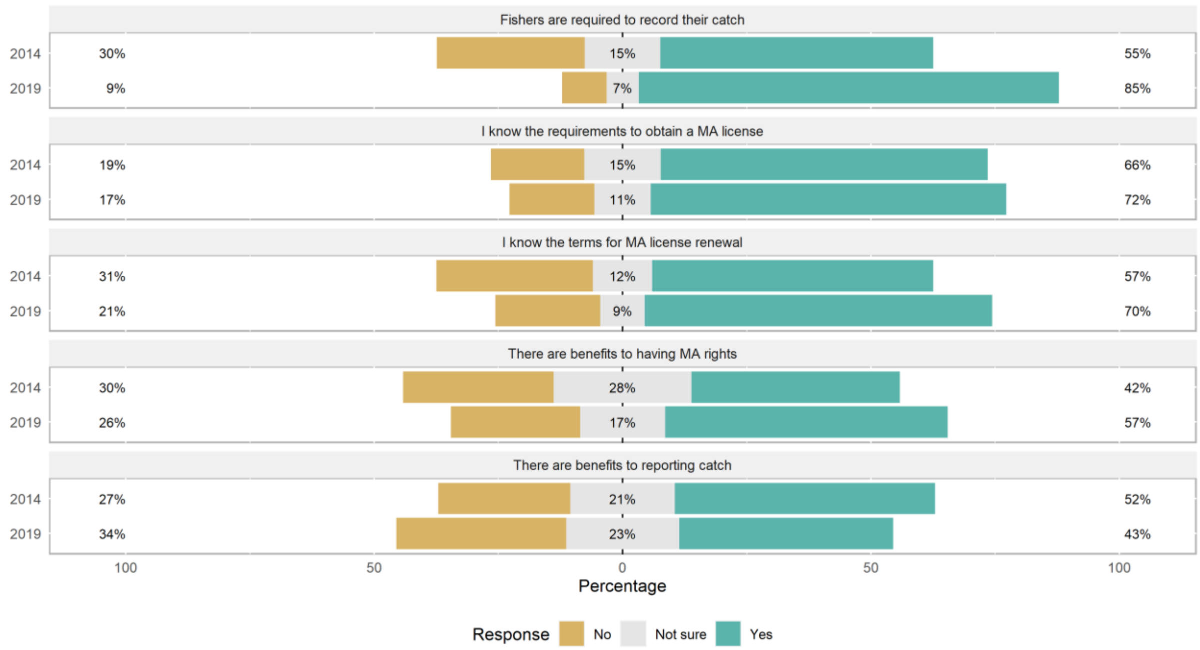

Figure 4. 2: Comparison of fishers' knowledge, attitudes, and practices towards the Managed Access rules and program components between 2014 and 2019, as measured with Yes/No/Not Sure. Sample size varied by question type, as there was some non-response for certain questions.

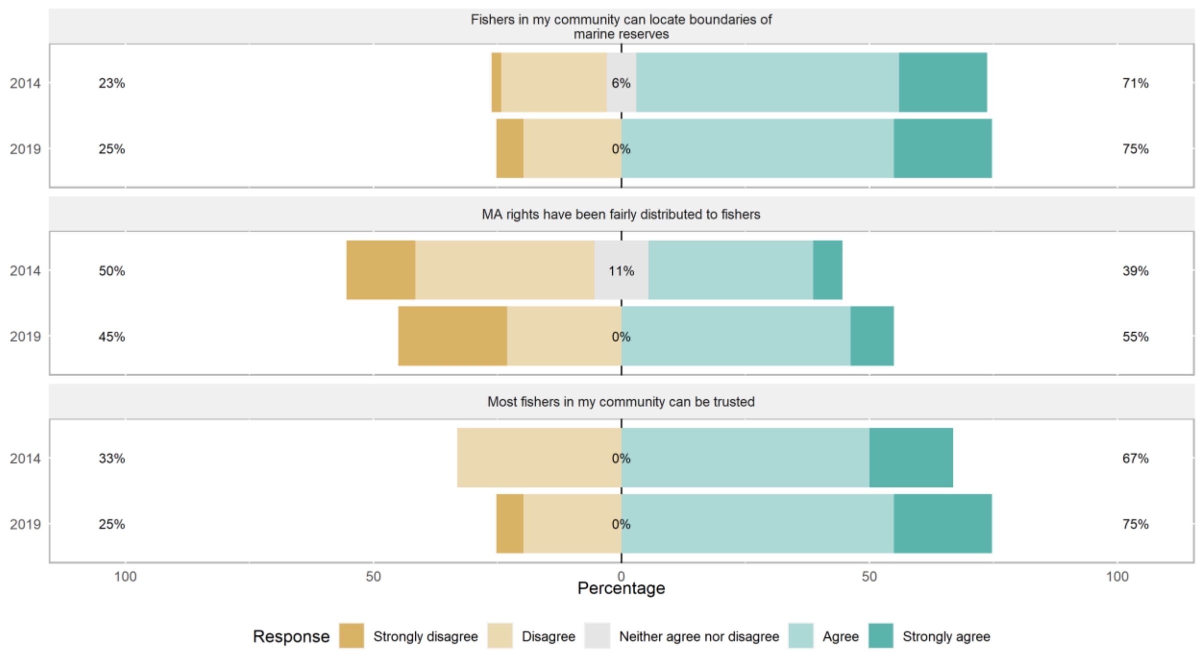

Figure 4. 3**:** Comparison of fishers' perceptions towards the Managed Access program between 2014 (n = 202) and 2019 (n = 91), as measured on a 5-point Likert scale.

Table 4. 4: Reported responses from 2019 respondents (n = 81) to examine fishers' perceptions towards MA program-specific components on a 5-point Likert scale. Responses were broken into three categories: (A) enforcement and rule following, (B) logbook reporting, (C) support for the MA program in general.

Category and Variable	**Number of Observations (%)**				
	Strongly disagree	**Disagree**	**Neither**	**Agree**	**Strongly agree**
Enforcement and Rule Following (n = 81)					
Most fishers in my community follow the rules	3 (3.70)	4 (4.94)	4 (4.94)	50 (61.73)	20 (24.69)
Fishers in my community can manage our fishery	4 (4.94)	6 (7.41)	3 (3.70)	46 (56.79)	22 (27.16)
I have seen fishers fishing without a license	3 (3.70)	17 (20.99)	3 (3.70)	41 (50.62)	17 (20.99)
I trust the enforcement of MA	11 (13.58)	21 (25.93)	5 (6.17)	36 (44.44)	8 (9.88)
Illegal fishing in the marine reserves has declined	18 (22.22)	20 (24.69)	3 (3.70)	34 (41.98)	6 (7.41)
Enforcement has improved under MA	17 (20.99)	23 (28.40)	5 (6.17)	28 (34.57)	8 (9.88)
Logbook Reporting (n = 81)					
Logbooks are easy to fill out	1 (1.23)	10 (12.35)	8 (9.88)	48 (59.26)	14 (17.28)
I fill out my logbook accurately	3 (3.70)	12 (14.81)	8 (9.88)	40 (49.38)	18 (22.22)

Support for MA Program (n = 81)					
I fully support MA in the long run	5 (6.17)	13 (16.05)	8 (9.88)	40 (49.38)	15 (18.52)
MA is improving marine resources	8 (9.88)	14 (17.28)	5 (6.17)	40 (49.38)	14 (17.28)
MA is benefitting my livelihood	11 (13.58)	15 (18.52)	10 (12.35)	38 (46.91)	7 (8.64)
I spend less time fishing now	7 (8.64)	32 (39.51)	9 (11.11)	31 (38.27)	2 (2.47)
My catch has improved under MA	12 (14.81)	26 (32.10)	11 (13.58)	27 (33.33)	5 (6.17)

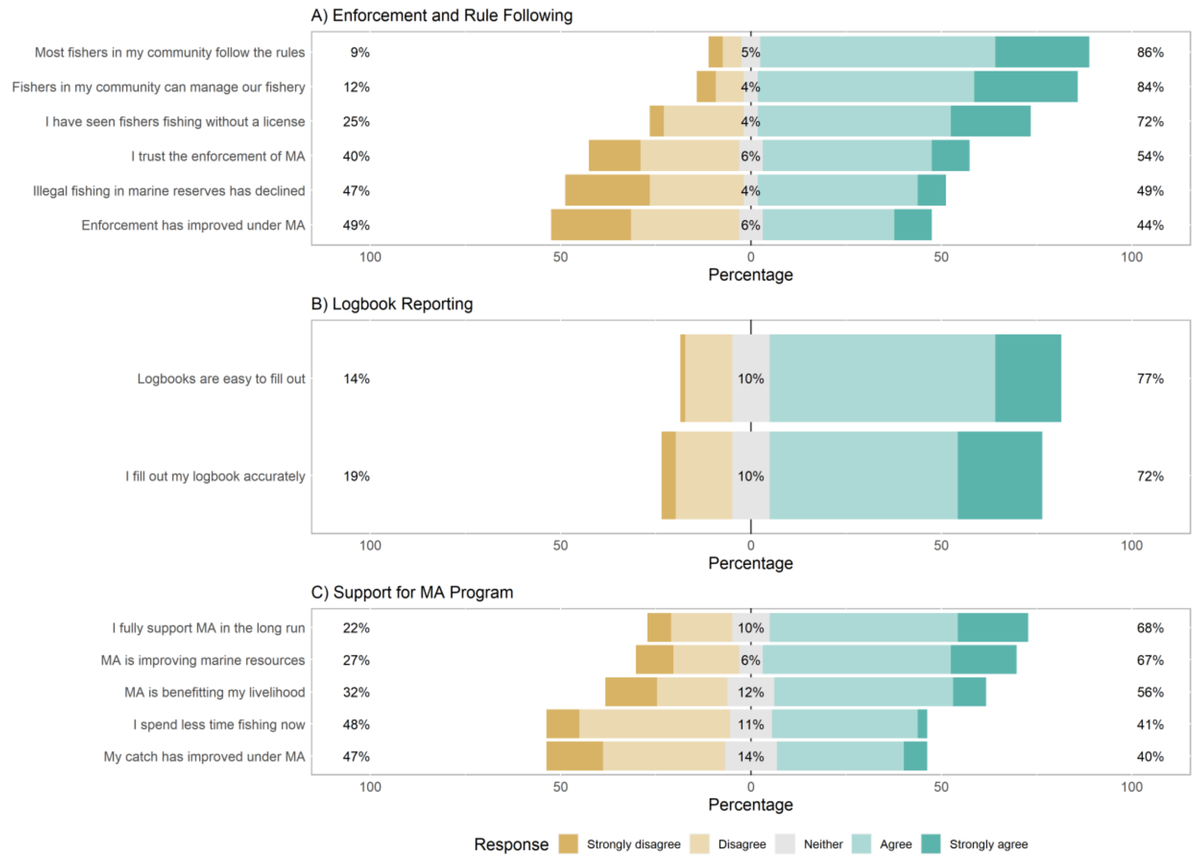

Figure 4. 4: Perceptions of fishers towards Managed Access program-specific components, from respondents in 2019 only (n = 81). Responses were broken into three categories: (A) enforcement and rule following, (B) logbook reporting, (C) support for the MA program in general.

CHAPTER 5: CONCLUSION

Global fisheries provide livelihoods and fish protein for billions of people annually (FAO 2014), yet they are incredibly challenging to sustainably manage (Cudney-Bueno and Basurto 2009, Urquhart et al. 2014, Levine and Richmond 2015). To prevent overfishing and manage common-pool resource system (CPRS) problems that result from such challenges, community-based fisheries management (CBFM) has emerged, particularly in small-scale fisheries contexts. These strategies incorporate traditional fisheries management techniques — like establishing marine protected areas (MPAs), monitoring catch per unit effort (CPUE), reporting maximum sustainable yield (MSY) and setting catch limits (Gaines et al. 2010, Valdés-Pizzini et al. 2012, Bonaldo et al. 2017, Chirico et al. 2017) — with increased participation by fishers in the monitoring and decision-making processes. An emerging CBFM strategy is the combination of catch share programs with territorial user rights for fishing (TURFs), which provide a way for fishers to contribute to resource monitoring (Islam and Yew 2013, Kittinger 2013, Barner et al. 2015, Alexander et al. 2015). Through these programs, fishers are granted rights to fish in select areas but they have to report their catch to management officials. Belize was the first country in the Caribbean to implement such a program, naming it Managed Access (MA, Foley 2012, Belize Fisheries Department 2015 and 2019, Fujita et al. 2017). My dissertation research applied Ostrom's social-ecological systems (SES) framework to evaluating the evolution of this program, and marine resource management in Belize more broadly (Ostrom 2007 and 2009). The results from my dissertation contribute to the growing peer-reviewed literature about CBFM efficacy, which will be used to improve science-based management decisions in small-scale fisheries.

In Chapter two, I combined review of secondary data, key informant interviews and participant observation to describe and evaluate the Governance System (i.e. institutions) involved in marine resource management in Belize. I found that the governmental, NGO, tourism and fishers institutions exhibit a polycentric, decentralized, and nested structure, which contributes to the potential for this system to be robust and resilient to future shocks (Chuenpagdee and Jentoft 2018). Chapter two also revealed that marine resource management in Belize represents all eight design principles for long-enduring common pool resource systems (CPRS, Ostrom 1990), including clearly defined boundaries, collective-choice arrangements, and graduated sanctions. This suggests that Belize has the potential to overcome the collective action problems associated with small-scale fisheries (Levine and Richmond 2015), and become a global leader in sustainable fisheries management.

Chapter three builds upon the understanding of fisheries management in Belize by examining how the benthic assemblages of the Resource System, the Belize Mesoamerican Barrier Reef (BMBR), changed throughout two decades (1997 – 2016) of disturbances (e.g. storms, bleaching and disease). I found that mean coral cover significantly declined from 26% to 11% while macroalgae cover significantly increased from 13% to 40%. There was a documented shift in benthic community composition between early (1997 – 2005) and late (2009 – 2016) sampling years. Furthermore, generalized linear mixed models indicated that hard coral, macroalgae, soft coral and sponge coral were negatively correlated with thermal stress anomalies, while higher human influence was a significant driver of lower sponge and soft coral cover. The changes in benthic community composition and cover are concordant with studies throughout the Caribbean that document shifts in coral reef communities following disturbances, regardless of management status storms (McClanahan et al. 2001, Coelho & Manfrino 2007, Graham et al. 2008, 2015, McClanahan 2008, Muthiga 2009, Darling et al. 2010, Huntington et al. 2011, Toth et al. 2014, de Bakker et al. 2017). This chapter suggests an overall shortcoming of the BMBR MPA network in mitigating the degradation of benthic reef assemblages following decades of disturbances.

To explore another component of the SES as it applies to marine resource management in Belize, I assessed how the knowledge, attitudes, and practices of fishers (the Actors in the SES) towards the MA program changed between 2014 and 2019 in Chapter four. Fishers from 10 communities in southern Belize were interviewed in 2014 by the Belize Fisheries Department (Belize Fisheries Department 2015) and again by me in 2019. Fishers from both years understood the requirements for acquiring and renewing their licenses, but in 2019, significantly more understood the logbook reporting requirements and the benefits of having MA rights than in 2014. Quantitative questionnaires and key informant interviews from 2019 revealed that a lack of enforcement by fisheries officers and illegal fishing by non-licensed fishers are two obstacles to the overall success of the MA program. These results are concordant with another study of fisherfolk in Belize, which found that enforcement and illegal fishing activities were negatively perceived by fishers (Wade et al. 2017), indicating a need for improvement by policymakers.

This interdisciplinary dissertation innovatively combines marine community ecology with the social sciences to inform marine resource management decisions. By drawing from multiple disciplines, my research provides holistic, science-based advice for sustaining fishers' livelihoods while preserving marine resources. Throughout the process, I worked closely with natural resource managers and marine stakeholders to co-develop interdisciplinary research questions and methodology, ultimately leading to long-lasting and practical conservation outcomes on the ground. This inter-institutional collaboration was essential for ensuring a practical application for this research and a platform to share the work with those it affects. While my dissertation is a case study of fisheries management in Belize, similar policies are being implemented in other small-scale fisheries contexts, including the Philippines and Cuba (EDF, personal communication). The results of my dissertation can directly improve the practices for those locations. It is important for me to share the lessons learned and methodology from Belize so the fisheries policies may improve for both the environment and those who rely on it for their livelihoods.

APPENDIX A: SUPPLEMENTARY MATERIAL FOR CHAPTER 3

A1. Supplemental Tables

Table A3. 1: All site-related variables, including list of study sites and survey years. Latitude and longitude are expressed in decimal degrees. Protection refers to one of three of the following management regimes: (1) fully protected zones where only non-extractive activities were permitted (FP), (2) general-use zones with restrictions placed on certain gear types (GU), and (3) non-protected zones (NP), where fishing is not restricted (Cox et al. 2017). HII is included at the 100 km, 75 km, 50 km, 25 km, and 10 km radii. Single asterisk indicates site where species-level cover data were not available. Double asterisk indicates site was surveyed each sampling year of the study.

Site	1997	1999	2005	2009	2016	Longitude	Latitude	Protection	HII 100km	HII 75km	HII 50km	HII 25km	HII 10km
Alligator				Y	Y	-88.05115	17.1966	NP	186234	100838	37768	870	42
Bacalar Chico**	Y	Y	Y	Y	Y	-87.82222	18.16282	FP	265863	113113	36727	5817	1304
Calabash	Y *	Y		Y		-87.8197	17.26147	NP	124826	50174	4088	1944	402
Gallows Reef	Y *	Y		Y	Y	-88.04255	17.49592	NP	222640	107300	41029	5359	368
Goffs Caye	Y *	Y		Y		-88.0288	17.3519	NP	196845	100781	37581	2729	34
Halfmoon Caye	Y *	Y		Y	Y	-87.54679	17.2056	FP	47605	3299	2480	32	32
Hol Chan	Y	Y	Y		Y	-87.97238	17.86343	FP	270893	118928	39311	2213	373
Mexico Rocks	Y			Y	Y	-87.90382	17.98782	NP	266313	118363	32687	2793	1188
Middle Caye**	Y	Y	Y	Y	Y	-87.8054	16.737	FP	82761	28341	100	4	NA
Nicholas	Y *	Y		Y		-88.2559	16.1123	NP	387947	166189	28520	NA	NA
Pompian	Y *	Y		Y		-88.0891	16.3731	NP	228362	66688	9416	NA	NA
South of Middle Caye	Y *	Y		Y		-87.8287	16.7288	NP	87915	31021	432	4	NA
South Water		Y		Y		-88.0776	16.8135	GU	150663	74522	30206	1409	14
Southwest Caye	Y		Y		Y	-87.8461	16.7108	GU	92221	32447	1003	4	NA
Tacklebox**	Y	Y	Y	Y	Y	-87.9508	17.9106	NP	270394	120568	34625	2719	575
Tobacco Caye				Y		-88.0476	16.9191	NP	157690	81005	28297	1455	4

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Table A3. 2: Three metrics of thermal stress anomalies (TSA) at all study sites sampled more than one year over the duration of this study. TSA is weekly SST minus the maximum weekly climatological SST. The frequency of TSA (“TSA_Freq”) is defined by the number of instances TSA was over 1 degree Celsius over the previous 52 weeks, the frequency of TSA between survey years (“TSA_Freq_btw_surveys”) is defined as the number of instances since the previous survey year that TSA was over 1 degree Celsius, and the accumulative TSA (“TSA_Freq_hist”) is represented by the number of times since the beginning of the dataset (1982) to survey year that TSA was over 1 degree Celsius.

Site	**Year**	**TSA_Freq**	**TSA_Freq_hist**	**TSA_Freq_btw_surveys**
Nicholas	1997	1	14	6
Nicholas_Control	1997	1	14	6
Pompian	1997	1	19	7
Southwest_Caye	1997	0	9	3
South_of_Middle_Caye	1997	0	9	3
Middle_Caye	1997	0	13	4
Glovers_Control	1997	1	11	4
South_Water	1997	1	15	4
Tobacco_Caye	1997	0	13	7
Alligator	1997	1	9	4
Halfmoon_Caye	1997	1	6	2
Calabash	1997	0	24	9
Goffs_Caye	1997	0	11	4
Gallows_Reef	1997	1	16	6
Chapel	1997	0	21	6
Hol_Chan	1997	1	19	6
Tacklebox	1997	1	27	7
Mexico_Rocks	1997	0	7	4
Bacalar_Chico	1997	2	14	7
Nicholas	1999	5	20	5
Nicholas_Control	1999	5	20	5
Pompian	1999	5	25	5
Southwest_Caye	1999	4	13	4
South_of_Middle_Caye	1999	4	13	4
Middle_Caye	1999	3	16	3
Glovers_Control	1999	2	13	2
South_Water	1999	3	18	3
Tobacco_Caye	1999	4	17	4
Alligator	1999	3	15	3
Halfmoon_Caye	1999	2	8	2
Calabash	1999	1	25	1
Goffs_Caye	1999	3	15	3

Gallows_Reef	1999	2	20	2
Chapel	1999	5	27	5
Hol_Chan	1999	2	22	2
Tacklebox	1999	5	33	5
Mexico_Rocks	1999	3	12	3
Bacalar_Chico	1999	4	19	4
Nicholas	2005	0	28	6
Nicholas_Control	2005	0	28	6
Pompian	2005	0	31	3
Southwest_Caye	2005	3	24	8
South_of_Middle_Caye	2005	3	24	8
Middle_Caye	2005	1	26	7
Glovers_Control	2005	0	17	1
South_Water	2005	0	26	5
Tobacco_Caye	2005	0	25	6
Alligator	2005	1	22	5
Halfmoon_Caye	2005	1	18	6
Calabash	2005	0	34	4
Goffs_Caye	2005	1	19	3
Gallows_Reef	2005	1	24	4
Chapel	2005	5	38	10
Hol_Chan	2005	2	28	6
Tacklebox	2005	4	45	11
Mexico_Rocks	2005	3	22	9
Bacalar_Chico	2005	2	25	5
Nicholas	2009	1	39	6
Nicholas_Control	2009	1	39	6
Pompian	2009	3	43	7
Southwest_Caye	2009	1	36	8
South_of_Middle_Caye	2009	1	36	8
Middle_Caye	2009	1	37	6
Glovers_Control	2009	1	28	8
South_Water	2009	0	35	4
Tobacco_Caye	2009	2	31	5
Alligator	2009	5	33	6
Halfmoon_Caye	2009	1	28	6
Calabash	2009	4	42	5
Goffs_Caye	2009	4	30	6
Gallows_Reef	2009	2	37	5
Chapel	2009	4	51	9
Hol_Chan	2009	3	39	6
Tacklebox	2009	4	56	5
Mexico_Rocks	2009	4	31	5

Bacalar_Chico	2009	1	31	3
Nicholas	2016	2	69	25
Nicholas_Control	2016	2	69	25
Pompian	2016	2	67	21
Southwest_Caye	2016	2	59	20
South_of_Middle_Caye	2016	2	59	20
Middle_Caye	2016	2	60	20
Glovers_Control	2016	2	47	15
South_Water	2016	3	55	17
Tobacco_Caye	2016	4	52	18
Alligator	2016	2	52	14
Halfmoon_Caye	2016	1	47	15
Calabash	2016	3	54	10
Goffs_Caye	2016	1	43	11
Gallows_Reef	2016	0	57	16
Chapel	2016	1	63	10
Hol_Chan	2016	3	53	11
Tacklebox	2016	5	72	13
Mexico_Rocks	2016	0	40	5
Bacalar_Chico	2016	5	54	20

A2. Supplemental Figures

Figure A3. 1: Human Influence Index (HII) for the Mesoamerican Barrier Reef System (MBRS).

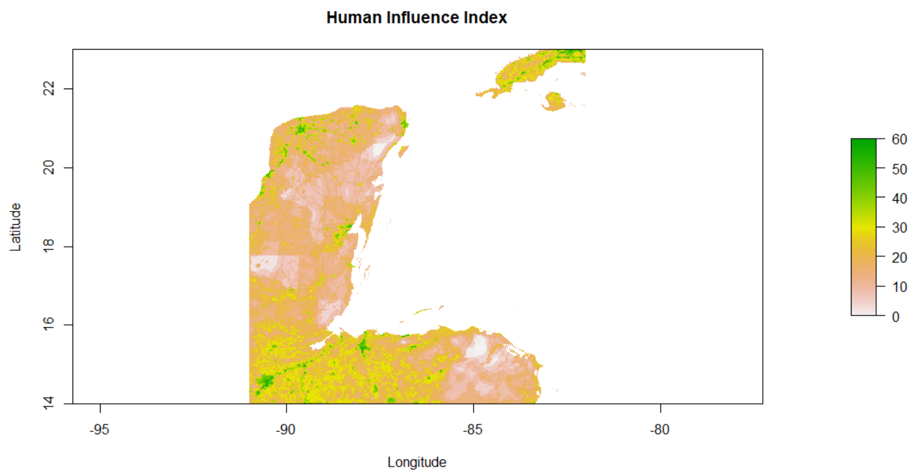


Figure A3. 2: The frequency thermal stress anomalies (TSA_freq) for each survey year. TSA_Freq is defined by the number of instances TSA was over 1 degree Celsius over the previous 52 weeks on our study sites (points) along the BMBR, where TSA is the weekly SST minus the maximum weekly climatological SST.

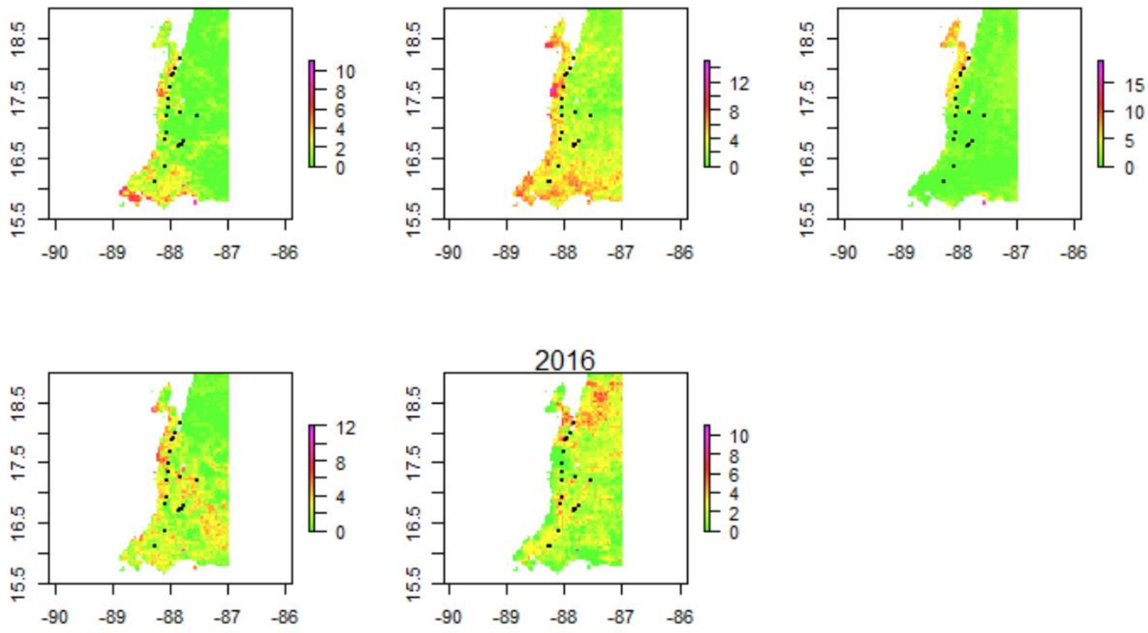
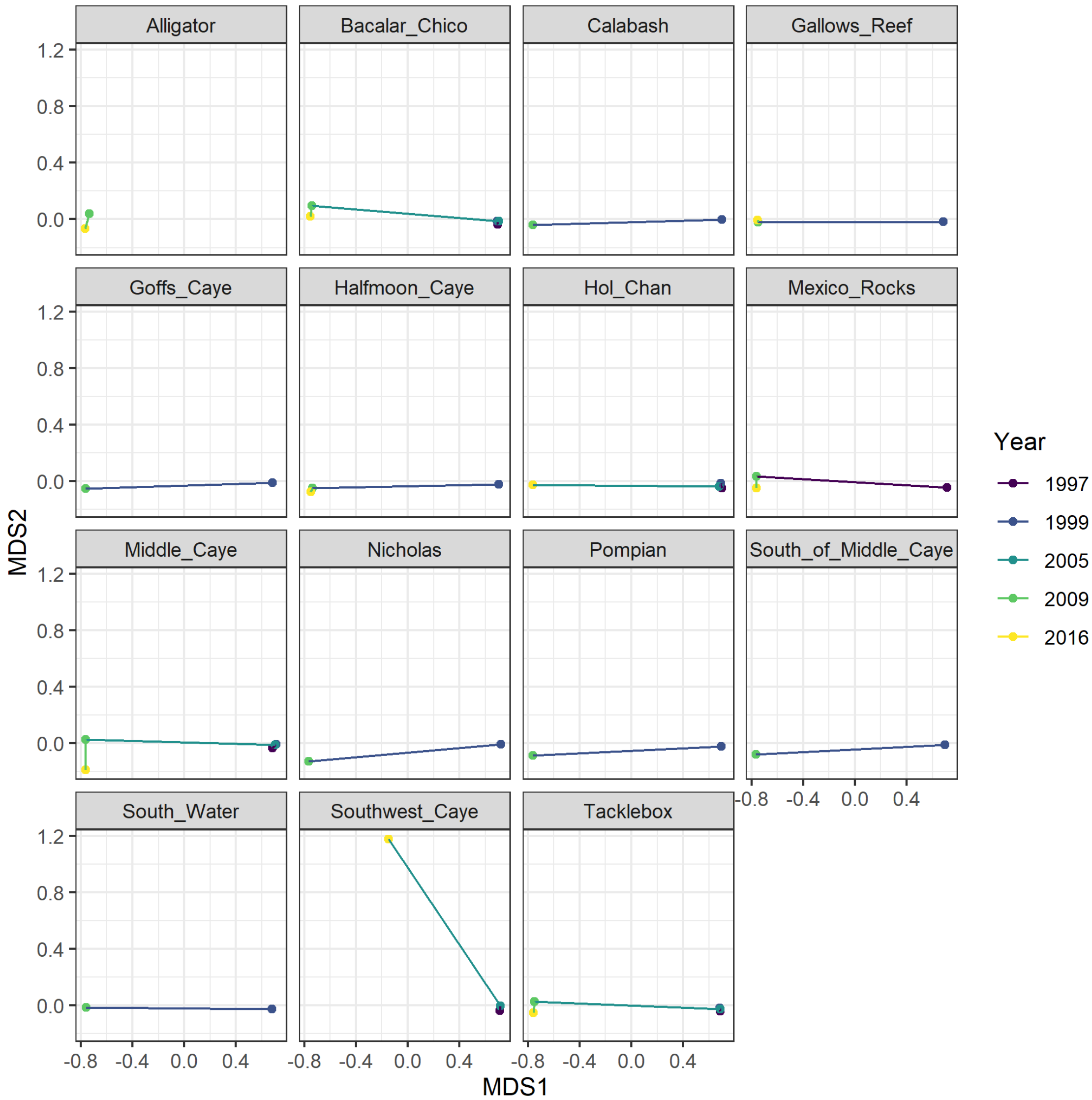


Figure A3. 3: Multidimensional scaling (MDS) plot of the species-level data, color coded for Year. Points represent individual sampling years, connected by lines. The Bray-Curtis dissimilarity matrix was used and the stress value is 0.029.



APPENDIX B: SUPPLEMENTARY MATERIAL FOR CHAPTER 4

A1. 2014 Survey Instrument

Latin America, Belize/Guad11 Cohort
Baseline Survey (2014) and Post-campaign Survey (2015)

FOLIO . . . . ☐

Hello, my name is_____________and I am working with fishing communities to assist them in the management of their resources. We are conducting a survey of fishers of Belize. We would very much appreciate your participation in this survey by answering a few questions about the coastal resources and its fisheries. Whatever information you provide will be kept strictly confidential and your name and answers will not be shown to or shared with any other person except for those people who are working on the survey. Your answers will help us inform for better management of fisheries resources. This survey will take about 30 minutes of your time.

To participate you need to be a fisher and at least 16 years old. Are you? (IF NOT, STOP THE INTERVIEW HERE).

Participation in this survey is voluntary and you can choose not to answer any individual question or all of the questions. However, your views are important to us and I hope you will participate. May I begin the survey now?

Respondent agrees to be surveyed . . . . ❑ Yes ❑ No

(1) If not, can you give me the reason why you prefer not to be interviewed __________________

Section 1
(BACKGROUND INFORMATION FILLED IN PRIOR TO THE SURVEY WITHOUT ASKING THE RESPONDENT)

Coordinator:

❑ Nidia Chacon ❑ Denise Garcia ❑ Andres Aldana ❑ Eliceo Cobb

Interviewer:

____

Name of Community:

____

Date (month/day/year): ____

Survey period:

❑ Pre campaign (Baseline) - Campaign area ❑ Post-campaign - Campaign area

Gender of respondent: . . . . ❑ Male ❑ Female

ENUMERATOR:

THROUGHOUT THE SURVEY YOU'LL SEE QUESTIONS THAT ARE ACCOMPANIED BY INSTRUCTIONS WRITTEN IN UPPERCASE. FOLLOWING THESE INSTRUCTIONS WILL ALLOW YOU, THE ENUMERATOR, TO POSE THE QUESTIONS IN A CORRECT AND UNBIASED MANNER. THEREFORE, PREVIOUS TO ASKING EACH QUESTION, PLEASE ENSURE TO CHECK FOR ANY ACCOMPANYING INSTRUCTION SO THE DELIVERY OF THIS SURVEY IS SUCCESSFUL.
ALSO, IT IS RECOMMENDED TO NOT READ OUT LOUD THE SECTION NUMBERS AND TITLES. THESE ARE JUST FOR YOUR REFERENCE.

Section 2
Socioeconomic and Demographic Questions

"To begin, I would like to ask you some questions about yourself"

(2) How old are you?

❑ 16 to 20 ❑ 21 to 30 ❑ 31 to 40 ❑ 41 to 50 ❑ 51 to 60 ❑ 61 or older

(3) How many persons live in your household?

❑ 0 ❑ 1 ❑ 2 ❑ 3 ❑ 4 ❑ 5 ❑ More than 5

(4) What is your highest level of education completed? (ONLY CHOOSE ONE. IF RESPONDENT HAS NEVER BEEN TO SCHOOL AND/OR NEVER COMPLETED PRIMARY SCHOOL, PLEASE MARK "NO SCHOOL COMPLETED".)

❑ Primary school level
❑ Secondary school/high school
❑ Tertiary school/post-high school level
❑ Other:
❑ Trade/Vocational course
❑ No school completed

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(5) Where do you currently live when you are not fishing? (CHOOSE ONLY ONE)

□ Sarteneja
□ Chunox
□ Copper Bank
□ Consejo
□ Progresso
□ Ranchito
□ Libertad
□ Caledonia
□ Monkey River
□ Punta Negra
□ Punta Gorda
□ Santa Clara/San Roman
□ San Victor
□ Orange Walk Town
□ San Estevan
□ Guinea Grass
□ San Jose
□ San Pablo
□ Trial Farm
□ Concepcion
□ Buena Vista
□ Corozol Town
□ Belize City
□ Dangriga Town
□ Hopkins
□ Riversdale
□ Seine Bight
□ Placencia
□ Mango Creek/Independence
□ Carmelita
□ San Pedro Town
□ Caye Caulker
□ Other: ___________________

(6) Can you tell me what cultural group you belong to? (ONLY CHOOSE ONE)

❑ Mestizo ❑ Garifuna ❑ Creole ❑ Maya ❑ East Indian
❑ Other: ___________________

(7) Which of the following languages are you comfortable speaking? (RESPONDENT CAN CHOOSE AS MANY AS APPLY)

❑ Spanish ❑ Maya ❑ Garifuna ❑ Creole ❑ English

(8) Which of the following languages are you comfortable reading? (RESPONDENT CAN CHOOSE AS MANY AS APPLY)

❑ Spanish ❑ Maya ❑ Garifuna ❑ Creole ❑ English

(9) Which of the following languages are you comfortable listening? (RESPONDENT CAN CHOOSE AS MANY AS APPLY)

❑ Spanish ❑ Maya ❑ Garifuna ❑ Creole ❑ English

(10) What kind of fishing vessel do you own?

❑ Canoe/Dorey ❑ Kayak ❑ Skiff ❑ Sailboat ❑ None
❑ Other: ______________________________

(11) Of the marine product you catch, could you please indicate how much comes from inside marine reserves? (PLEASE CHOOSE ONLY ONE)

❑ 1 to 20 percent comes from inside marine reserves
❑ 21 to 40 percent comes from inside marine reserves
❑ 41 to 60 percent comes from inside marine reserves
❑ 61 to 80 percent comes from inside marine reserves
❑ 81 to 100 percent comes from inside marine reserves
❑ I dont know/Not sure

(12) In the map provided, can you indicate by drawing, in which area you conduct your fishing activities anytime of the year? (PLEASE ASK THE FISHER TO DRAW THIS AREA WITH A MARKER IN THE MAP PROVIDED.)

(A) DON'T READ THIS QUESTION: Coordinators overlay the transparency with the 6 BFD fishing areas over the printed map marked by the respondent and indicate in the following list all the ones that are marked.

❑ Area 1 ❑ Area 2 ❑ Area 3 ❑ Area 4 ❑ Area 5 ❑ Area 6 ❑ None

(B) DON'T READ THIS QUESTION: Coordinators overlay the transparency with the marine reserves over the printed map marked by the respondent and indicate the marine reserves identified.

❑ Bacalar Chico (1)
❑ Hol Chan MR (2)
❑ Caye Caulker (3)
❑ Turneffe Atoll (4)
❑ Light House (5)
❑ Glovers Reef (6)
❑ South Water Caye (7)
❑ Gladden Spit/Silk (8)
❑ Port Honduras MR (9)
❑ Sapodilla Cayes MR (10)
❑ None

(C) DON'T READ THIS QUESTION: After the survey coordinators fill out this question by overlaying the transparency with the fishing sectors over the printed map marked by the respondent and indicate the sectors identified:

❑ Area 4A ❑ Area 4B ❑ Area 5A ❑ Area 5B ❑ Area 6A ❑ Area 6B

(13) Which months of the year do you spend most nights away from home fishing (either at sea or camping)? (CHOOSE ALL THE MONTHS THAT APPLY)

❑ January
❑ February
❑ March
❑ April
❑ May
❑ June
❑ July
❑ August
❑ September
❑ October
❑ November
❑ December
❑ Do not apply

(14) Please indicate which of the following description best describes you. (ENUMERATORS FIRST READ OUT ALL OPTIONS BEFORE MARKING THE ANSWER)

❑ I currently hold a valid commercial fisherfolk license
❑ I held a valid commercial fisherfolk license but it expired
❑ I never held a commercial fisherfolk license.

(15) Please indicate which of the following description best describes you. (ENUMERATORS FIRST READ OUT ALL OPTIONS BEFORE MARKING THE ANSWER)

❑ I currently hold a valid Managed Access license for Port Honduras
❑
❑

I held a valid Managed Access license for Port Honduras, but it has expired

I never held a Managed Access license for Port Honduras

(16) Please indicate which of the following description best describes you. (ENUMERATORS FIRST READ OUT ALL OPTIONS BEFORE MARKING THE ANSWER)

❑ I currently hold a valid Managed Access license for Glover's Reef
❑ I held a valid Managed Access license for Glover's Reef, but it has expired
❑ I never held a Managed Access license for Glover's Reef

(17) Which of the following fishing methods do you engage in?

❑ Handline ❑ Speargun ❑ Longline ❑ Beach trap
❑ Seine ❑ Fish Trap/ ❑ Cast net ❑ Hawaiian sling
❑ Gillnet ❑ Fish pot ❑ Crab trap
❑ Hookstick ❑ Lobster Trap/Lobster Shade ❑ Free diving
❑ Other:

(18) On average, how much of your daily catch do you keep/consume for your family? (CHOOSE ONLY ONE)

❑ All ❑ more than half ❑ None ❑ Refused to answer
❑ half ❑ less than half ❑ Don't know
❑ Other:

Section 3
Media Preferences and Trusted Sources

(19) When you are at sea, there are several ways to know what is happening on the mainland. For the list below mention how important each of the communications methods is for you to stay informed.

	Very Important	Somewhat Important	Little Importance	Not Needed
(A) Radio	❑	❑	❑	❑
(B) Telephone/cell phone	❑	❑	❑	❑
(C) Conversations with fishers from other vessels	❑	❑	❑	❑
(D) Newspaper	❑	❑	❑	❑
(E) Letters from institutions (Hand outs from NGOs/organizations)	❑	❑	❑	❑
(F) NGO/Fisheries Department staff	❑	❑	❑	❑

(G) How else would you get information when you are out at sea?

(20) How often, when you are out at sea,do you listen to the radio? (IF RESPONDENT ANSWERS "NEVER" GO TO QUESTION 21)

❑ Never ❑ 4 to 6 days a week ❑ Only on weekends
❑ Up to 3 days a week ❑ 7 days a week

(A) When you are out at sea, at what time of the day do you most likely listen to the radio? **Please indicate up to 2 times more than likely you will be listening to the radio.**

- ❑ before 6:00 am
- ❑ 6:00 am to 8:00 a.m
- ❑ 8:00 am to 12:00 a.m
- ❑ 12:00pm to 4:00pm
- ❑ 4:00p.m to 7:00 p.m
- ❑ After 7:00 p.m

(B) If you listen to radio at sea, which two radio stations do you listen to the most? Please indicate two choices.

- ❑ Love FM
- ❑ Estereo Amor
- ❑ Other:
- ❑ MAR FM
- ❑ Krem FM
- ❑ More FM None
- ❑ Wamalali Fiesta FM
- ❑ Radio Bahia

(21) When you are out at sea, which cell phone company do you use? (IF THEY GIVE MORE THAN ONE ANSWERS THE ENUMERATOR SHOULD ASK WHICH ONE THEY USE MOST. AND ONLY MARK THAT ONE)

- ❑ BTL
- ❑ SMART
- ❑ None
- Other: ❑ ______

(22) How often, when you are on the mainland,do you listen to the radio? (IF RESPONDENT ANSWERS "NEVER" GO TO QUESTION 23)

- ❑ Never
- ❑ Up to 3 days a week
- ❑ 4 to 6 days a week
- ❑ 7 days a week
- ❑ Only on weekends

(A) When you are on the mainland, at what time of the day do you most likely listen to the radio? **Please indicate up to 2 times more than likely you will be listening to the radio.**

- ❑ before 6:00 am
- ❑ 6:00 am to 8:00 a.m
- ❑ 8:00 am to 12:00 a.m
- ❑ 12:00pm to 4:00pm
- ❑ 4:00p.m to 7:00 p.m
- ❑ After 7:00 p.m

(23) When you are on the mainland, which radio stations do you listen to? **Please indicate up to two options only.**

- ❑ Love FM
- ❑ Estereo Amor
- ❑ Other:
- ❑ MAR FM
- ❑ Krem FM
- ❑ More FM
- ❑ None
- ❑ Wamalali Fiesta FM
- ❑ Radio Bahia

(24) When you are on the mainland, which cell phone company do you use the most? **Only choose one**

- ❑ BTL
- ❑ SMART
- ❑ None
- Other: ❑ ______

(25) When you are on the mainland, what radio programs do you listen to the most? **Please indicate up to two options only.**

- ❑ Morning Show Love FM
- ❑ Belize Watch
- ❑ Making Waves
- ❑ Other:
- ❑ Krem Morning Show
- ❑ None
- ❑ Faith FM
- ❑ Despierta Belice

(26) What local television station de you prefer to watch? **Please indicate up to two options.**

- ❑ Love TV
- ❑ Krem TV
- ❑ Other:
- ❑ Wave TV
- ❑ Coral TV
- ❑ PGTV
- ❑ Chanel 5
- ❑ None/I don’t watch Television

(27) What local television show do you prefer to watch? **Please indicate up to two options only.**

- ❑ Belize Watch
- ❑ Wake up Belize
- ❑ Love FM morning show
- ❑ Open Your Eyes
- ❑ Other:
- ❑ The Dickey Bradley Show
- ❑ Rise and Shine
- ❑ Seasonal Shows Developing Toledo
- ❑ Show
- ❑ None/I don't watch television

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(28) Which newspaper do you prefer to read? **(Check only one)**

- ❑ Amandala
- ❑ Reporter
- ❑ Other:
- ❑ Guardian
- ❑ Belize Times
- ❑ San Pedro Sun
- ❑ Placencia Breeze
- ❑ None/I don't read newspaper

Section 4
Establish Baselines for and Measure Change in Knowledge SMART Objectives

(29) Have you ever heard of Managed Access? IF THE RESPONDENT ANSWERS "NO" OR "NOT SURE", GO TO QUESTION 32.

❑ Yes ❑ No ❑ Not sure

(30) Do you know what are the requirements to obtain a Managed Access license? IF THE RESPONDENT ANSWERS "NO" OR "DO NOT KNOW", GO TO QUESTION 31.

❑ Yes ❑ No ❑ Not sure

(A) If answered yes, can you please list these requirements to obtain a Managed Access license? (DO NOT READ THE ANSWERS. YOU CAN CHECK MORE THAN ONE OPTION.)

- ❑ Fill out socioeconomic form
- ❑ Be a holder of a valid fisherfolk license
- ❑ Be 18 years old or older
- ❑ Proof of Belizean citizenship
- ❑ Proof of residence
- ❑ Fill out MA application form
- ❑ Pay the license fee
- ❑ Show proof of landing product in Belize
- ❑ Have fished in the area at least 3 years before now

(B) DON'T READ THIS QUESTION TO RESPONDENT. ENUMERATOR SHOULD INDICATE HOW MANY CORRECT ANSWERS RESPONDENT GAVE IN PREVIOUS QUESTION (30A)

❑ 0 ❑ 1 ❑ 2 ❑ 3 ❑ 4 ❑ 5 ❑ 6 ❑ 7 ❑ 8 ❑ 9

(31) Do you know what are the terms for Managed Access license renewal? IF THE RESPONDENT ANSWERS "NO" OR "NOT SURE", GO TO QUESTION 32.

❑ Yes ❑ No ❑ Not sure

(A) If answered yes, can you please list these terms to renew the Managed Access license? (DONT READ THE ANSWERS)

- ❑ Pay annual license fee
- ❑ Comply with fisheries rules and regulations
- ❑ Fish 6 times a year at a minimum in the area
- ❑ Report catch data
- ❑ Have less then 3 infractions with fisheries regulations
- ❑ Fill out socioeconomic form
- ❑ Be a holder of a valid fisherfolk license
- ❑ Proof of Belizean citizenship
- ❑ Show proof of landing product in Belize

(B) DON'T READ THIS QUESTION TO RESPONDENT. ENUMERATOR SHOULD INDICATE HOW MANY CORRECT ANSWERS RESPONDENT GAVE IN PREVIOUS QUESTION (31A)

❑ 0 ❑ 1 ❑ 2 ❑ 3 ❑ 4 ❑ 5 ❑ 6 ❑ 7 ❑ 8 ❑ 9

(32) Are there benefits to having Managed Access rights? IF THE RESPONDENT ANSWERS "NO" OR "NOT SURE/DO NOT KNOW", GO TO QUESTION 33.

❑ Yes ❑ No ❑ Not sure/Do not know

(A) If yes, can you list the benefits of having managed access rights? (DO NOT READ THE ANSWERS. YOU CAN CHECK MORE THAN ONE OPTION.)

❑ Fewer fishers
❑ Fishermen will be partners in the decision-making process (Transparency in the process)
❑ Less rush to fish
❑ Improved enforcement
❑ Fishers have better control/ are more responsible over their fishing activities
❑ Other:
❑ Better communication and more partnership with fisheries department
❑ Ensure long-term fishing activity
❑ Help sustain the livelihoods of fishers
❑ Reduced illegal fishing
❑ Better planning of fishing trips
❑ Do not know/not sure

(B) DON'T READ THIS QUESTION TO RESPONDENT. ENUMERATOR SHOULD INDICATE HOW MANY CORRECT ANSWERS RESPONDENT GAVE IN PREVIOUS QUESTION (32A)

❑ 0 ❑ 1 ❑ 2 ❑ 3 ❑ 4 ❑ 5 ❑ 6 ❑ 7 ❑ 8 ❑ 9 ❑ 10 ❑ 11

(33) Are fishers required to submit the records of their catch to the Belize Fisheries Department?

❑ Yes ❑ No ❑ Not sure/Do not know

(34) Are there benefits of reporting your catch? IF THE RESPONDENT ANSWERS "NO" OR "DO NOT KNOW", GO TO QUESTION 35.

❑ Yes ❑ No ❑ Not sure/Do not know

(A) If yes, can you list the benefits of reporting your catch? (DO NOT READ THE ANSWERS. YOU CAN CHECK MORE THEN ONE OPTION.)

❑ Make better resource management decisions
❑ Knowledge about species caught in the area
❑ Helps renew your Managed Access license
❑ Better planning of my fishing activity
❑ Other:
❑ Have record of production all year round
❑ Can be used to demonstrate loss in case of bad weather of disaster (e.g. hurricane)
❑ To know the status of the species over time
❑ Do not know/not sure

(B) DON'T READ THIS QUESTION TO RESPONDENT. ENUMERATOR SHOULD INDICATE HOW MANY CORRECT ANSWERS RESPONDENT GAVE IN PREVIOUS QUESTION (34A)

❑ 0 ❑ 1 ❑ 2 ❑ 3 ❑ 4 ❑ 5 ❑ 6 ❑ 7 ❑ 8

Section 5
Establish Baselines for and Measure Change in Attitude SMART Objectives

(35) Can you please indicate your level of willingness to apply for a managed access license?

❑ Very low ❑ Low ❑ Medium ❑ High ❑ Very high ❑ N/A

(36) Can you please indicate your level of willingness to fish in a designated number of marine reserves?

❑ Very low ❑ Low ❑ Medium ❑ High ❑ Very high ❑ N/A

(37) Can you please indicate your level of willingness to report your catch data?

❑ Very low ❑ Low ❑ Medium ❑ High ❑ Very high ❑ N/A

Section 6
Establish Baselines for and Measure Change in Interpersonal Communication SMART Objectives

(38) Over the past 12 months, have you spoken with another fisher about the requirements to obtain a managed access license?

❑ Yes ❑ No ❑ Not sure/Do not know

(39) Over the past 12 months, have you spoken to other fishers about the benefits of Managed Access?

❑ Yes ❑ No ❑ Not sure/Do not know

(40) Over the past 12 months, have you spoken to another fisher about the benefits of reporting catch data?

❑ Yes ❑ No ❑ Not sure/Do not know

Section 7
Establish Baselines for and Measure Change in Barrier Removal SMART Objectives

(41) To which of the following kind of fisheries organizations do you belong? (ENUMERATORS FIRST READ OUT ALL OPTIONS BEFORE MARKING THE ANSWER. YOU CAN CHECK MORE THAN ONE OPTION)

❑ Cooperative
❑ Fisheries Association
❑ Other: ______________________________
❑ Belize Fishermen Cooperative Association
❑ None

Please rate your agreement with the following statements on a scale from strongly agree to strongly disagree.

(42) Over the past 12 months the Belize Fisheries Department's licensing system has become more efficient.

- ❑ Strongly Agree
- ❑ Agree
- ❑ Neither agree nor disagree
- ❑ Disagree
- ❑ Strongly disagree
- ❑ Don't know/Don't have opinion

(43) Managed Access rights have been distributed fairly to fishers.

- ❑ Strongly Agree
- ❑ Agree
- ❑ Neither agree nor disagree
- ❑ Disagree
- ❑ Strongly disagree
- ❑ Don't know/Don't have opinion

(44) The fishers in my community have the ability to locate the boundaries of the existing marine reserves.

- ❑ Strongly Agree
- ❑ Agree
- ❑ Neither agree nor disagree
- ❑ Disagree
- ❑ Strongly disagree
- ❑ Don't know/Don't have opinion

Please answer the following question on a scale of 1 to 10, where 1=to no extent, 5=to some extent and 10=to a great extent.

(45) How comfortable do you feel with correctly filling out a fisheries log book?

❑ 1 ❑ 2 ❑ 3 ❑ 4 ❑ 5 ❑ 6 ❑ 7 ❑ 8 ❑ 9 ❑ 10

Section 8
Establish Baselines for and Measure Change in Behavior SMART Objectives

(46) Which of the following options best describes you? Over the past 12 months:

- ❑ I have never considered applying for a managed access license
- ❑ I am considering applying for a managed access license
- ❑ I intend to apply for a managed access license
- ❑ I intend to apply for a managed access license and I have discussed my intention to apply for a managed access license with someone.
- ❑ I have applied for a managed access license at least once
- ❑ I have renewed my managed access license

(47) Which of the following options best describes you? Over the past 12 months:

- ❑ I have never considered only fishing in a designated number of marine reserves
- ❑ I am considering to only fish in a designated number of marine reserves
- ❑ I intend to fish only in a designated number of marine reserves
- ❑ I intend to fish only in a designated number of marine reserves and I have talked to someone about my intention to fish only in a designated number of marine reserves.
- ❑ I currently fish in a designated number of marine reserves

(48) Which of the following options best describes you? Over the past 12 months:

- ❑ I have never considered reporting catch data
- ❑ I am considering reporting catch data
- ❑ I intend to report catch data
- ❑ I intend to report catch data and I have talked to someone about my intention to report catch data.
- ❑ I am currently reporting catch data

Section 9
Exposure to Campaign Activities & Messages

(49) I am going to ask you about a number of ways in which you may or may not have seen or heard about Managed Access. For each method, I would like you to tell me whether you remember seeing or hearing that source in the past 12 months.

	Yes	No	Do not know
(A) TV advertisement in a local cable	❑	❑	❑
(B) Radio spots	❑	❑	❑
(C) Posters	❑	❑	❑
(D) Community meetings, forums, workshops	❑	❑	❑
(E) Festivals	❑	❑	❑
(F) Song on radio	❑	❑	❑
(G) Speech/Talk by Respected Official	❑	❑	❑
(H) Mascot	❑	❑	❑
(I) T-shirt with message	❑	❑	❑
(J) Campaign song	❑	❑	❑
(K) Brochures	❑	❑	❑
(L) Banners	❑	❑	❑
(M) Billboards	❑	❑	❑

(50) For you, what marine species represents best your fishing activity? DON'T READ THE ANSWERS. RESPONDENT SHOULD ONLY MENTION ONE.

❑ Conch ❑ Sea Cucumber ❑ Goliath Grouper ❑ Silk Snapper
❑ Lobster ❑ Shark ❑ Dog Snapper ❑ Red Snapper
❑ Nassau Grouper ❑ Crab ❑ Mutton Snapper
❑ Other:

Section 10
Social Impact Questions

Now I am going to ask you a few general questions about your household and community. Please answer them as honestly and accurately as possible. Your answers will remain confidential.

(51) Which of these statements best describes the food eaten in your household in the last 12 months?

- ❑ We always had enough food to feed everyone in the household.
- ❑ We sometimes did not have enough food to feed everyone in the household.
- ❑ We often did not have enough food to feed everyone in the household.
- ❑ We never had enough food to feed everyone in the household.
- ❑ Refuse to answer

(52) Have you or someone in your household participated in Managed Acces events and or activities?

❑ Yes ❑ No ❑ Don't know/Unsure ❑ Refused to answer

Please answer the following question on a scale of 1 to 10, where 1=completely dissastisfied and 10=completely satisfied.

(53) All things considered, how satisfied are you with your life these days?

❑ 1 ❑ 2 ❑ 3 ❑ 4 ❑ 5 ❑ 6 ❑ 7 ❑ 8 ❑ 9 ❑ 10 ❑ Refused to answer

Please answer the following question on a scale of 1 to 10, where 1=to no extent, 5=to some extent and 10=to a great extent.

(54) The fishers in my community have the ability to sustainably manage our fishery so that we can benefit from it long into the future.

❑ 1 ❑ 2 ❑ 3 ❑ 4 ❑ 5 ❑ 6 ❑ 7 ❑ 8 ❑ 9 ❑ 10 ❑ Refused to answer

(55) Most fishers in my community will follow the rules and regulations set forth for our fisheries.

❑ 1 ❑ 2 ❑ 3 ❑ 4 ❑ 5 ❑ 6 ❑ 7 ❑ 8 ❑ 9 ❑ 10 ❑ Refused to answer

Please rate your agreement with the following statements on a scale from strongly disagree to strongly agree.

(56) Generally speaking, most fishers in my community can be trusted.

❑ Strongly Agree ❑ Neither Agree nor Disagree ❑ Strongly Disagree
❑ Agree ❑ Disagree ❑ Refused to answer

(57) It is not difficult for myself and members of my family to find job as is needed to provide for the home.

❑ Strongly Agree ❑ Neither Agree nor Disagree ❑ Strongly Disagree
❑ Agree ❑ Disagree ❑ Refused to answer

(58) My family is able to benefit from our fishery as much as any other members of the community.

❑ Strongly Agree ❑ Neither Agree nor Disagree ❑ Strongly Disagree
❑ Agree ❑ Disagree ❑ Refused to answer

Thank you for all of your help in responding to this anonymous questionnaire survey. Your answers will remain confidential. I look forward to keeping in contact with you.

A2. 2019 Survey Instrument

SCRIPT FOR ENUMERATOR:

Hello, my name is ______(SAY YOUR NAME)___________ and I am working with Catherine Alves at the University of North Carolina to conduct a survey of fishers in Belize. We are working with fishing communities to assist them in the management of their resources. We hope to evaluate how participation in the zonation of fisheries has affected your livelihood and perceptions. We would very much appreciate your participation in this survey by answering a few questions about the coastal resources and its fisheries.

Whatever information you provide will be kept strictly confidential and your name and answers will not be shown or shared with any other person except for those people who are working on the survey. Your answers will help us inform better management of fisheries resources. This survey will take about 30 minutes of your time. Participation in this survey is voluntary and you can choose not to answer any question or all of the questions. However, your views are important to us and I hope you will participate.

To participate you need to be a licensed commercial fisher in 2019 and at least 18 years old. Are you? (IF NOT, STOP THE INTERVIEW HERE) May I begin the survey now? (BEGIN THE SURVEY BY GETTING THEIR VERBAL CONSENT – THEY MUST SAY "YES" ALOUD)

1.) If not, can you give me the reason why you prefer not to be interviewed:

____

SECTION 1: BACKGROUND INFORMATION FILLED IN PRIOR TO SURVEY WITHOUT ASKING RESPONDENT

Interviewer: ____

Name of Community: ____

Date (month/day/year): ____

Time (00:00 hr:min): ____

Gender of Respondent: □ Male □ Female □ Other

SECTION 2: FISHING BEHAVIOR/ACTIVITIES
"To begin, I'm going to ask you about your fishing behavior and activities related to fishing."

2.) How many years have you been fishing?

□ 0 – 5 □ 6 – 10 □ 11 – 15 □ 16 – 20 □ 21 – 25 □ 26 or more

3.) How many generations in your family have been fishing?

□ One (mine) □ Two □ Three □ Four □ Five or more

4.) What is your role on the vessel?

□ Boat Owner □ Captain □ Crew Member/Deck Hand □ Cook
□ Solo fishers □ Other: ___________________________

5.) What type of fishing vessel do you use?

□ Canoe/Dorey □ Kayak □ Skiff □ Sailboat □ None
□ Other: ____

6.) Which of the following fishing methods do you engage in? (MAY SELECT MORE THAN ONE)

□ Handline □ Speargun □ Longline □ Beach trap
□ Seine □ Fish Trap/Fish Pot □ Cast net □ Hawaiian sling
□ Gillnet □ Lobster Trap □ Crab trap
□ Hookstick □ Lobster Shade □ Free diving
□ Other: ____

7.) On average, how many days long are your fishing trips?

□ 0 – 5 days □ 6 – 10 days □ 11 – 15 days □ 16 – 20 days
□ 21 – 25 days □ 26 – 30 days □ 31 days or more

8.) On average, for each season listed, how many trips do you make each month?

	1	2	3	4	5	6	7	8	9	10 or more
Conch	○	○	○	○	○	○	○	○	○	○
Lobster	○	○	○	○	○	○	○	○	○	○
Everything else (finfish, crabs, etc)	○	○	○	○	○	○	○	○	○	○

9.) On average, how much do you spend (in Belize dollars) per fishing trip?

$____________

10.) Which of the following catch options do you primarily target? (DON'T READ THE ANSWERS, MAY PROVIDE MORE THAN ONE)

□ Conch □ Sea Cucumber □ Grouper □ Snapper
□ Lobster □ Shark □ Crab □ Jacks
□ Red Hind □ Spanish Mackerel □ Mullet □ Barracuda
□ Other: ____

11.) What is the average number of pounds of each of the following that you catch in a fishing trip? (SKIP LOGIC: ONLY BASED OFF OF ANSWERS IN Q11)

□ Conch: _____ □ Sea Cucumber: _____ □ Grouper: _____ □ Snapper: _____
□ Lobster: _____ □ Shark: _____ □ Crab: _____ □ Jacks: _____
□ Red Hind: _____ □ Spanish Mackerel: _____ □ Mullet: _____ □ Barracuda: _____
□ Other: ____

12.) What is the average market value of the following catch options? (SKIP LOGIC: ONLY BASED OFF OF ANSWERS IN Q11)

□ Conch: _____ □ Sea Cucumber: _____ □ Grouper: _____ □ Snapper: _____
□ Lobster: _____ □ Shark: _____ □ Crab: _____ □ Jacks: _____
□ Red Hind: _____ □ Spanish Mackerel: _____ □ Mullet: _____ □ Barracuda: _____
□ Other: ____

13.) What percentage of your total catch per year is caught inside a marine reserve? (PLEASE CHOOSE ONLY ONE)

□ 1 – 20 percent □ 41 – 60 percent □ 81 – 100 percent
□ 21 – 40 percent □ 61 – 80 percent □ I don't know/not sure

14.) On average, how much of your daily catch do you keep/consume for your family? (CHOOSE ONLY ONE)

□ All □ More than half □ None □ Refused to answer
□ Half □ Less than half □ Don't know
□ Other: ____

15.) Where do you sell your product? (HAVE RESPONDENT INDICATE PERCENT OF PRODUCT SOLD AT EACH SECTOR AND PUT A CHECK IN THE CORRESPONDING BOX).

	0%	1 – 25%	25 – 50%	50 – 75%	75 – 100 %
Cooperative	○	○	○	○	○
Restaurant (includes Hotels/Resorts)	○	○	○	○	○

Local Market (includes formal and informal)	○	○	○	○	○
Own Use	○	○	○	○	○
Other:	○	○	○	○	○

16.) To which of the following kind of fisheries organizations do you belong? (ENUMERATORS, FIRST READ OUT ALL OPTIONS BEFORE MARKING THE ANSWER. YOU MAY SELECT MORE THAN ONE OPTION).

□ Cooperative □ Belize Fishermen Cooperative Association
□ Fisheries Association □ None
□ Other: ______________________________
□ Specify Cooperative: ______________________________

17.) For which Managed Access area(s) do you have a commercial fishing license? (SELECT ALL THAT MAY APPLY.)

□ Area 1 □ Area 2 □ Area 3 □ Area 4 □ Area 5 □ Area 6
□ Area 7 □ Area 8 □ Area 9 □ None □ Other (if other, specify)

SECTION 3: PERCEPTIONS
"Thank you for your responses. I will now ask you your opinions about several fisheries-related issues."

18.) Do you know what the requirements are to obtain a Managed Access license?
□ Yes □ No □ Not Sure

A. **If answered Yes, can you please list these requirements? (DO NOT READ THE ANSWERS. YOU CAN CHECK MORE THAN ONE OPTION).**

□ Fill out socioeconomic form □ Fill out MA application form
□ Be a holder of a valid fisherfolk license □ Pay the license fee
□ Be 18 years old or older □ Show proof of landing product in Belize
□ Proof of Belizean citizenship □ Proof of residence
□ Have fished in the area at least 3 years before now

B. **DO NOT READ THIS QUESTION. DATA PROCESSING WILL PROVIDE NUMBER OF CORRECT ANSWER(S) RESPONDENT GAVE IN PREVIOUS QUESTION**
□ 0 □ 1 □ 2 □ 3 □ 4 □ 5 □ 6 □ 7 □ 8 □ 9

19). Do you know what are the terms for Managed Access license renewal? (IF THE RESPONDENT ANSWERS "NO" OR "NOT SURE," ADVANCE TO NEXT QUESTION).

□ Yes □ No □ Not Sure

A. If answered Yes, can you please list these terms to renew the Managed Access license? (DO NOT READ THE ANSWERS YOU CAN CHECK MORE THAN ONE OPTION).

□ Pay the annual license fee
□ Comply with fisheries rules and regulations
□ Fish 6 times a year at a minimum in the area
□ Report catch data
□ Have less than 3 infractions with fisheries regulations
□ Fill out socioeconomic form
□ Be a holder of a valid fisher folk license
□ Proof of Belizean citizenship
□ Show proof of landing product in Belize

B. DO NOT READ THIS QUESTION. DATA PROCESSING WILL PROVIDE NUMBER OF CORRECT ANSWER(S) RESPONDENT GAVE IN PREVIOUS QUESTION

□ 0 □ 1 □ 2 □ 3 □ 4 □ 5 □ 6 □ 7 □ 8 □ 9

20.) Are there benefits to having Managed Access rights? (IF THE RESPONDENT ANSWERS "NO" OR "NOT SURE," ADVANCE TO NEXT QUESTION).

□ Yes □ No □ Not Sure

A. If Yes, can you list the benefits of having Managed Access rights? (DO NOT READ THE ANSWERS. YOU CAN CHECK MORE THAN ONE OPTION).

□ Fewer fishers
□ Fishermen will be partners in the decision-making process (transparency in the process)
□ Less rush to fish
□ Improved enforcement
□ Fishers have better control/are more responsible over their fishing activities
□ Better communication and more partnership with Fisheries Department
□ Ensure long-term fishing activity
□ Help sustain the livelihoods of fishers
□ Reduced illegal fishing
□ Better planning of fishing trips
□ Do not know/Not sure
□ Other: ____________________

B. **DO NOT READ THIS QUESTION. DATA PROCESSING WILL PROVIDE NUMBER OF CORRECT ANSWER(S) RESPONDENT GAVE IN PREVIOUS QUESTION**
□ 0 □ 1 □ 2 □ 3 □ 4 □ 5 □ 6 □ 7 □ 8 □ 9

21.) Are fishers required to submit the records of their catch to the Belize Fisheries Department?
□ Yes □ No □ Not Sure

22.) Are there benefits of reporting your catch? (IF THE RESPONDENT ANSWERS "NO" OR "DO NOT KNOW," ADVANCE TO NEXT QUESTION).
□ Yes □ No □ Not Sure

A. **If yes, can you list the benefits of reporting your catch? (DO NOT READ THE ANSWERS. YOU CAN CHECK MORE THAN ONE OPTION).**
□ Make better resource management decisions
□ Knowledge about species caught in the area
□ Helps renew your Managed Access license
□ Better planning of my fishing activity
□ Have record of production all year round
□ Can be used to demonstrate loss in case of bad weather or disaster (e.g. hurricane)
□ To know the status of the species over time
□ Do not know/Not sure
□ Other: ____

B. **DO NOT READ THIS QUESTION. DATA PROCESSING WILL PROVIDE NUMBER OF CORRECT ANSWER(S) RESPONDENT GAVE IN PREVIOUS QUESTION**

□ 0 □ 1 □ 2 □ 3 □ 4 □ 5 □ 6 □ 7 □ 8 □ 9

23.) Have you or someone in your household participated in Managed Access events and/or activities?

□ Yes □ No □ Don't know/Unsure □ Refused to answer

□ If Yes, how many? _______________ □ If Yes, why? ____________________
□ If No, why not? _________________

24.) How often does your Managed Access Committee representative provide you with feedback?

□ Never □ Seldom □ Sometimes □ Often □ Unsure

25 - 40.) Indicate the level to which you agree with the following statements on a scale of 1-7:

		Refuse to Answer (1)	Don't Know (2)	Strongly Disagree (3)	Disagree (4)	Neither Agree nor Disagree (5)	Agree (6)	Strongly Agree (7)
25.)	Managed Access is helping to improve the marine resources	○	○	○	○	○	○	○
26.)	My catch has improved under Managed Access	○	○	○	○	○	○	○
27.)	Enforcement has improved since Managed Access was implemented	○	○	○	○	○	○	○
28.)	Illegal fishing in the marine reserves has declined	○	○	○	○	○	○	○
29.)	Logbooks are easy to fill out	○	○	○	○	○	○	○
30.)	I fill out my logbook after each fishing trip	○	○	○	○	○	○	○
31.)	I spend less time fishing now that I am a part of Managed Access	○	○	○	○	○	○	○
32.)	I trust the enforcement of Managed Access	○	○	○	○	○	○	○
33.)	Managed Access rights	○	○	○	○	○	○	○

	have been distributed fairly to fishers							
34.)	The fishers in my community can locate the boundaries of the existing marine reserves	○	○	○	○	○	○	○
35.)	The fishers in my community can sustainably manage our fishery so that we can benefit from it long into the future	○	○	○	○	○	○	○
36.)	Most fishers in my community follow the rules and regulations set forth to regulate our fisheries	○	○	○	○	○	○	○
37.)	Generally speaking, most fishers in my community can be trusted	○	○	○	○	○	○	○
38.)	I have seen fishers fishing in areas where they don’t have a license	○	○	○	○	○	○	○
39.)	Managed Access is benefitting my livelihood	○	○	○	○	○	○	○

40.)	I fully support Managed Access in the long run	○	○	○	○	○	○	○

SECTION 4: DEMOGRAPHIC AND SOCIO-ECONOMIC QUESTIONS
"Thank you for your responses. Now, I would like to ask you some questions about yourself."

41.) How old are you?
□ 18 – 20 □ 21 – 30 □ 31 – 40 □ 41 – 50 □ 51 – 60 □ 61 or older

42.) How many persons live in your household?

□ 0 □ 1 □ 2 □ 3 □ 4 □ 5 □ More than 5

43.) What is your highest level of education completed? (ONLY CHOOSE ONE. IF RESPONDENT HAS NEVER BEEN TO SCHOOL AND/OR NEVER COMPLETED PRIMARY SCHOOL, PLEASE MARK "NO SCHOOL COMPLETED".)

□ Primary school level
□ Secondary school/high school level
□ Tertiary school/post-high school level
□ Trade/Vocational course
□ No school completed
□ Other: ___________________________________

44.) Where do you currently live when you are not fishing: (CHOOSE ONLY ONE)

□ Sarteneja
□ Chunox
□ Copper Bank
□ Consejo
□ Progresso
□ Ranchito
□ Libertad
Creek/Independence
□ Monkey River
□ Punta Negra
□ Punta Gorda
□ Santa Clara/San Roman
□ San Victor
□ Orange Walk Town
□ San Estevan
□ Guinea Grass
□ San Jose
□ San Pablo
□ Caledonia
□ Concepcion
□ Buena Vista
□ Corozol Town
□ Belize City
□ Dangriga Town
□ Hopkins
□ Riversdale
□ Seine Bight
□ Placencia
□ Mango
□ Trial Farm
□ Carmelita
□ San Pedro Town
□ Caye Caulker
□ Other: ___________________

45.) Can you tell me what cultural group you belong to? (CHOOSE ONLY ONE)

□ Mestizo
□ Maya
□ Garifuna
□ East Indian
□ Creole
□ Other: _______________________

46.) What percentage of your annual income comes from fishing?

□ 1 – 20% □ 21 – 40 % □ 41 – 60 % □ 61 – 80 % □ 81 – 100%

47.) Are you involved in any other income generating activities other than fishing?
□ Yes □ No □ If yes, what? (options: Tour guide, SCUBA, Farming, Construction, Teacher, Retail, Other)

48.) Are there other members in your household involved in an income generating activity?

□ Yes □ No □ If yes, what? (same options as Q47)
□ If yes whom? (options: Mother, Father, Sister, Brother, Daughter, Son, Other)

49.) Do you own your home?

□ Yes □ No

50.) Does your dwelling have any of the following? (CHECK ALL THAT APPLY)

□ Toilet □ Shower/bath
□ Running Water □ Electricity
□ Kitchen □ Computer
□ Telephone/cell phone □ Television
□ Washing Machine □ Refrigerator
□ Stove □ Land-based motor vehicle (includes motorcycles)
□ WiFi □ Pool
□ Other: ________________________

51.) (DO NOT READ) What language was the survey conducted in today?
□ English □ Garifuna □ Kriol
□ Ketchi □ Spanish □ Other: ______________________

52.) Is there anything else you'd like to tell us today?

____
____
____
____
____
____
____
____

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