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Connecting Social and Ecological Systems in Small-Scale Fisheries in the Philippines

Sara Eisler Marriott
University of Southern Mississippi

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CONNECTING SOCIAL AND ECOLOGICAL SYSTEMS IN SMALL-SCALE FISHERIES IN THE PHILIPPINES

by

Sara Sophie Eisler Marriott

A Dissertation
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and the School of Ocean Science and Engineering
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Dr. Kim de Mutsert, Committee Chair
Dr. Wei Wu
Dr. Zachary Darnell
Dr. Courtney Cox
Dr. Leslie Acton

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ABSTRACT

Nearly 50% of all marine fish capture in the Philippines is from artisanal fisheries, most of which is un- or under-reported. As in many emerging nations around the world, the Philippines cannot fully address overfishing by managing only half of the catch that comes from commercial fisheries. Marine reserves are a popular governance strategy for conservation and of growing interest for fisheries management. Many marine reserves in the Philippines, however, are not considered effective. In 2014, Rare, an international NGO, implemented a community-based management program to increase the effectiveness of the marine reserves, and while it found biomass increased, there is still a need to link the governance strategy with the ecological results. Using data including Rare's large database of dependent and independent fisheries data, interviews, and geospatial data, this dissertation seeks to understand how social and ecological systems are connected within the small-scale fisheries in the Philippines. Small-scale fishery management solutions are necessary to create a sustainable ecosystem of natural resources and those who use them, not only in the Philippines but worldwide. First, I used multivariate methods to determine if fish community structure and biodiversity changed with the implementation of community-based management. The results showed that there was variation between the sites, leading to questions about why this variation occurred and if it is due to ecological or societal differences. Next, I used GAMs to analyze different variables, including mangrove edge and area, to investigate ecological reasons for the differences in fish abundance and biodiversity. Finally, I conducted a thematic analysis of fisher interviews to understand the compliance and enforcement landscape.

The results provide insights on how governance strategies influence marine resources and explains potential reasons why sites in the Philippines respond differently to the same governance strategy, thereby providing a holistic story of how community-based management of marine reserves in the Philippines function. My research builds on the empirical work that Rare has conducted and has recommendations for NGOs and managers for strategies that may increase the success of community-based managed marine reserves within the Philippines.

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DEDICATION

To the late Roquelito Mancao, without whom, I would not have been able to accomplish my fieldwork.

To my whole heart: George, Vera, and Bali. Thank you for your sense of adventure and sacrifice these years to allow me to follow my fish-filled dreams.

“So long, and thanks for all the fish.” (Douglas Adams, 1984)

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AIC	Akaike Information Criterion
CBM	Community-based Management
GAM	General Additive Model
GDP	Gross Domestic Product
IUCN	International Union for Conservation of Nature
MPA	Marine Protected Area
NGO	Non-governmental Organization
SSF	Small-scale fishing
USAID	United States Agency for International Development

CHAPTER I – INTRODUCTION

Small-scale fishing (SSF) makes up at least 30% of global catch (Pauly & Zeller, 2016) Small-scale is generally defined by the types of vessels and technology used by the fishermen rather than the number of fish captured or the overall size of the fishing fleet (FAO, 2008). Globally, it is estimated that there are 37 million small-scale fishers and even more who depend on small-scale fishing for their livelihood (FAO, 200). Many small-scale fishermen live in developing nations or in rural coastal areas, making them uniquely vulnerable to fishery collapse and environmental change. Because of this, governments and non-governmental organizations (NGOs) have been focusing on management methods to create more sustainable fishing practices for small-scale fishers as well as resilience for fishing communities. Examples include Rare's Fish Forever program on community-based marine reserves (Rare, 2018), the Environmental Defense Fund's toolkits on resilient fishing (EDF, 2023), Bloomberg's Ocean Initiative working on stemming illegal fishing and conserving reef habitat (Bloomberg, n.d.), and USAID and the National Oceanic and Atmospheric Administration's partnership to support sustainable fisheries in the Pacific (USAID, 2022).

In many parts of the world, top-down approaches are the most common type of fisheries management. This relies on centralized governance with catch limits or gear restrictions to reduce fishing pressure. In emergent countries, top-down approaches in fishing governance are a challenge due to lack of infrastructure for monitoring and enforcement (Brownman et al., 2004). When monitoring of catch is poor, the fishing mortality of a species is severely underestimated and can impact fish population models

(Pauly & Zeller, 2016). Community-based management (CBM) of natural resources has been a way for users to self-enforce and monitor those resources (Pinkerton, 1989; R. S. Pomeroy, 1995). This dissertation focuses on small-scale fishing management in the Philippines, which has used community-based management for both marine protected areas (MPAs) and managed access areas with varying success (Aliño et al., 2002; Arceo et al., 2013; Campos & Aliño, 2008; Christie et al., 2002; Rohrer, 2017).

1.1 The Use of Marine Protected Areas

Marine protected areas or marine reserves are widely deployed to manage ecosystem resources. The definition of marine protected areas used by the United States is "any area of the marine environment that has been reserved by federal, state, territorial, tribal or local laws or regulations to provide lasting protection for part or all of the natural and cultural resources therein" (Wenzel & D'lorio, 2011). MPAs are also classified by their different functions based on five characteristics: conservation focus, level of protection, permanence of protection, constancy of protection, and scale of protection. The most protected type of MPA is a 'no-take' zone, which are areas that are off-limits to extraction or destruction of natural or cultural resources, globally these account for less than 3% of the oceans (Marine Conservation Institute, 2021; UNEP, 2016; Wenzel & D'lorio, 2011).

While the global area of MPAs is small, the Philippines is often cited as a success story for MPAs because of how early they started to use them (since the 1970s) and how many were delineated (1,800 as of 2014) (Cabral et al., 2014). However, only 2% of reefs in the Philippines are under MPA protection and of those, only 10-30% are effectively managed (Arceo et al., 2013; Campos & Aliño, 2008). As a part of the Convention on Biological Diversity, the Philippines had agreed to protect 10% of the country's marine resources by 2020 (Cabral et al., 2014), a target that was not achieved (Marine Conservation Institute, 2021).

MPAs may be an effective method to reduce fishing pressure and increase production of fish biomass, where there is less capacity for individual stock assessments, such as in lower income nations (Halpern, 2003). However, there is continued discussion on whether there is a direct benefit to fishermen (Kerwath et al., 2013; Mascia et al., 2010).

1.2 Property Rights Fishing

In addition to marine protected areas, another method to manage typically under- or unreported catch from small-scale fishers is by incorporating property rights into fishery management strategies (Schlager & Ostrom, 1992). These theories involve giving fishers, or a community of fishers, the exclusive rights to fish in a spatial region of the ocean as well as the authority to help manage by enforcing these limits for outside fishers.

Most MPAs in the Philippines are already managed on a local level, so the concept of CBM is not new there (Weeks et al., 2010). Traditionally, no-take MPAs can create conflict amongst fishers, which may lead to non-compliance (Campbell et al., 2012). However, providing a managed access area provides a designated place where local fishers are allowed to fish exclusively, without external fisher conflict (McClanahan et al., 2006; Wirawan, 2017). Though it is not clear if marine resources will also benefit from this management structure given that fished species that have benefited from spatial regulations tend to be more sessile or have a small home range (Hilborn et al., 2004; Kramer & Chapman, 1999; Lowe et al., 2003). The size of the managed access area can therefore also impact both the biomass of marine resources and the incentives for fishermen to work cooperatively (Aceves-Bueno et al., 2017).

In order to assist fishermen in designing fishing policy, Rare, with the Environmental Defense Fund and University of California Santa Barbara, developed the Fish Forever Program. The program paired managed access with marine reserves with the hypothesis that the combination would provide further benefits to both fish, fishers, and the broader marine ecosystem (Rare, 2018). Importantly, the program implemented community-based management of both the MPA and the managed access areas.

1.3 Beyond the Boundaries

While MPAs and reduced fishing effort should benefit fish populations and biodiversity, the reef ecosystems are not a closed system. Mobile organisms and spawned larvae will move beyond the boundaries, temporarily for nursery habitat or migration, or permanently as part of their life history (Harmelin-Vivien et al., 2008; Moffitt et al., 2009; Planes et al., 2009; Roberts, 2001). Additionally, other ecosystems can provide inputs into the system as well, such as excess nutrients from runoff. Habitat quality is important outside the limits of the MPA, because those regions are necessary for juvenile growth and appropriate nutrient cycle functions.

One of the most important habitats in the tropics are mangrove forests, which have a special relationship with coral reefs; not only do mangroves help keep offshore water nutrient poor (oligotrophic), but they also provide nursery habitats to fish larvae that spend their early years in this ecosystem before going out to live on coral reefs (Mumby et al., 2004; Naylor et al., 2000). Decline of mangroves may negatively impact corals by the increase of turbidity and sedimentation in coral areas (Manson et al., 2005). When the reef structure and nursery habitat is threatened, continued production of important fishery species can also be vulnerable (Manson et al., 2005).

The transfer of fish biomass from mangrove areas to coral reefs create links between these two habitats. Habitat linkages are an important feature of ecosystem management, but how exactly habitats are connected can differ regionally, due to geographic distance of ocean currents. Therefore, the broader-scale impacts from damaging one type of habitat can be confounded when comparing across regions. Additionally, each study uses different fish species to identify linkages, so making management decisions from research can be difficult. In the Caribbean, fishes such as snappers (*Lutjanidae spp*.) are found to widely use mangroves in their juvenile stages (Nagelkerken et al., 2000), while in the Indo-Pacific, there is evidence that seagrasses may be more important than mangroves for nursery habitat (Dorenbosch et al., 2005). However, even if the fish do not directly move from mangroves habitat to reefs, they do benefit from the other ecological functions that mangroves provide (Mumby, 2006). Therefore, understanding how these systems are connected is important to management.

1.4 Rare Background

Rare is an international NGO that has been operating in conservation for 40 years. It has evolved from single-species conservation to management of ecosystems, though its underlying strategy has remained constant, to engage local people in the conservation process (P. Butler, 2017). Rare’s mission is to create behavioral change by influencing social norms, and it uses social marketing techniques to influence a change in behavior. The organization started influencing conservation through the implementation of “Pride Campaigns” (Butler, 2017). “Pride” is used to connect people to their natural resources and empower them to be a part of the solution to protect them. The founders of Rare brought together the theories of product marketing and appealing to people’s emotions of pride of place and applied them to conservation issues. Rare has used this as its model for transforming behavior since 1988 and have found that these campaigns have been successful at promoting positive conservation behaviors, such as complying with marine reserves to reduce fishing or using fuel efficient stoves to reduce deforestation (Green et al., 2019). Through the Fish Forever Program, the Philippines’ fishery campaigns employed local community members as leaders, bringing mascots, persuasive slogans, and fun events to bring the community together to celebrate their pride of their fishermen and important fishery resources (Butler, 2017). Having a large number of sites, fishers, and community members scales the social norms in a region and is important to create a reinforcing effect of behavior change.

Through these Pride Campaigns, the Fish Forever Program at Rare has implemented managed access and marine reserves in the Philippines since 2010. They use a theory of behavior change (Figure 1.1) to address knowledge gaps, facilitate interpersonal communication, improve conservation attitudes, remove barriers to change, and change behaviors that result in positive conservation outcomes (J. R. A. Butler et al., 2013; Green et al., 2019; Sowards et al., 2017). Rare tackles conservation problems by facilitating and coordinating the monitoring of ecological outcomes, governance, compliance, and stakeholder input. Through connecting all the components of this program, behavior change and the impacts on the environment and people can be monitored.

Figure 1.1 *Rare's theory of change model*

Taken from Butler et al. (2013)

1.5 Study Area

The Philippines is a case study of how a government reversed course on its historic management of fisheries to find a way to prevent the decline of its fisheries. Fishing is an important sector of the Philippine economy. The percent of GDP from fisheries for the Philippines is 1.8%, over three times the contribution of fisheries to the U.S. economy (FAO, 2014). Artisanal capture fisheries constitute nearly 50% of marine fish production in the Philippines (FAO, 2014). There has also been a lot of investment in the Philippines from NGOs and the government in rebuilding the fisheries and community resilience (World Fishing & Aquaculture, 2015).

Prior to colonization, the Philippines had traditional fisheries rights and allocation of resources to communities (Pomeroy, 1995). Since colonization, the government held the rights to allocate fish resources. After fish resources continued to decline, the

Philippine government decided to decentralize fishery regulations and move towards a participatory approach through the Local Government Code (Pomeroy, 1995). This initiative laid the groundwork for future co-management and property rights-based fisheries regulations.

Rare has facilitated the transition from centralized government to co-management of resources, which has given the community agency to monitor and enforce its own region. Ostrom (2000) discusses how users will monitor and sanction themselves in order to prevent others from getting “free rides” from collective benefits. Fishermen at the Rare sites have been protective of their municipal waters and have helped discourage outside fishermen from fishing within their territorial boundaries (Wirawan, 2017).

There are 20 different sites that Rare works in for the Philippines (Figure 1.2). These sites are named by the municipality where they are located. Sites applied to be a part of the Fish Forever Program and were evaluated through a Rapid Selection Assessment (RSA) in order to quantify site quality based on a variety of factors for the program. Each site received points for different qualities, up to 430. For four of the sites, they had matched control sites based on closeness of point value. Importantly, because sites applied to be a part of Fish Forever, only sites that applied were considered as control groups.

At each site, Rare worked directly with a few fishing villages to achieve stakeholder buy-in. Rare hosted workshops where fishermen could provide their input on where reserves or fishing areas should be based on their knowledge, after an ecological model was created. After these workshops took place, Rare worked with the community and the local government to establish the managed access areas and community management. These areas have different levels of governance starting at the government run level to full community-based management.

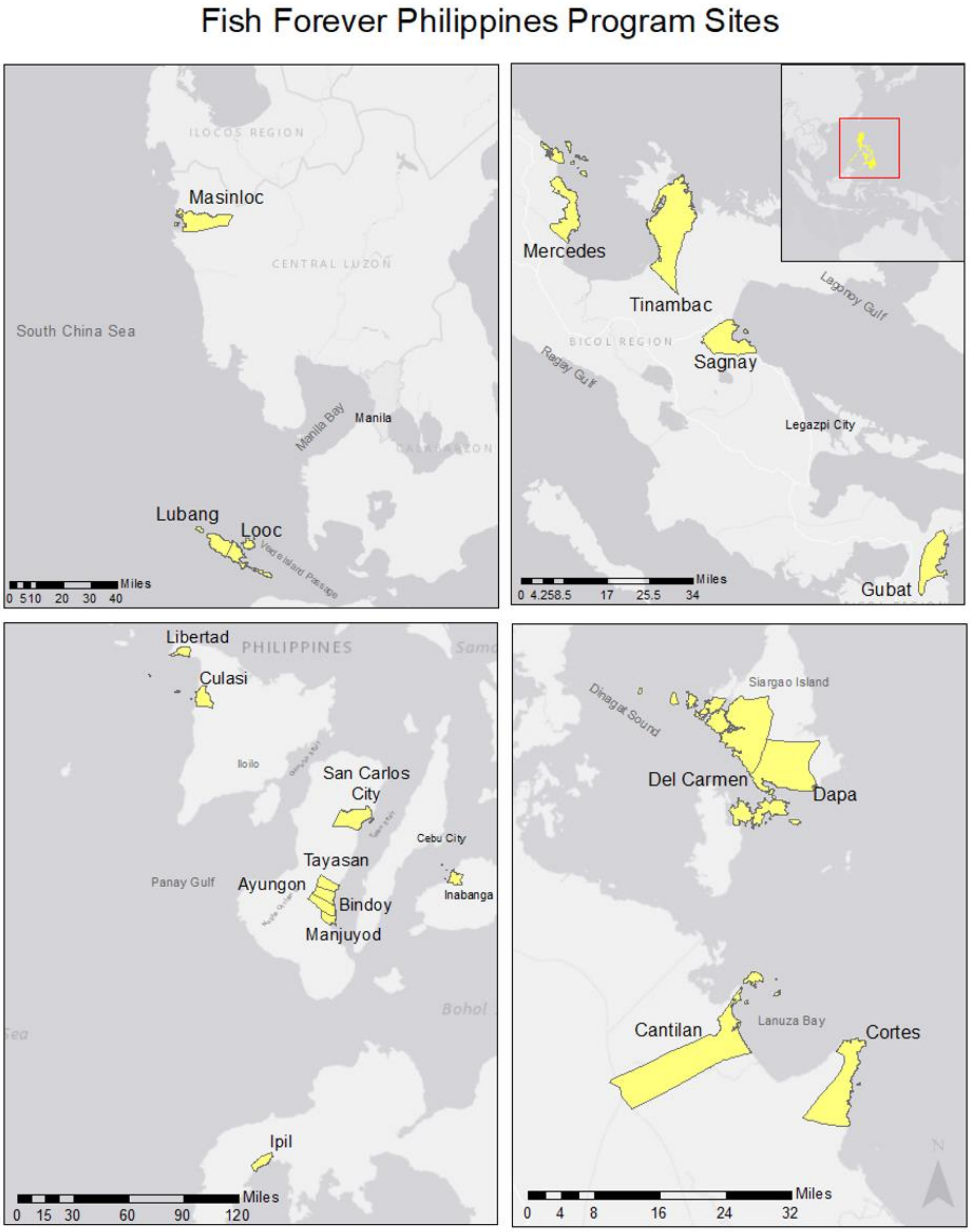

Figure 1.2 *Site Map*

Locations of 20 Fish Forever program sites where MPAs are located. Data Source: GADM, Spatial Reference: GCS WGS 1984

1.6 Scientific Goals

This dissertation research sits within a Social-Ecological Systems (SES) framework adapted from Ostrom (2009) (Figure 1.3). There is limited empirical literature detailing how these complex interactions between the society (compliance, livelihoods, and governance) and ecology (habitat availability and health) increase fishery production (Cinner et al., 2009; R. Pollnac et al., 2010). Kittinger et al. (2013) call for systems thinking and connecting social and ecological systems in order to better understand how humans are impacting resources and vice versa. The challenge lies with protocol development and implementation, which are complicated and expensive.

Non-governmental organizations, such as Rare, have been implementing social-ecological programs in the form of community-based management schemes to address these complex interactions. This research aims to draw links between the social and ecological data to empirically evaluate the SES in SSF. Additionally, I evaluate the interactions within social-ecological systems with empirical data sources. Social-ecological systems research is growing, with mixed results of how governance strategies impact fish biomass and social well-being. The knowledge gained from this research provides information for managers on the interactions between social and ecological systems that can improve design and implementation of future MPAs.

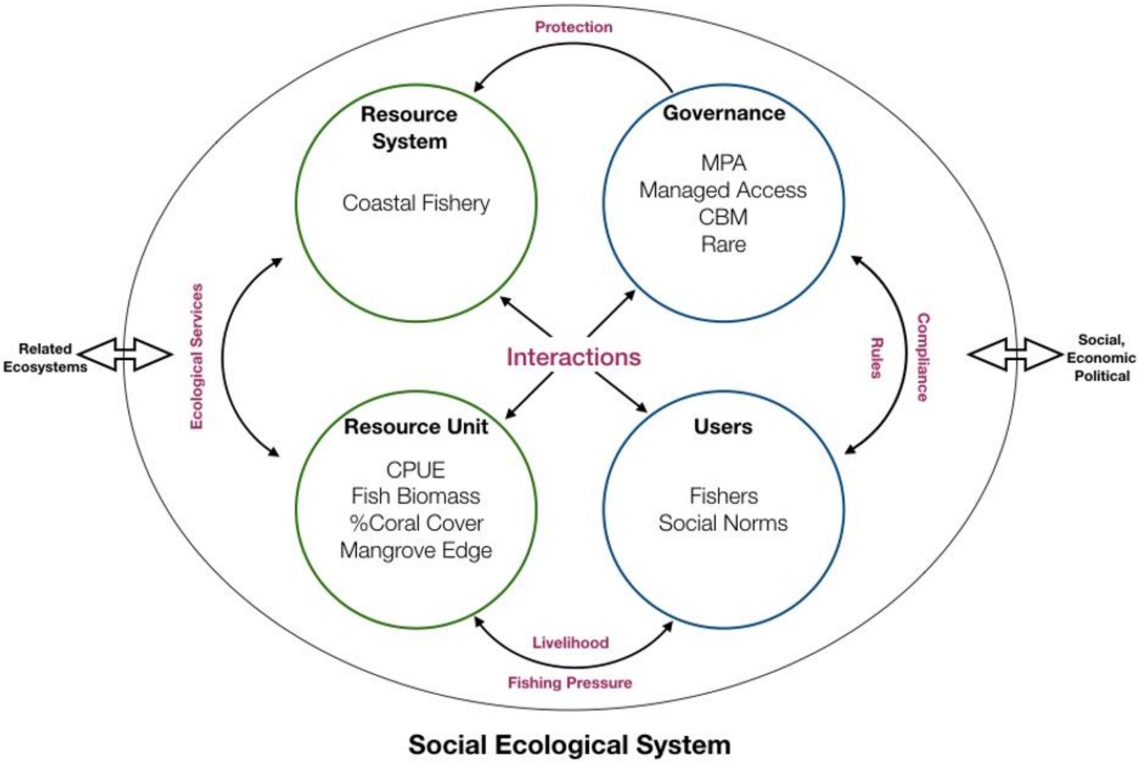

Figure 1.3 *Conceptual diagram*

The social-ecological system described in this dissertation, describing the different variables within the subsystems. Adapted from Ostrom (2009).

1.7 Data Description

In order to pursue these goals, a dataset from Fish Forever as well as new data to fill data gaps were used. The fisheries data were collected by visual surveys by a third-party contractor. All fish species that were seen on a 50m transect had length and count estimates and were identified to the species level of classification. Across all sites over 600 species of fish were identified during the visual surveys. Catch data was also collected, which included the fisherman’s name, the species, gear type, number of fishermen, effort (in hours fished), weight of catch (by species), and number of individuals caught (by species). This data was only collected for 18 sites, all except for Ipil and San Carlos had catch data. The data collection for the visual surveys and catch used in this analysis occurred in various years across sites, but fall into three time categories: 2011-2017, 2012-2017 and 2015-2017 (Table 1.1). For all the sites there are data for “before” and “after” community-based management implementation. Additionally, habitat data was collected using transects to calculate the percentage of hard coral, soft coral, substrate, algae, and other biota that was covering the bottom. This data is often available for the same years as the fisheries data.

Spatial data was extracted from available shapefiles. Fisheries and coral cover data have coordinates associated with them and can be tied to a specific location. Finally, to collect data on the fisher perceptions, interviews were conducted at four sites in the Philippines in March 2022.

Table 1.1 *Description of Site Factors*

Site Name	Municipal Waters (ha)	Marine Reserve (ha)	% Protected	Reserve Est Date	Data Dates	Protected Habitat
Ayungon	9,399	237	2.5	2008*	2012-2017	Coral reef
Bindoy	10,230	332	3.2	2006*	2012-2017	Coral reef
Cantila	41,830	250	0.6	2006	2011-2017	Coral reef
Cortes	56,000	307	0.5	2007	2011-2017	Coral reef
Culasi	151,506	146	0.1	1991	2015-2017	Coral reef
Dapa	17,174	152	0.9	2006	2015-2017	Coral reef
Del Carmen	44,816	38	0.1	2015	2015-2017	Coral reef, seagrass beds
Gubat	8,244	35	0.4	2012*	2011-2017	Coral reef
Inabanga	14,837	100	0.6	2000	2011-2017	Coral reef
Ipil	20,270	1,923	9.5	2004*	2012-2017	Coral reef, seagrass beds
Libertad	35,657	16	0.04	1998	2015-2017	Coral reef
Looc	138,304	913	0.7	2010	2015-2017	Coral reef
Lubang	109,886	581	0.5	2010	2015-2017	Coral reef
Manjanyud	12,158	83	0.7	1994	2015-2017	Coral reef
Masinloc	11,080	128	1.2	1989*	2015-2017	Coral reef
Mercedes	53,850	22	0.04	2002	2015-2017	Coral reef
Sagnay	13,566	475	3.5	1993	2012-2017	Coral reef
San Carlos	27,868	108	0.4	2005	2015-2017	Coral reef
Tayasan	6,552	6	0.1	1993	2015-2017	Coral reef
Tinambac	20,900	182	0.9	2006	2011-2017	Coral reef

Site factors include name, size of the municipal waters, size of the marine reserve, the percent of the municipal waters in the marine reserve, the established date, dates where there is data, and what type of habitat is protected. *Data retrieved from Muallil et al. (2019).

1.8 Outline

The body of this dissertation is made up of three separate but related studies, which all strive to investigate a portion of social-ecological systems of small-scale fisheries in the Philippines. This research explores both the governance and ecological implications on fish biomass and fish communities. Chapter One investigates how the implementation of community-based management impacted fish abundance, biodiversity, and fish communities inside and outside marine reserves. Chapter Two researches the impact of mangrove habitat, edge habitat and total canopy area on the biodiversity, total abundance of fish, and abundance of key fished species that are mangrove dependent at Fish Forever sites. Chapter Three includes qualitative methods to identify fisher perceptions on compliance, enforcement, the marine reserve and catch between ecologically successful and unsuccessful sites, defined by Chapter Two. A final general discussion synthesizes the three research chapters to evaluate the social-ecological system of the small-scale fisheries in the Philippines.

CHAPTER II – IMPLICATIONS OF COMMUNITY-BASED MANAGEMENT OF MARINE RESERVES IN THE PHILIPPINES FOR REEF FISH COMMUNITIES AND BIODIVERSITY

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2.1 Introduction

Destructive fishing habits, overfishing, and pollution have impacted coral reef systems and fisheries (Graham et al., 2017; Mcmanus & Reyes, 1997; Pastorok & Bilyard, 1985; Wenger et al., 2015). Unsustainable fishing techniques as well as sediment and nutrient pollution can transition coral reef ecosystems from oligotrophic complex living coral reef structures with high biodiversity to eutrophic, macro-algae algae covered structures with reduced biodiversity (Mumby et al., 2007). Overfishing or destructive fishing practices exist in commercial or industrial fishing fleets as well as small-scale fishing (SSF) (Alfaro-Shigueto et al., 2010; Mora, 2008; Muallil et al., 2019; Selgrath et al., 2018; Shester & Micheli, 2011). Small-scale fishing, generally defined by small, man- or low-powered vessels, makes up at least 30% of global catch (Pauly and Zeller 2016). In the Philippines, approximately 50% of catch is harvested by over 1.9 million small-scale fishers (FAO 2014) and 68% of fisheries have been found to be unsustainable (Muallil, Mamauag, Cabral, et al., 2014). Additionally, small-scale fishers are growing in number in the Philippines, increasing the total annual fishing pressure (Selgrath et al. 2018). Rural coastal communities, where much of small-scale fishing occurs, rely on subsistence fishing and are uniquely vulnerable to fishery collapse and environmental changes, such as sea-level rise or ocean acidification (FAO, 2010; World Bank, 2012). Thus, it continues to be important to focus on sustainable management strategies for SSF.

In many parts of the world, top-down management approaches, such as catch limits and gear restrictions, are the most common type of commercial fisheries management (Hilborn & Ovando, 2014). For these traditional approaches to be successful, they typically rely on centralized governance, limited targeted species and large quantities of biological data. In emergent countries with a high proportion of SSF, these top-down approaches are challenging due to lack of infrastructure for monitoring and enforcement (Brownman et al., 2004). In order to overcome these challenges, governments and non-governmental organizations (NGOs) have been focusing on management methods to create more sustainable fishing practices for small-scale fishers and create resilience for fishing communities (FAO, 2018).

Rare, one such international NGO, has been working with local communities in the Philippines to address overfishing. Rare, with the Environmental Defense Fund and University of California Santa Barbara, developed the Fish Forever Program using Pride Campaigns to inspire behavior change to reduce illegal fishing in marine reserves and increase effectiveness. Beginning in 2011, the program paired managed access with marine reserves hypothesizing that the combination would provide benefits to both fish, fishers, and the broader marine ecosystem (Rare, 2018). Importantly, local communities manage both the marine reserves and the managed access areas to reduce illegal fishing of the marine reserve and reduce destructive fishing habits outside the reserves.

Marine reserve areas, where fishing is prohibited, can be a powerful management tool for protection of an essential habitat and also benefit fishers through increased catch (Guidetti, 2006; Kerwath et al., 2013; Strain et al., 2019). However, marine reserves will only be beneficial to both if they are effectively managed (Mora 2008; Strain et al. 2019). The Philippines is often cited as a success story for marine reserves because of how early they were implemented (since the 1970s) and how many were delineated (1,800 as of 2014) (Cabral et al. 2014). However, only 2% of reefs are under protection, many of them small, and only 10-30% are effectively managed (Campos and Aliño 2008; Arceo et al. 2013; Weeks et al. 2010). As a part of the Convention on Biological Diversity, the Philippines had agreed to protect 10% of the country's marine resources by 2020 (Cabral et al. 2014), a target that was not achieved (Marine Conservation Institute, 2021).

One way to potentially increase effectiveness of marine reserves is to implement or strengthen community-based management (CBM) of those areas, which addresses the need for multi-species management and enforcement or compliance of fishing regulations (Smallhorn-West et al., 2019). Community-based management of natural resources has been a way for users to self-enforce and monitor those resources (Kearney et al., 2007; Ostrom, 2000; Pinkerton, 1989; R. S. Pomeroy, 1995). The Philippines government has decentralized fishery regulations, moving toward participatory approaches through the Local Government Code in 1991 and Fisheries code in 1998, which allow local governments or municipalities to manage fishery resources (Pomeroy & Courtney, 2018). Since then, the Philippines has used CBM in marine reserves with varying success (Aliño et al., 2002; Arceo et al., 2013; Campos & Aliño, 2008; Rohrer, 2017). Notably, Apo Island, one of the best studied marine reserves, has demonstrated that important fish species increase in both biomass and catch (Maypa et al., 2002; G. Russ et al., 2003; G. Russ & Alcala, 1996). Other studies have found that CBM marine reserves maintain fish abundance and diversity within the reserves, but not in the surrounding reefs (Christie et al., 2002).

Many of the existing marine reserves already established in the Philippines were "paper parks", protected in name only (Campos & Aliño, 2008). One of the issues with small-scale fishing is that top-down governance structures frequently lack enforcement and therefore are ineffective at reducing fishing pressure (Brownman et al., 2004). Managing these fisheries on a local level may increase enforcement and compliance of the marine reserves (McClanahan et al., 2006). Depending on the location and ecosystem, designation of a no-take marine reserves is not enough to protect the ecosystem and does not show significant regeneration of coral reef habitat or fishes, such as in parrotfish in Belize (Cox et al., 2017). Community-based management has been identified as a key component of effective marine reserves where increases in biomass of fished species is observed (Guidetti & Claudet, 2010; Kearney et al., 2007; Smallhorn-West et al., 2019).

In the Philippines, biomass of fish has increased both inside and outside CBM marine reserves (Rare, 2018; G. Russ et al., 2003). While fish biomass is higher in marine reserves, the stocks themselves are generally overfished (Muallil et al., 2019). In addition to biomass for evaluating management strategies, fish community structure is also needed because total biomass does not account for the diversity of species contributing to that biomass. Additionally, the increase of one species may not be as ecologically significant as the increase of all species across the community.

Researchers have repeatedly concluded that marine reserves will not lead to an increase in fishery resources if they are not effectively managed or designed (Gaines et al., 2010; Mora, 2008; Muallil et al., 2019; Rife et al., 2013). Here we investigated the impact of implementing community-based management on fish community structure and biodiversity in marine reserves and open access areas across the Philippines.

2.2 Methods

2.2.1 Data Description

Fisheries independent data, such as species name, abundance, and estimated length were collected from 20 sites in the Philippines between the years of 2011 and 2017 as part of Rare's Fish Forever Program. The data were collected using five 50m transects and two swimmers at each site, who would visually identify species, count, and estimate total lengths of each fish. In each of the sites, abundance data were collected inside and outside the marine reserve. Reserve implementation occurred as early as 1989 and as late as 2012 (Table 1.1). Rare facilitated the implementation of community-based management in 2014 at all of these sites.

2.2.2 Analysis

To determine the reef fish communities inside and outside the marine reserves before and after CBM was implemented, one-way PERMANOVA and SIMPER analyses were run using PRIMER-e (Clarke & Gorley, 2006). Both analyses were completed on a combination factor of whether the samples were inside or outside the marine reserve and if they were before or after CBM. Of all the combinations we used pair-wise tests within the PERMANOVA to compare four of the combinations: 1) “inside before” and “inside after” 2) “outside before” and “outside after” 3) “inside before” and “outside before” and 4) “inside after” and “outside after”. Fish abundance data were transformed using a 4th-root transformation and then a Hellinger similarity matrix was applied. Fish community structure was then visualized using nonmetric multidimensional scaling (nMDS). The nMDS allows us to see similarities of species composition between treatment groups. PERMANOVAs were performed on each site to test the significance of difference between fish community structures, using the interaction of marine reserves status and before and after implementation of CBM. The PERMANOVAs ran up to 10,000 permutations. Where significant differences were found, SIMPER analyses, using the same combinations, were conducted to determine which fish families and species were the main contributors to the differences between treatment groups. Special attention was given to important fishery families jacks (*Carangidae*), fusiliers (*Caesionidae*), wrasses (Labridae), breams (*Lethrinidae* and *Nemipteridae*), rabbitfish (*Siganidae*), snapper (*Lutjanidae*), goatfish (*Mullidae*), grunts (*Haemulidae*), hogfish (*Bodianinae*), grouper (*Serranidae*, specifically *Epinephelinae*), parrotfish (*Scaridae*), surgeonfish (*Acanthuridae*) and ponyfish (*Leiognathidae*) (Fish Forever, 2020; Muallil, Mamauag, Cababaro, et al., 2014).We investigated CBM implementation effects on all sites aggregated as well as each site separately to observe overall patterns of fish community change and site level dynamics.

Biodiversity was assessed by calculating a Shannon Index on each transect and testing the interactions at the site, reserve status, and CBM level. The Shannon Index calculates both the species richness and evenness in an area, giving weight to rarer species. This type of diversity index is useful for areas where overexploitation of fishing resources may have resulted in more rare species, and accounting for the differences in abundance of these rare species is relevant to the study. Kruskal-Wallis tests were then performed on the Shannon Index values to test if CBM implementation resulted in significant differences. Biodiversity analyses were performed using the R package vegan and rstatix (Okansen et al., 2020.; R Core Team, 2020; Kassambara 2020)

2.3 Results

2.3.1 Community Structure

When all site data were aggregated, there is no clear clustering of fish communities between those inside marine reserves and outside marine reserves, but instead a strong clustering by site (Figure 2.1). However, when each site was analyzed separately, the percent of sites that had significant differences between fish community structure inside and outside marine reserves increased from 65% of sites to 85% of sites after the implementation of CBM (Table 2.1).

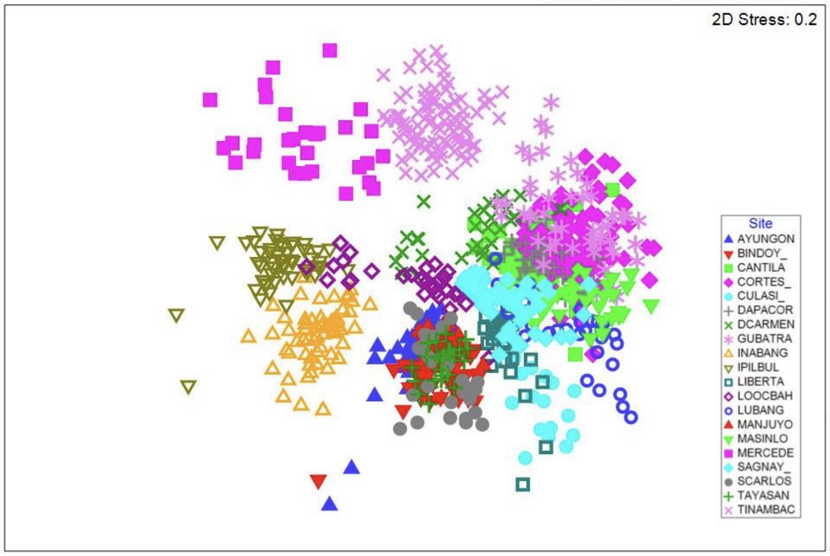

Figure 2.1 *nMDS Plot for All Sites*

Non-metric multidimensional scaling (nMDS) plot of fish species community structure of all sites. Symbols indicate site.

Table 2.1 *PERMANOVA pair-wise test results at each site for each combination factor*

Site	**Interaction Group**	**Pair-wise t**	**P**	**Permutations**
Ayungon	Insidebefore, Insideafter	1.1924	0.018*	9822
	Insidebefore, Outsidebefore	1.3709	0.0022*	9362
	Insideafter, Outsideafter	1.5592	0.0001*	9854
	Outsidebefore, Outsideafter	1.0102	0.3938	9842
Bindoy	Insidebefore, Insideafter	0.93102	0.6620	9837
	Insidebefore, Outsidebefore	1.6926	0.0001*	9318
	Insideafter, Outsideafter	2.0107	0.0001*	9846
	Outsidebefore, Outsideafter	1.1027	0.1224	9762
Cantila	Insidebefore, Insideafter	1.4291	0.0002*	9829
	Insidebefore, Outsidebefore	1.4887	0.0001*	9825
	Insideafter, Outsideafter	1.3999	0.0001*	9809
	Outsidebefore, Outsideafter	1.5028	0.0001*	9806

Table 2.1 continued

Site	Interaction Group	Pair-wise t	P	Permutations
Cortes	Insidebefore, Insideafter	1.4745	0.0001*	9825
	Insidebefore, Outsidebefore	1.4769	0.0002*	9824
	Insideafter, Outsideafter	1.6373	0.0001*	9816
	Outsidebefore, Outsideafter	1.2704	0.0021*	9798
Culasi	Insidebefore, Insideafter	1.0789	0.2735	15
	Insidebefore, Outsidebefore	1.1831	0.0629	15
	Insideafter, Outsideafter	1.6225	0.0015*	494
	Outsidebefore, Outsideafter	0.99826	0.4280	495
Dapa	Insidebefore, Insideafter	1.0265	0.3477	2900
	Insidebefore, Outsidebefore	1.1623	0.0462*	126
	Insideafter, Outsideafter	1.2076	0.0248*	9350
	Outsidebefore, Outsideafter	0.96393	0.6181	2896
Del Carmen	Insidebefore, Insideafter	1.0611	0.2562	1000
	Insidebefore, Outsidebefore	0.94441	0.5870	210
	Insideafter, Outsideafter	1.1169	0.1488	9351
	Outsidebefore, Outsideafter	1.0597	0.2534	5701
Gubat	Insidebefore, Insideafter	2.0684	0.0001*	9851
	Insidebefore, Outsidebefore	0.98791	0.4782	9557
	Insideafter, Outsideafter	1.8759	0.0001*	9805
	Outsidebefore, Outsideafter	1.4304	0.0002*	9808
Inabanga	Insidebefore, Insideafter	1.0853	0.1543	8777
	Insidebefore, Outsidebefore	1.5218	0.0001*	9833
	Insideafter, Outsideafter	1.2544	0.0271*	2871
	Outsidebefore, Outsideafter	1.4027	0.001*	9872
Ipil	Insidebefore, Insideafter	1.1123	0.0976	9781
	Insidebefore, Outsidebefore	1.24	0.0081*	9312
	Insideafter, Outsideafter	1.4839	0.0001*	9850
	Outsidebefore, Outsideafter	1.2109	0.0248*	9842

Table 2.1 continued

Site	Interaction Group	Pair-wise t	P	Permutations
Libertad	Insidebefore, Insideafter	1.2152	0.0157*	2869
	Insidebefore, Outsidebefore	0.90107	0.9045	126
	Insideafter, Outsideafter	1.1161	0.0572	9301
	Outsidebefore, Outsideafter	1.3003	0.0003*	2870
Looc	Insidebefore, Insideafter	1.0598	0.2423	2877
	Insidebefore, Outsidebefore	1.3194	0.033*	126
	Insideafter, Outsideafter	1.7291	0.0002*	9366
	Outsidebefore, Outsideafter	0.9031	0.7444	2878
Lubang	Insidebefore, Insideafter	1.0165	0.3559	2884
	Insidebefore, Outsidebefore	1.6057	0.0081*	126
	Insideafter, Outsideafter	2.0124	0.0001*	9338
	Outsidebefore, Outsideafter	0.96575	0.6228	2881
Manjuyod	Insidebefore, Insideafter	1.1161	0.0733	2872
	Insidebefore, Outsidebefore	1.0104	0.4004	126
	Insideafter, Outsideafter	1.1652	0.045*	9318
	Outsidebefore, Outsideafter	1.044	0.2695	1978
Masinloc	Insidebefore, Insideafter	1.1679	0.0374*	2880
	Insidebefore, Outsidebefore	1.2292	0.0243*	126
	Insideafter, Outsideafter	1.4242	0.0027*	9325
	Outsidebefore, Outsideafter	0.94929	0.6460	1983
Mercedes	Insidebefore, Insideafter	1.0241	0.3733	2871
	Insidebefore, Outsidebefore	1.2486	0.0477*	126
	Insideafter, Outsideafter	1.1981	0.0418*	9310
	Outsidebefore, Outsideafter	1.0515	0.2696	2879
Sagnay	Insidebefore, Insideafter	1.12	0.1367	9843
	Insidebefore, Outsidebefore	1.1131	0.1329	9307
	Insideafter, Outsideafter	1.1321	0.0808	9834
	Outsidebefore, Outsideafter	1.0552	0.2312	9763

Table 2.1 continued

Site	Interaction Group	Pair-wise t	P	Permutations
San Carlos	Insidebefore, Insideafter	1.3202	0.0026*	7658
	Insidebefore, Outsidebefore	1.4902	0.0053*	210
	Insideafter, Outsideafter	2.0183	0.0001*	9473
	Outsidebefore, Outsideafter	1.1381	0.1010	494
Tayasan	Insidebefore, Insideafter	1.0722	0.2491	495
	Insidebefore, Outsidebefore	1.1236	0.0629	35
	Insideafter, Outsideafter	1.2372	0.0147*	5097
	Outsidebefore, Outsideafter	1.096	0.1524	495
Tinambac	Insidebefore, Insideafter	1.3424	0.0017*	9865
	Insidebefore, Outsidebefore	1.3688	0.0006*	9841
	Insideafter, Outsideafter	1.4386	0.0001*	9813
	Outsidebefore, Outsideafter	1.3806	0.0002*	9828

* Indicates significance

Additionally, shifts in fish community structures were observed after CBM was implemented both inside marine reserves (40% of sites had a significant difference) and outside marine reserves (35% of sites had a significant difference). Due to the large total number of fish species observed (over 600), no single species makes up a large percentage of the dissimilarity between factors (inside versus outside the marine reserve before CBM, and inside versus outside the marine reserve after CBM) for any site in the SIMPER analyses. The SIMPER analyses performed after aggregating the data to the family level revealed that increases of abundance of many important fishery families contributed to the differences seen in community composition after the CBM was implemented.

Some sites, such as Lubang, San Carlos City, Bindoy, and Looc, had clearly defined clusters (P<0.05) for fish communities inside and outside the marine reserve, but no significant differences for changes before and after the implementation of CBM (Figure 2.2, A.1-4). For example, in Bindoy an increase of important fishery families (snappers, wrasses, jacks, goatfish, groupers, parrotfish, and breams) made up 25.9% of dissimilarity between inside and outside the marine reserves before CBM (Figure 2.3). However, not every important fishery family increased uniformly at each site. For the same location (Bindoy) and treatment (inside and outside reserve before CBM implementation), a decrease in fusiliers, rabbitfish, hogfish, and surgeonfish was responsible for 12.3% of the dissimilarity. Additionally, when comparing the differences inside and outside the marine reserves after CBM was implemented the increase of important families (snappers, wrasses, jacks, goatfish, groupers, parrotfish, breams, fusiliers, surgeonfish, and rabbitfish) contributed to 34.5% of the dissimilarity. Notably, there were increases in fusiliers and rabbitfish contributing to 6.8% of dissimilarity between inside and outside marine reserves after CBM was implemented.

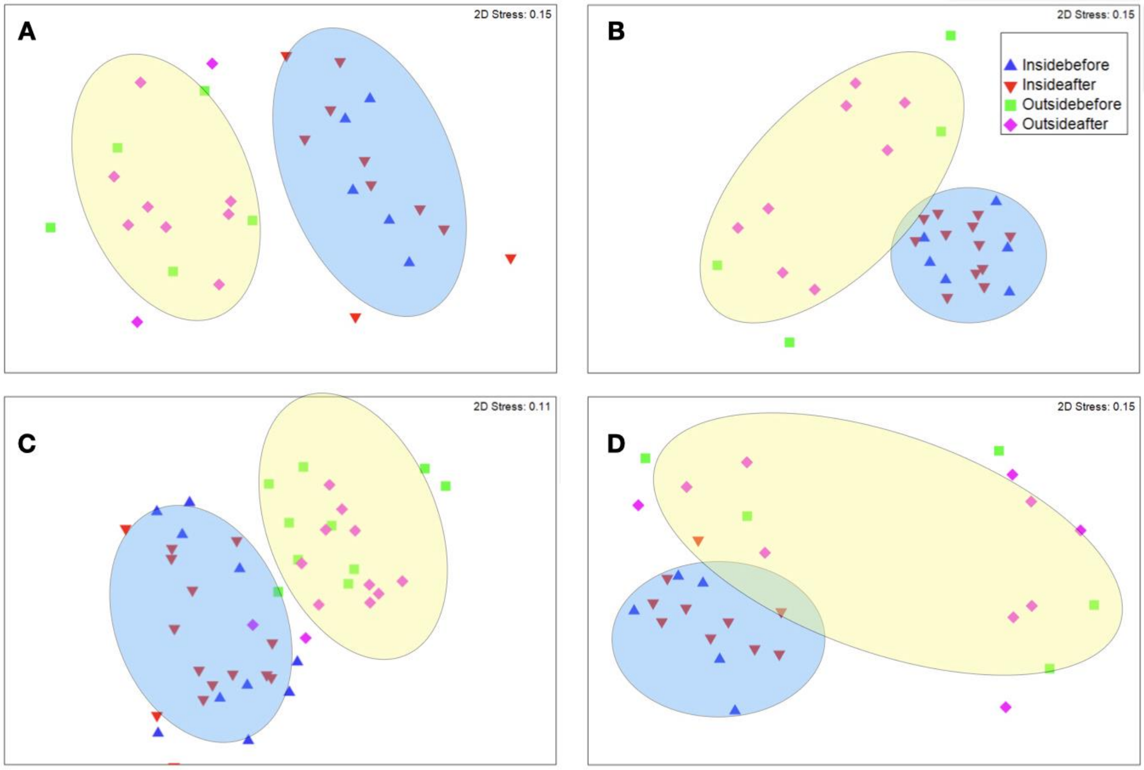

Figure 2.2 *nMDS Plot of Fish Species Community Structure Similarities*

a) Lubang, b) San Carlos City, c) Bindoy, and d) Looc. Triangles denote the community structure inside marine reserve (blue indicates before and red indicates after CBM implementation), and squares and diamonds outside of marine reserves, with squares indicating before, and diamonds indicating after CBM implementation. The ellipses indicate significant clusters ($P< 0.05$).

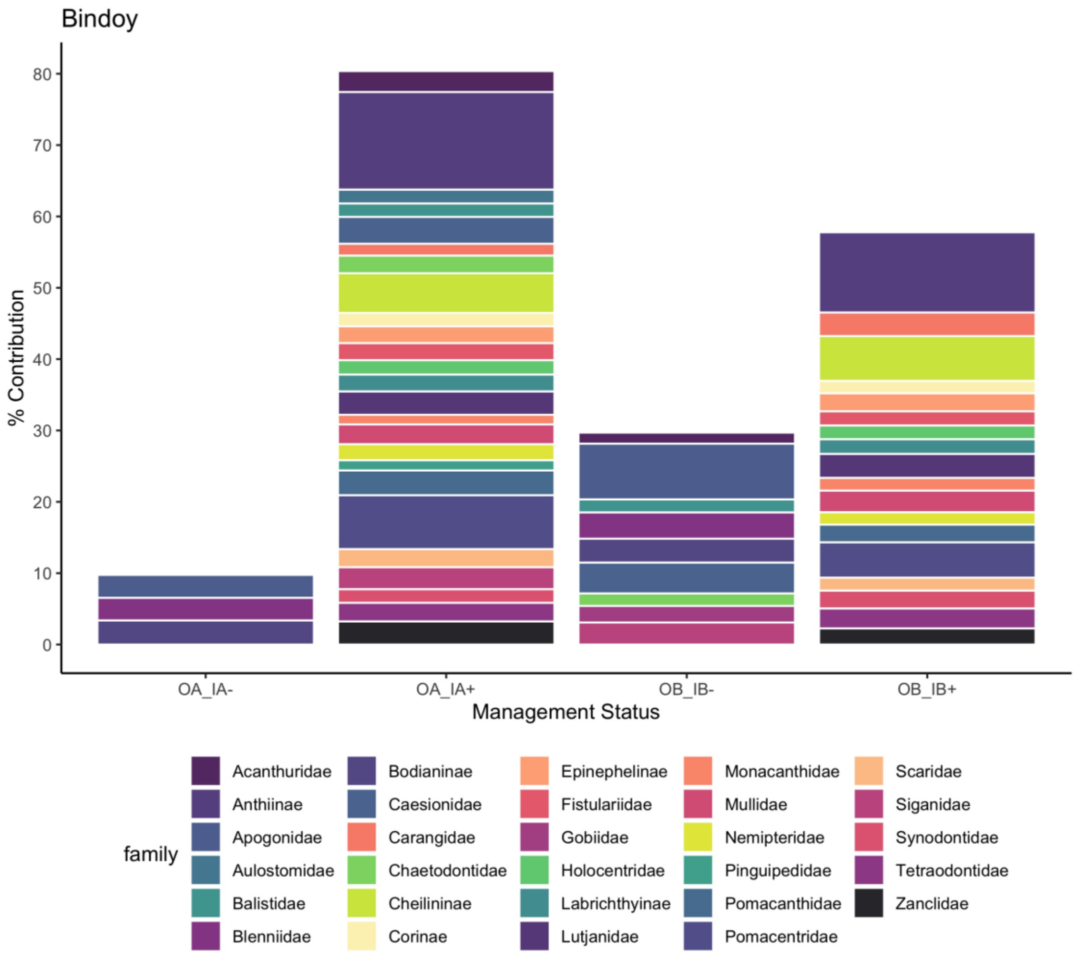

Figure 2.3 *Percent Contribution to the Dissimilarity in Bindoy*

Percent contribution to the dissimilarity between inside and outside before. (average dissimilarity 30.36) and after (average dissimilarity 34.82) CBM implementation in Bindoy, aggregated by family. OA = outside marine reserve, after CBM implementation, OB = outside marine reserve, before CBM implementation, IA = inside marine reserve, after CBM implementation, IB = inside marine reserve, before CBM implementation. + means that there was higher abundance after CBM, - means there was lower abundance after CBM.

Other sites, such as Cantilan, Tinambac, and Cortes, had significant clusters (P<0.05) for each interaction of reserve and CBM status (Figure 2.4, A.20 and A.21). For these three sites, the general effect of CBM implementation for both inside and outside the reserve was increasing abundances of most important fishery families. Tinambac outside the reserves after CBM was implemented was an exception, where a decrease in abundance of fusiliers, rabbitfish, wrasses, and parrotfish were responsible for 23% of dissimilarity (Figure 2.5). For Tinambac, both outside and inside the marine reserve after CBM was implemented, fusiliers decreased in abundance.

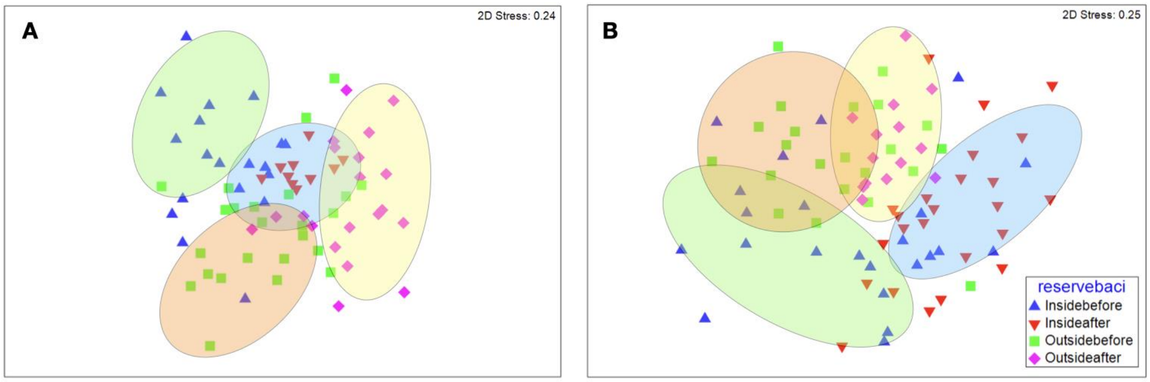

Figure 2.4 *nMDS Plot of Fish Species Community Structure Similarities*

A) Cantila and B) Cortes. Triangles denote the community structure inside marine reserve (blue indicates before and red indicates after CBM implementation), and squares and diamonds outside of marine reserves, with squares indicating before, and diamonds indicating after CBM implementation. The ellipses indicate significant clusters ($P < 0.05$).

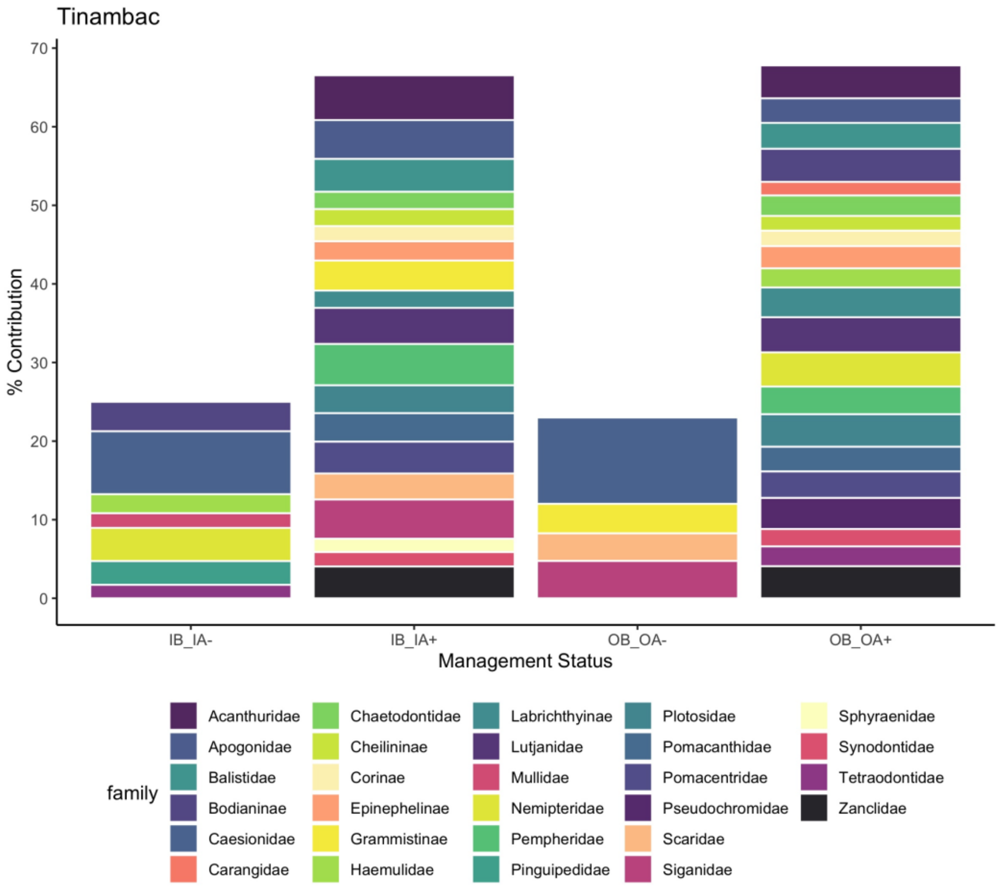

Figure 2.5 *Percent Contribution to the Dissimilarity in Tinambac*

Percent contribution to the dissimilarity Tinambac between inside before and after (average dissimilarity 31.86) and outside marine reserves before and after (average dissimilarity 31.80) CBM in Tinambac, aggregated by family. OA = outside marine reserve, after CBM implementation, OB = outside marine reserve, before CBM implementation, IA = inside marine reserve, after CBM implementation, IB = inside marine reserve, before CBM implementation. + means that there was higher abundance after CBM, - means there was lower abundance after CBM.

Four sites, Manjuyod, Culasi, Tayasan, and Gubat, had no difference in fish community structure before CBM inside and outside marine reserves, however, after CBM was implemented, there was a significant shift in community structure inside marine reserves (Figure 2.6, A.22, A.25, A.31 and A.36). This was also accounted for in the SIMPER analysis for species where prior to CBM there was a lower dissimilarity (56.68) between inside the marine reserve and outside the marine reserve. However, after

CBM implementation the average dissimilarity increased both within the reserve (69.71) and in comparison, to outside the reserve (64.63). The SIMPER analysis of Gubat revealed that an increase of snappers, goatfish wrasse, fusiliers, hogfish, and rabbitfish contributed to 23% of the dissimilarity between inside the marine reserve before and after CBM was implemented, indicating the application of CBM marine reserves for fisheries, not just conservation (Figure 2.7). Similarly, to the previous sites, not all important fishery species had an increase of relative abundance after CBM, approximately 8% of the dissimilarity inside the reserves after CBM was due to the decrease of surgeonfish and parrotfish. Finally, two sites, Del Carmen and Sagnay had no community structure changes after CBM was implemented either inside or outside the marine reserve.

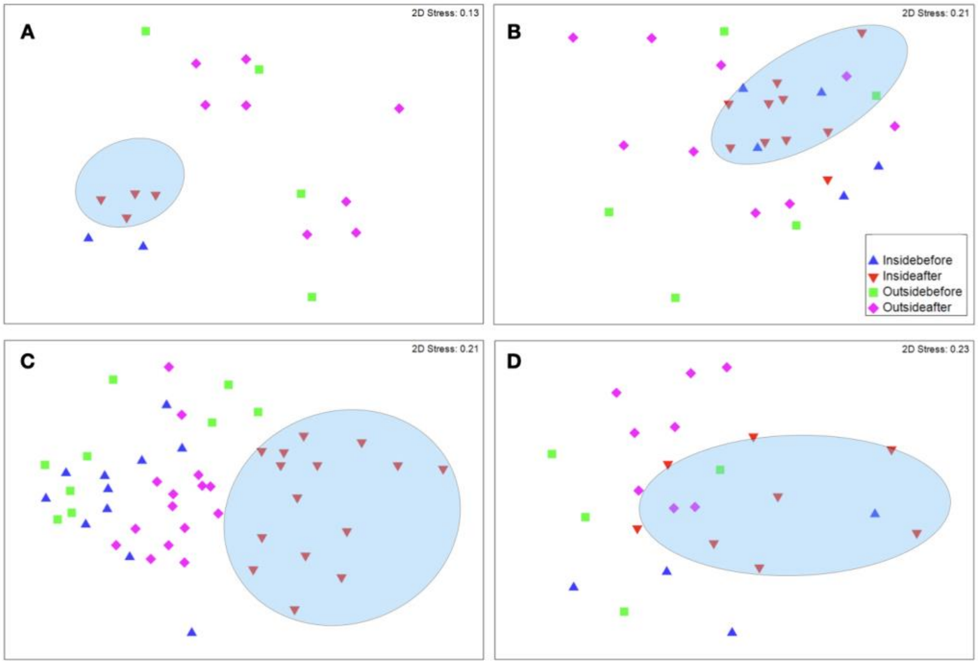

Figure 2.6 *nMDS of Community Structure Similarities*

A) Culasi, B) Manjuyod, C) Gubat, and D) Tayasan. Triangles denote the community structure inside marine reserve and squares and diamonds outside of marine reserves. Triangles denote the community structure inside marine reserve (blue indicates before and red indicates after CBM implementation), and squares and diamonds outside of marine reserves, with squares indicating before, and diamonds indicating after CBM implementation. The ellipses indicate significant clusters (P< 0.05).

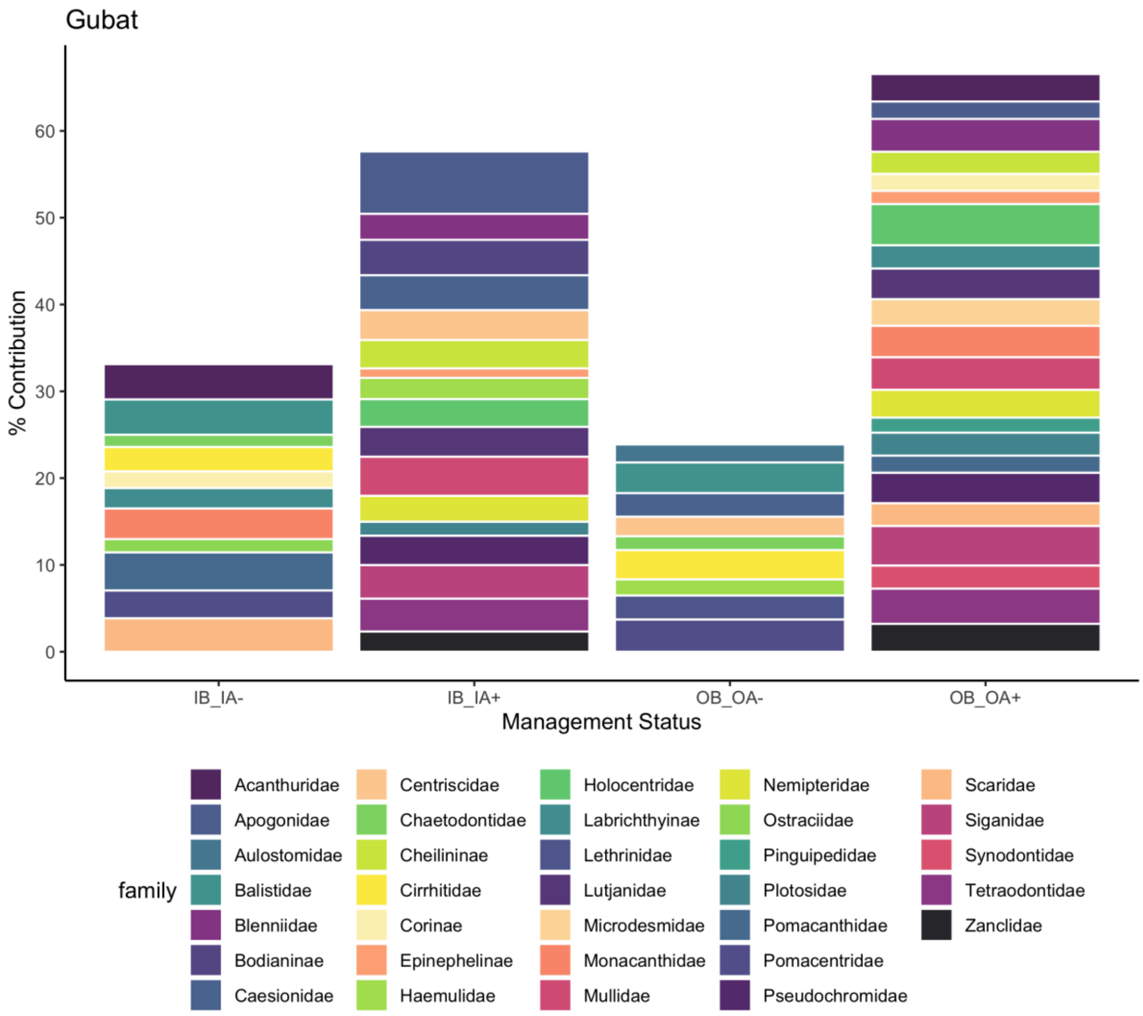

Figure 2.7 *Percent Contribution to the Dissimilarity in Gubat*

Percent contribution to the dissimilarity between inside the marine reserves before and after CBM, inside and outside marine reserves before CBM, and inside and outside after CBM. OA = outside marine reserve, after CBM implementation, OB = outside marine reserve, before CBM implementation, IA = inside marine reserve, after CBM implementation, IB = inside marine reserve, before CBM implementation. + means that there was higher abundance inside the reserve or after CBM, - means there was lower abundance inside the reserve or after CBM.

2.3.2 Biodiversity

At the site level, six sites (30%) had significant differences in biodiversity inside or outside marine reserves and five (25%) had differences before and after community-based management. Cortes and Libertad had similar biodiversity inside and outside marine reserves, but after CBM was implemented were significantly different, with high diversity inside the reserve than outside after implementation (Figure 2.8). Additionally, while some sites (Cantila, Masinloc, and Tinambac) had no significant differences in biodiversity inside and outside the marine reserves, biodiversity significantly increased in both areas after CBM was implemented. One site, Del Carmen, decreased in biodiversity overall after CBM, though the remaining sites increased in biodiversity. While there is some overlap between sites that had significant community structure changes and biodiversity changes there is no overall pattern.

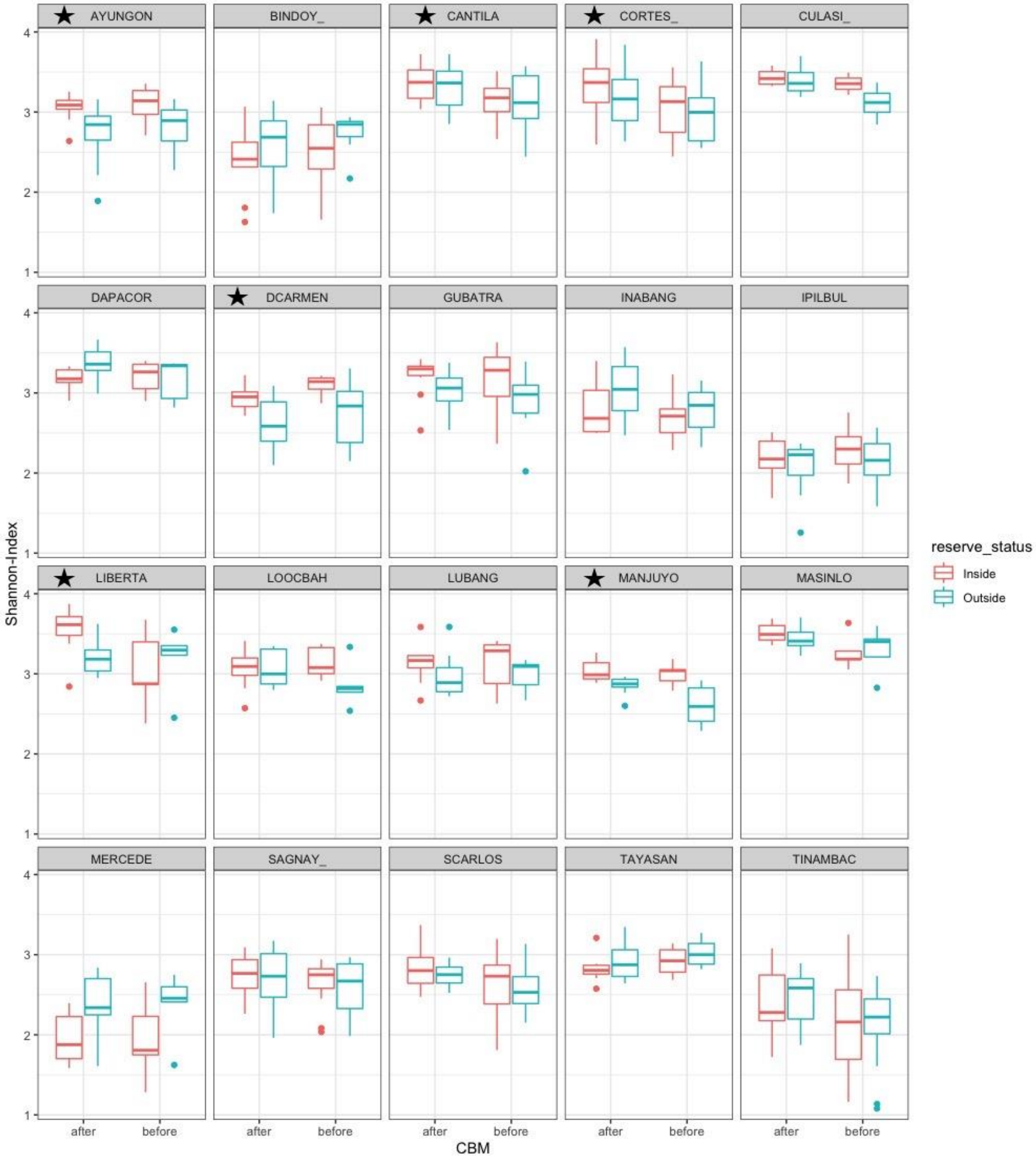

Figure 2.8 *Biodiversity Index*

Biodiversity Index inside and outside marine reserves before and after CBM. * indicates the interaction between CBM and reserve status at each site is $P < 0.05$

2.4 Discussion

Well-managed marine reserves in the Philippines have the potential to increase abundance of important species and biodiversity. Typically, when evaluating the indicators of success for marine reserves, age and size of the reserve are important (Halpern, 2003; Vandeperre et al., 2011). While many of the marine reserves at our study sites have been established for many years (x= 18 years; SD= 7.5), it is possible they had little enforcement and were considered “paper parks” (Campos and Aliño, 2008). It is likely that there was little effect on fish and fisheries from the marine reserves prior to the implementation of managed access and CBM governance structure in 2014. Other studies have demonstrated that reduction of fishing pressure can result in changes in fish communities, such as an increase of high trophic level fish after fishing effort was reduced (Graham et al., 2017). Our study found that when looking at site-specific community composition, shifts in community structure occurred inside the marine reserve after community-based management was implemented.

There are large numbers of reef fish that are important for small-scale fisheries in the Philippines contributing to differences in communities after CBM was implemented. Fishers rely on a wide variety of fish species, but fusiliers (*Casionidae*.), rabbitfish (*Siganidae*), and groupers (*Serranidae*) make up the top ten fished species at these sites (Fish Forever, 2020). Because of this, their increased abundance after CBM implementation, as was seen in our study, is significant to the communities who depend on them. One target species, the leopard coral grouper (*Plectropomus leopardus*), was previously listed as “Near-Threatened” by the International Union for Conservation of Nature (IUCN), citing population declines in the Philippines(Choat & Samoilys, 2018).

In our study, the leopard coral grouper did contribute to the dissimilarity between communities inside marine reserves before and after community-based management, though with mixed results. In Bindoy, groupers, such as *P. leopardus*, decreased in relative abundance inside marine reserves after CBM (0.55% contribution to dissimilarity), but in Looc, they increased in abundance (0.56% contribution to dissimilarity). *P. leopardus* increased in abundance inside marine reserves after CBM in other sites such as Cantilan and Tinambac as well (contributing to 0.61% and 1.12% respectively). Though the IUCN status has recently been updated to "Least Concern", populations are still declining, and effectively managed marine reserves may be key to their continued recovery, especially since groupers have smaller home ranges and their populations generally respond well to marine reserves (Kramer & Chapman, 1999; Lowe et al., 2003).

In addition to groupers increasing in abundance inside the marine reserve after CBM implementation, other families of fishes displayed interesting movements. For example, in Tinambac rabbitfish (*Siganidae*) and parrotfish (*Scaridae*) decreased in abundance outside of the reserve but showed relative increases inside the reserves. One explanation for this is that these fish are fished more heavily outside the reserve after CBM implementation. Another explanation is that fish leave fished areas and move into protected areas (Pittman et al., 2014). While this would appear as an increase of abundance inside the marine reserves, fish movement as opposed to fish reproduction is not a net increase of fish for the fishery. Though, the ability for fish to have refuge from fishing gives them a better chance for growth and reproduction in the future.

Biodiversity is typically used as an indicator of ecosystem health in relation to conservation, additionally, biodiversity is also correlated with higher catch and biomass, which is vital to small-scale fishers (Micheli et al., 2014). Marine reserves can assist in achieving both conservation and fishery goals if designed and enforced effectively (Cinner et al., 2020). While previous studies at the Fish Forever sites could not link the presence of the Fish Forever Pride Campaigns to increased biodiversity in marine reserves (Veríssimo, 2019), the implementation of community-based management investigated in this study does affect biodiversity in Philippine reefs. Overall, biodiversity increased after the implementation of CBM across all aggregated sites, which is a change from previous studies that did not find significant differences in biodiversity inside and outside marine reserves (Muallil et al., 2015). CBM at the sites in this study increased the effectiveness of the reserves and fostered higher biodiversity. A reason for this may be that Muallil et al. (2015) used one year of data (2012-2013), while our study uses a time series that allows for more time for populations to grow after fishing ceases. Additionally, our study tests biodiversity inside and outside marine reserves after CBM implementation, which occurred in 2014. Though, following the trends of the community structure analyses in this study, not all biodiversity indices increased significantly after the implementation of CBM for all sites. Our analyses reveal that sites do not all follow the same patterns, which leads to additional questions about why these fish communities differ.

In the Philippines, there are still instances of fishing occurring within marine reserves, which counteracts the ecological protections for the fish resulting in a lack of sustainability of the fishery (Muallil et al. 2014b). To increase the ecological function and protection of the reserves some suggest that marine reserves need to be larger (Muallil et al. 2014b). If community-based management does lead to reduced fishing pressure inside the marine reserves and more thoughtful fishing outside the marine reserves, we should expect greater biodiversity, abundance, and different fish communities. Our results suggest some sites performed better after CBM was implemented but not uniformly, approximately 30%. Some hypothesize that small marine reserves do not offer enough protection to impact fish community changes or biodiversity differences (Friedlander et al., 2017; Halpern, 2003), though the sites in our study that did show evidence of increase of biodiversity and abundance after community-based management were smaller reserves under 100 hectares. The sites that had a significant difference in biodiversity in the interaction between reserves and CBM ranged from 16 to 307ha in size. Even Tayasan, the smallest of the marine reserves at six hectares, and Gubat, a recently established marine reserve (in 2015), showed a significant change in community structure, showing increases of important fishery species, after CBM, which indicates that even small and recently established well-managed reserves can positively affect community structure for fisheries. It is also possible that some sites that did not show differences after CBM was implemented were already functioning and managed well prior to CBM. Of the sites where there were no community structure differences inside and outside reserves before CBM, 57% of them had differences after CBM. These sites indicate there is promise in well-designed CBM programs. Even though, the ‘after’ dataset only encompassed three years, previous studies have shown that marine reserve impacts are seen within one to three years of implementation (Halpern & Warner, 2002; Micheli et al., 2004). Longer timeframes of data may allow for representation in the data of fish reproduction, spill-over, and growth, as well as for rules to be fully established and enforced, which may result in future changes to community structure and biodiversity (Friedlander et al., 2017; Halpern et al., 2009; G. Russ & Alcala, 1996).

Coastal fisheries exist in a complex socio-ecological system that involves many factors that determine the success of a particular management regime, but two major factors are compliance with fishery regulations and availability of nursery habitat. We provide evidence that community-based management leads to ecological changes that could benefit fisheries in the Philippines. However, our study is limited in answering “why” communities respond differently to CBM. We intend to further explore precise reasons why CBM may not be effective across all communities and address other impacts on fish communities, abundance, and biodiversity to improve the function of CBM of marine reserves. For example, marine reserves tend to be more effective when there is higher compliance within CBM (R. Pollnac & Seara, 2011). Though, there are many other indicators that also lead to increases in abundance of fish and biodiversity in CBM marine reserves such as residential community size, individual perceptions of fish populations, alternative livelihoods, trust in the marine reserve, and high participation in decision making (R. B. Pollnac et al., 2001; Quintana et al., 2021). These socio-ecological factors are dynamic, each heavily linked to the next, creating challenges in identifying a singular predictor for CBM marine reserve success. Negative perceptions on fish populations may result in the belief that the marine reserve is failing, thus that CBM is not working and create a feedback loop resulting in fewer rules for the marine reserves (Quintana et al 2021). Additionally, external actors, such as fishers from other communities, may influence resources within the community fishing boundaries. Many municipalities in the Philippines have reported commercial fishers illegally fishing in municipal waters, who may have no regard nor knowledge of local regulations (Muallil, Mamauag, Cabral, et al., 2014). The presence of the commercial fishers may be impacting the success of these marine reserves to no fault of the local communities managing them. Future research will include interviewing fishers to clarify levels of compliance of regulations and what types of effects external commercial fishers have on the resources where CBM has not shown to have significant effects on fish biodiversity and community structure.

This study examined the fishery independent data in the context of marine reserves and the implementation of community-based management of those reserves. The implementation of these strategies does not necessarily result in compliance of the regulations. Additionally, marine reserves assessed in this study protect the near-shore reef, but not adjoining habitats. Many species of fish in this region, especially parrotfish and snappers, which are both commercially important species, undergo ontogenetic migration from nursery habitats onto the reef(Jones et al., 2010; Mumby, 2006; Nagelkerken et al., 2000; Unsworth et al., 2008). Mangroves and seagrasses provide much of that nursery habitat that many fish depend on (Honda et al., 2013). Mangroves have declined rapidly, with 80% percent loss in the Philippines in the last 100 years (Primavera, 2000). The loss of mangrove habitat has been linked to declines in fishery stock (Melana et al., 2005; Tran & Fischer, 2017), which may occur regardless of protection of reefs. Decline of mangroves may also negatively impact corals by the increase of turbidity and sedimentation on reefs (Manson et al., 2005). When the reef structure and nursery habitat is threatened, continued production of important fishery species can also be vulnerable (Manson et al., 2005). Additional research will examine the habitat availability and quality at these sites as part of the suite of variables that may contribute to why sites responded differently to CBM implementation.

Protecting coastal coral reef areas and managing fishing access through marine reserves are important steps in sustainability of fishery resources, however, if critical nursery habitat or habitat that provides ecological functions for corals is not protected, then the efforts of marine reserves may be in vain. Thus, small-scale fishery management through community-based management needs to fit into a broader social-ecological systems model, considering both the compliance of the fishing communities and the relationship of nursery habitats.

2.5 Conclusion

Fish communities have a high site fidelity, supporting the notion that marine reserves and fishery management strategies need to be evaluated by site. Our study highlights the importance of site level dynamics in the success of community-based management. While CBM implementation resulted in positive changes of biodiversity in 25% of the sites and fish community structure increasing from 65% to 85% of the sites, further research is needed to investigate the reasons why some sites successfully increased fish biodiversity and abundance and others did not. Understanding the variability across sites, enabling conditions, and drivers of success will promote better design and implementation of CBM marine reserves. We suggest that resource managers explore interactions occurring between social and ecological factors within reef fishing communities to tailor interventions for each locality and increase potential for success when implementing community-based management.

CHAPTER III – SPATIAL CHARACTERIZATION OF SOCIAL-ECOLOGICAL VARIABLES AND THEIR IMPACT ON REEF FISH

3.1 Introduction

Overfishing is a global crisis that requires management of stocks and ecosystems for people to continue to depend on marine living resources. While most fisheries management focuses on commercial fleets to reduce overfishing, “small-scale” fishing makes up a large portion of fish capture and is much more difficult to regulate (Pauly & Zeller, 2016). Globally, there are 50 million people who participate in small-scale fishing (FAO et al., 2023), and because this type of fishing is dispersive, with landings occurring in non-centralized locations, it is hard to use top-down fishery management techniques employed in commercial fishing (Brownman et al., 2004). The magnitude of impact from individual fishing activities may seem small in comparison to commercial fishing activities, but the combined impact of all individual artisanal fishers has a significant impact on ecosystems (Shester & Micheli, 2011).

Small-scale or artisanal fishers also tend to live in rural coastal areas, which means that they are uniquely vulnerable to collapsed fisheries and environmental change. The Philippines, a nation of more than 7,000 islands, has over 1.4 million small-scale fishers who are dependent on marine resources for food security and economic stability (FAO, 2018). Globally, small-scale fishing comprises 30% of marine fish capture (Pauly & Zeller, 2016). But in the Philippines, artisanal capture fisheries constitute nearly 50% of marine fish production (FAO, 2018). Loss of fishery resources through overfishing and habitat loss leaves small-scale fishers particularly vulnerable.

In order to address overfishing and support sustainable small-scale fishing practices, over 1,800 marine protected areas (MPAs), also referred to as marine reserves, were implemented by the government in the Philippines to provide protection for reef ecosystems and increase fish production (Cabral et al., 2014). However, less than 30% of these are managed effectively and international non-governmental organizations (NGOs) have worked with local communities in the Philippines to create community-based management of MPAs to improve their effectiveness. Chapter Two of this dissertation demonstrates that fish resources did improve at some sites after community-based management was implemented while others did not, raising questions about the external drivers of fish abundance and biodiversity within and around these marine reserves (Marriott et al., 2021). Protection measures of nearshore reef habitat may not be enough to promote fish population growth if nursery habitat, such as mangroves, is degraded. There is a complex relationship between mangrove ecosystems and reef ecosystems where fish benefit from the numerous ecosystem services that mangroves provide, such as shelter, food (Laegdsgaard & Johnson, 2001), migratory paths (Reis-Filho, 2016), filtration of water, and other services that may be less documented. But a 50-year-review of mangroves as fish habitat revealed there is a gap in the research on the interaction between structural or landscape parameters (such as edge habitat and total area of the mangroves) on fish populations (Faunce & Serafy, 2006). Understanding how fish abundance and biodiversity is coupled with spatial parameters of mangroves is critical to address, as habitat management becomes imperative to long-term survival of mangrove habitats that directly support fisheries.

3.1.1 Habitat Linkage

Mangrove habitat has been heavily modified and degraded by humans, resulting in different shapes of mangrove habitat (Figure 3.1). The loss of mangrove habitat (through deforestation or degradation) has been linked to declines in fishery stock (Tran & Fischer, 2017). Manson et al. (2005) calls for empirical work using spatial data for mangroves and fisheries data in order to understand the relationship between these systems. Protecting coastal coral reef areas and managing fishing access is an important step in resource governance. Marine reserves are socio-cultural features fixed in space but some of the organisms they are meant to protect are not beholden to boundaries. Therefore, if critical nursery habitat or habitat that provides ecological functions for reef ecosystems is not protected, then the MPAs may be in vain. This research aims to add to the knowledge on how socio-ecological factors, such as nursery habitat availability and land use, are drivers of biodiversity and fish abundance.

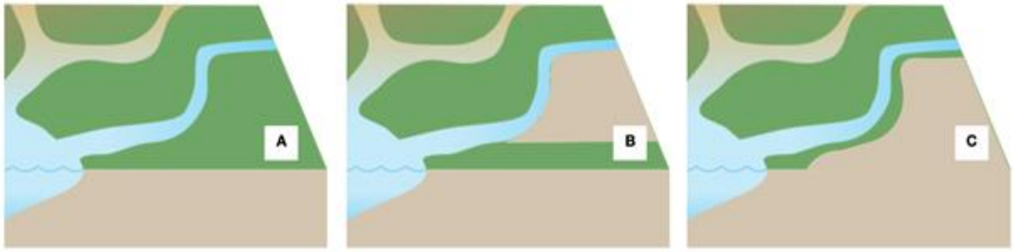

Figure 3.1 *Examples of shapes and sizes of mangrove edge and habitat on coastlines*

Green is mangrove, blue is water, and beige is deforested land. A) Natural mangrove habitat. B) Mangrove habitat that has a short edge but wide shape. C) Mangrove edge that is long but narrow. Courtesy of the Integration and Application Network

While MPAs and reduced fishing effort should benefit fish populations and biodiversity, the reefs are not closed systems. Mobile organisms, such as fish and spawned larvae, will move beyond the boundaries, temporarily for nursery habitat or migration, or permanently as part of their life history (Harmelin-Vivien et al., 2008; Moffitt et al., 2009; Planes et al., 2009; Roberts, 2001). Additionally, other land or sea uses can provide inputs into the system as well, such as excess sedimentation and nutrients from runoff that can impact overall coral reef health (Carlson et al., 2019; Duke & Wolanski, 2001). Adjacent habitat quality is important to MPAs because the regulatory framework of the protected areas do not currently protect areas that cover the entirety of the life cycle.

One of the most important adjacent habitats to tropical waters are mangrove forests, which have a special relationship with coral reefs. Not only do mangroves help keep offshore water oligotrophic to promote coral growth, but they also provide nursery habitats to fishes that spend their early years in this ecosystem before recruiting onto coral reefs (Mumby et al., 2004; Naylor et al., 2000). Deforestation is a major threat to mangrove, which reduce their functionality as nursery habitat and therefore may be linked to decrease in catch. For example, in the Philippines over 600 kg of fish catch is lost for every hectare of mangrove deforested (Melana et al., 2005). Decline of mangroves may also negatively impact corals by the increase of turbidity and sedimentation on reefs (Manson et al., 2005). When the reef structure and nursery habitat is threatened, continued production of important fishery species can also be vulnerable (Manson et al., 2005).

The transfer of fish biomass from mangrove areas to coral reefs creates links between these two habitats. Habitat linkages are an important feature of ecosystem management, but the role mangrove habitats play in the life history of reef fish can differ regionally. Therefore, the broader-scale impacts from damaging one type of habitat can be confounded when comparing across regions. Additionally, scientific studies on fish habitats can be species-specific, thus making encompassing management decisions from research in a different region led to less optimal results. However, even if the individual fish do not directly move from mangroves habitat to reefs, they benefit from the other ecological functions that mangroves provide, such as filtering excess nutrients and suspended sediments (Mumby, 2006). Understanding how these systems are connected is important for advancing science of marine reserve design.

3.1.2 Mangroves Nursery Habitat Is Declining

Mangroves are an important coastal tree species; there are 73 described species of mangroves that extend over 120 countries. Their geo-political range is large, but their worldwide geographical range is relatively small, covering only 150,000 km^2, and are declining at a rate of 0.2-2.0% globally (Mumby et al., 2004; Richards & Friess, 2016; Spalding et al., 2007). However, the rate of loss is regionally specific with some countries experiencing higher rates of loss than others. The Philippines is the sixth most mangrove-rich country in Asia and has approximately 2% of the global mangrove forest. Mangroves in the Philippines have been under threat with a drastic decline over the last 100 years (Giri et al., 2011). Between 1918 and 1994, 80% of mangrove forest was lost in the Philippines, mostly to aquaculture (Primavera, 2000).

However, the economic value of mangroves is beyond their weight in wood or land, through providing ecosystem services such as eco-tourism (Salam et al., 2000), flood protection worth $1 billion dollars in the Philippines (Menéndez et al., 2020), blue carbon finance worth over $17 million per year in the Philippines (Zeng et al., 2021), or nursery habitat worth $35,000 per hectare of edge habitat to fisheries in Mexico (Aburto-Oropeza et al., 2008). Valuation of mangrove habitat intact can be worth more than the converted lands. For example, in Indonesia, total ecosystem services of mangrove habitat were $4,000-8,000 per hectare versus $2,000-3,000 per hectare of shrimp aquaculture production (Malik et al., 2015). One of the major economic benefits of mangroves is the use of this habitat by fisheries species, given that over 20% of commercially important fish use mangrove habitat during some point of their life history (Abu El-Regal & Ibrahim, 2014; Aburto-Oropeza et al., 2008; Honda et al., 2013). While individual species may have varied relationships, some commercially important fish biomass doubled when mangrove were present (Mumby et al., 2004). A commercially fished parrotfish species, for example, was determined to be mangrove dependent in the juvenile stage, which has implications for reef health depending on the presence of connected mangroves (Mumby, 2006; Mumby et al., 2004). Thus, if there is an absence of mangrove habitat for this keystone reef species, there is potential for a decrease in grazing of algae on corals. Due to the link between mangroves and coral reefs, both for nursery habitat and providing ecosystem functions, the decline of mangroves may have negative impacts on fish biomass, catch, or diversity (Manson et al. 2005).

Mangrove edge habitat is defined by the area that is periodically inundated by water, which can vary by location due to tidal range. Edge habitat is what fish typically benefit from most directly, through underwater root structures to hide in for protection. Fish have been found to use this habitat regardless of the width of the mangrove stands (Dunbar et al., 2017). Additionally, the transfer of fishes between mangrove habitat and reef can be complex. As Halpern (2004) found, the density of mangrove-dependent reef fish was correlated to island-wide mangrove habitat, not local level distance of mangrove stands to the reef. Another study found that fish biodiversity is impacted by the shape and size of neighboring mangrove habitat (Tran and Fischer 2017). For the greatest ecological function, conserved or restored mangroves stands should be of a shape that resembles an unmodified forest (Figure 3.1A) (Lewis & Gilmore, 2007). Dunbar et al. (2017) identified that size and shape of habitats both may impact fish populations; however, their research focused solely on size and shape of inundated habitat, but not the extent of the landward habitat, which may exclude other ecosystem services that fish benefit from (other than physical swimming area). This chapter delineated the "edge" of the mangrove forest polygons by defining the boundary as the line of stable vegetation between open water and coastal wetland habitat.

3.1.3 Theoretical Framework

This chapter sits within my Social-Ecological Systems (SES) framework adapted from Ostrom (2009) (Figure 3.2). This framework breaks systems into four main subsystems, resource system, resource unit, governance, and users. Kittinger et al. (2013) call for systems thinking and connecting social and ecological systems in order to better understand how humans are impacting resources and vice versa. However, there is still a limited, though growing, body of empirical literature detailing how these complex interactions between society and ecology increase fishery production (Cinner et al., 2009; Colding & Barthel, 2019; R. Pollnac et al., 2010).

In the context of this chapter, I primarily researched the interactions between the resource system (coastal fishery), resource units (mangrove habitat, fish abundance, land use and other parameters) and governance (community-based management and MPAs). Nongovernmental organizations, such as Rare, have been implementing social-ecological programs in the form of community-based management schemes to address these complex interactions. The goal of this research is to empirically evaluate ecological interactions within small-scale fisheries.

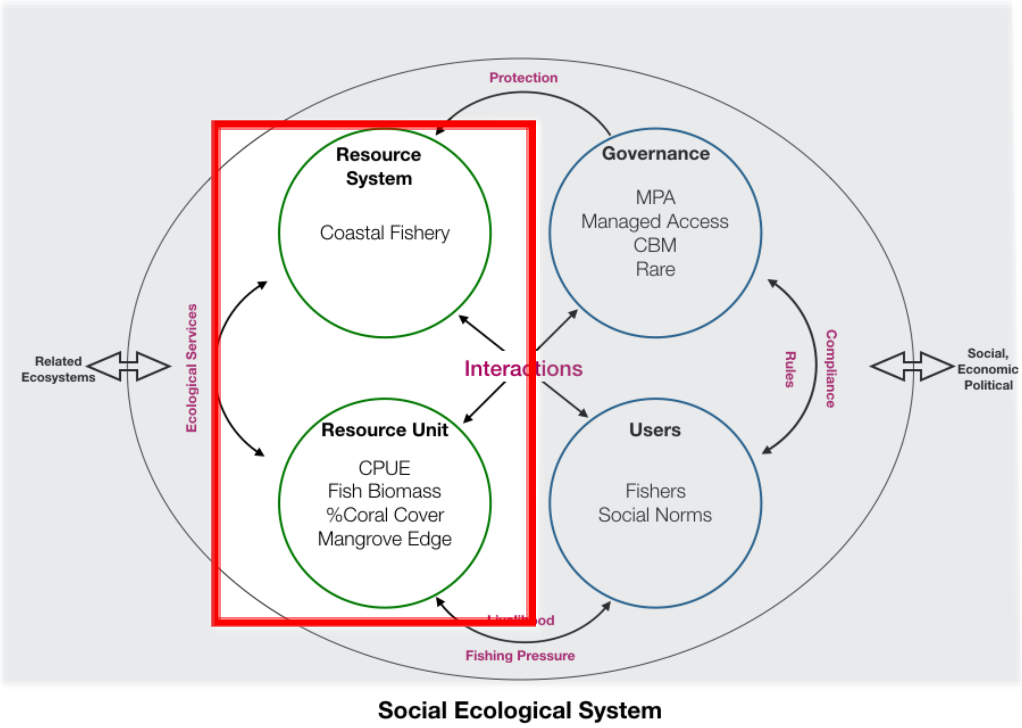

Figure 3.2 *Conceptual diagram of the social-ecological system described in this chapter outlined in red, with example parameters in each subsystem*

Adapted from Ostrom (2009).

3.2 Research Question and Hypothesis

R1: What is the relationship between the ratio of mangrove edge to area, population density, coral cover, and MPA characteristics and biodiversity?

R2: What is the relationship between the ratio of mangrove edge to area, population density, coral cover, and MPA characteristics and fish abundance?

R3: What is the relationship between the ratio of mangrove edge to area, population density, coral cover, and MPA characteristics and abundance of key fishery species?

I expect mangrove habitat to be an important driver in fish biodiversity, abundance, and abundance of important fishery species, especially in key fish species that are dependent on mangroves. Similarly, coral reef is an important habitat for these reef species and is associated with ecosystem health, therefore, I would expect that coral cover would have a positive relationship with my dependent variables. Additionally, I anticipate a negative relationship between my dependent variables and population density due to pollution and fishing pressure. Finally, I expect that for my MPA characteristics of age, size, and percent of protected area there to be a positive relationship with my dependent variables.

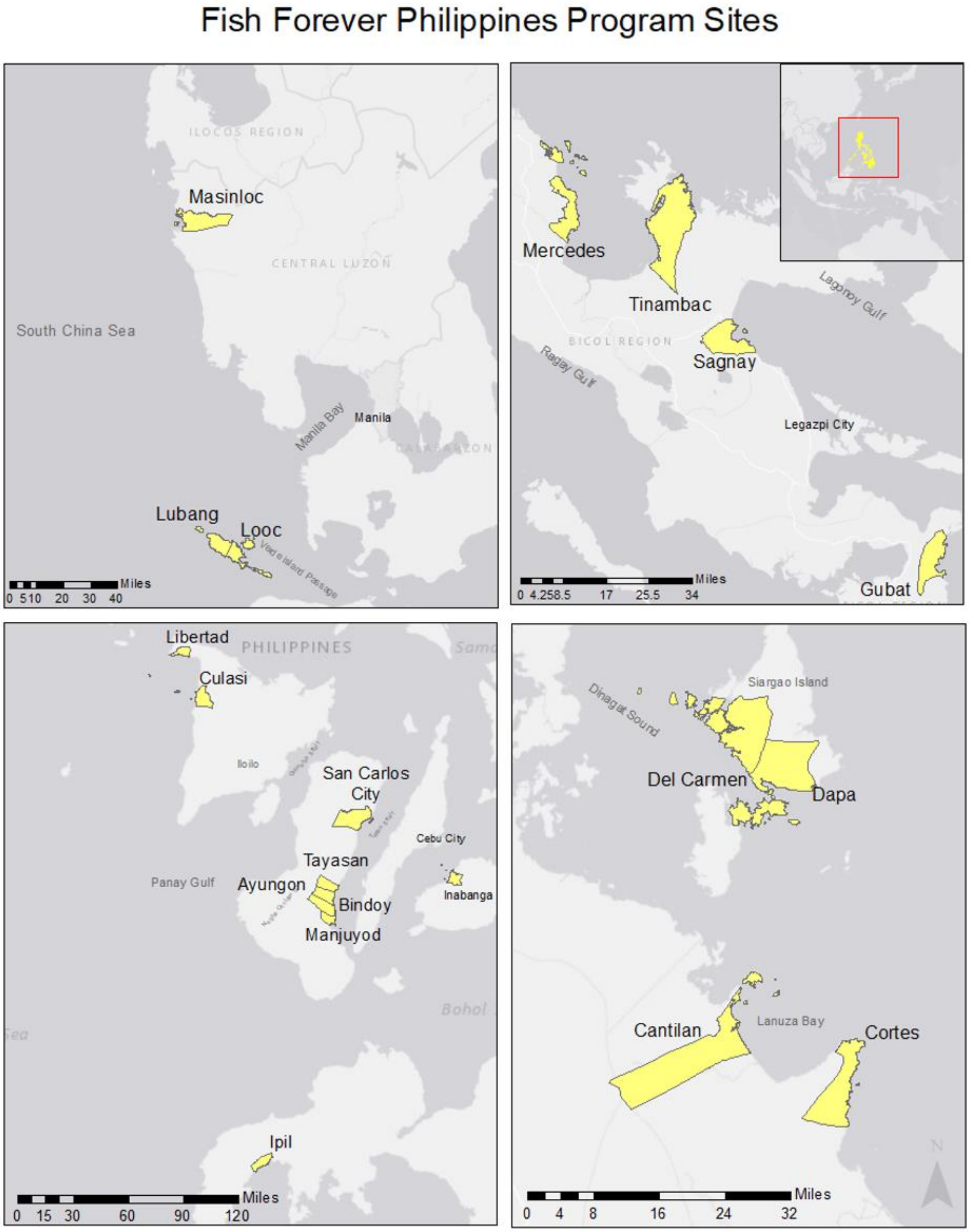

Figure 3.3 *Site Map of the 20 Fish Forever program sites*

Data Source: GADM, Spatial Reference: GCS WGS 1984

3.3 Methods

3.3.1 Site Description

The selected study sites in the Philippines are based on the Fish Forever Program by Rare (Figure 3.3). Starting in 2010, the program has intervened at the local level to implement community-based management governance strategies for their marine protected areas and fishery resources. In the Philippines, the government, NGOs, and local communities are using MPAs and managed access areas, such as the ones designed through Rare's Fish Forever Program, to increase the biomass of fish and thereby the catch for fishers.

The Philippines boasts some of the highest diversity in mangroves, including six species on the IUCN Red List of endangered species, and is a global area of concern due to the rapid decline of mangrove habitat (Polidoro et al., 2010). Mangroves in the Philippines under some estimates have approximately 19% of their habitat in protected areas, but the vast majority of those protected mangroves are localized to one island, which is not ecologically functional on a wider scale (Chape et al., 2005; Long & Giri, 2011). The Fish Forever sites vary widely size of mangrove forest. As of 2000, the range of site size varied between 2 ha to 3,900 ha, with a total of 8,768 ha (Figure 3.4). These 20 municipal areas represent about 3% of the country's total mangrove extent. Because some of these sites have a relatively small mangrove area, it is important to conserve the mangroves that are left, especially if they are found to contribute to the fishery.

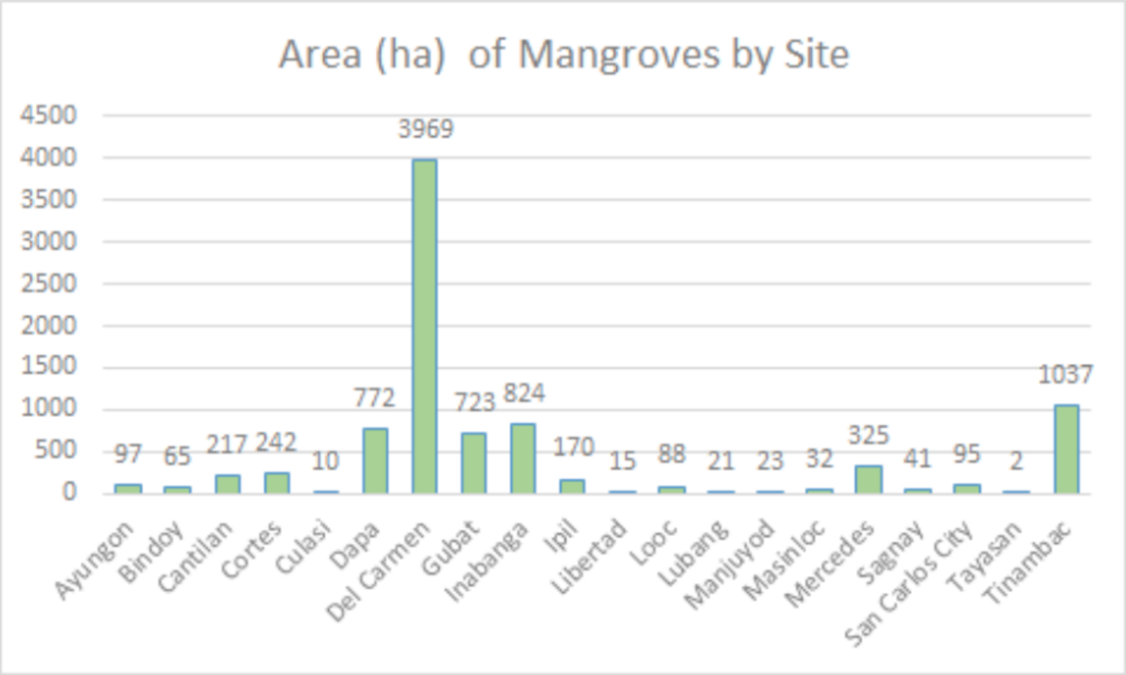

Figure 3.4 *Mangrove area by site. Mangrove area in hectares for all sites*

3.3.2 Data Collection and Description

This project draws on three main sources of data. *Fish survey data*: The Fish Forever Program provided visual survey data collected from 2011-2017. These data include visual fish surveys that contained species, length, and abundance (count per hectare) for 50 meter transects inside and outside marine protected areas in my study sites. Additionally, coral cover was surveyed throughout the Fish Forever Program. I included percent live coral cover for each site. For the year 2017, when fish surveys were conducted but coral surveys were not, I used the last available coral cover data from 2016. These data are collected nearshore, sited near municipalities that contain varying levels of mangrove habitat from 2-4,000 ha, and will be tested for proximity to habitat. *Geospatial data*: I gathered temporal mangrove data from Global Mangrove Watch from

2010 to 2017, pairing mangrove data with years that had fish survey data (Figure 3.5). I extracted mangrove area and perimeter within the boundaries of the municipality in which the site is located and within a radius of 20 miles of the site to represent local and broader-scale mangrove conditions. Both area of mangroves and linear perimeter of mangroves were extracted. I then created a mangrove habitat index, by dividing the perimeter by area to account for both collinearity and patchiness of habitat. For some years mangrove extent was not available, when necessary, I used data from 2010, the last available year for sites where there was abundance data collected in 2011, 2012 and 2013. There was a large typhoon in 2014 and due to the potential difference between 2013 and 2014, I used data from 2015, the next available year where there was abundance data collected in 2014. Area of the marine reserve, municipal waters, and percent protected were acquired from Rare's data. *Census data*: Lastly, population density was taken from census data. Population density information was only available for 2010, 2015, and 2020 so a logistic regression was fit for each site and values were calculated for each year to match the fisheries survey.

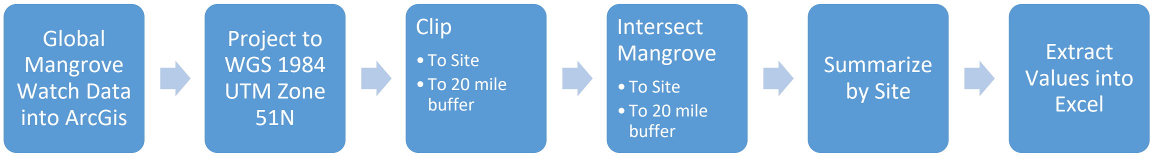

Figure 3.5 *ArcGIS workflow for mangrove data extraction*

3.3.3 Analysis

Rare collected transect level data on species, length, and number, from visual fish count surveys. I aggregated the transect data to get site level abundance, which was count per hectare. A Shannon-Wiener index was applied to the transects, prior to aggregating, and an average biodiversity index for the site-level was calculated. Additionally, I separately analyzed the combined abundance of families of fish that are important to artisanal fisheries in my study sites: *Lutjanidae, Mullidae, Epinephelinae*, and *Carangidae,* which are found to use mangrove habitat in their life cycle (Honda et al., 2013). Urbanized area, using population density as a proxy, was included as an independent variable because many of the sites are devoid of mangrove habitat due to anthropogenic impact. MPA size, MPA age, and percent of site area protected were taken from site information and percent of live coral cover was taken from habitat surveys conducted by Rare.

To test for collinearity, I applied a correlation matrix to my independent variables (Figure 3.6). The area of the mangrove was strongly correlated (R2 = 0.89) to the perimeter of the mangroves within a site and the area of the marine reserve was strongly correlated to the percent protected (R2 = 0.88). Mangrove perimeter and area were originally chosen to answer different questions; perimeter is a proxy area available for direct fish usage, while area is a proxy for the extent to which a mangrove stand can provide ecosystem services such as nutrient load reduction, which affects fish in a different way. However, because of the collinearity, I created a mangrove habitat index by dividing the perimeter by the area for both mangroves within the site and within 20 miles of the site. This ratio also accounts for the potential patchiness of habitats that may result in lots of edge habitat but very little mangrove area. When the number is larger, edge is more important than area, and when the number is small, area is more important than edge. I then removed the individual mangrove perimeter and area variables. I chose to leave both marine reserve area and percent of area protected within the model because I wanted to know if absolute area was more influential than relative area to fishing grounds.

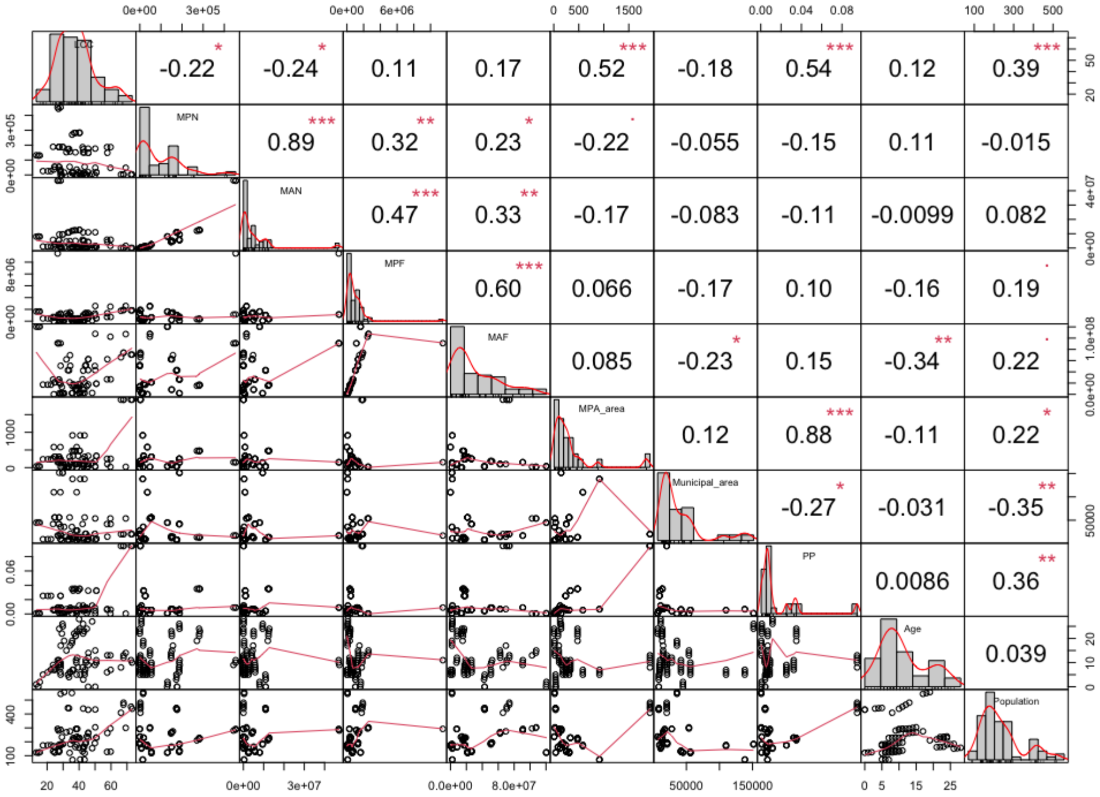

Figure 3.6 *Correlation Matrix of variables including a scatterplot, histogram, and correlation*

* Indicate significance. LCC = percent live coral coverage MPN = perimeter of mangroves within a site MAN = area of mangroves within a site MPF = perimeter of mangroves within 20 miles of a site MAF = area of mangroves within 20 miles of a site MPA_Area= the area of the marine reserve Municipal_Area = the area of municipal waters PP= the percent of municipal waters that are under protection of a marine reserve Age = the age of the marine reserve in 2017 Population = the population density

I subsequently evaluated the relationships between biodiversity, fish abundance, and abundance of fishery species with my ecological, social, and spatial variable using a general additive model (GAM). General additive models have been used in numerous fisheries applications to uncover environmental influence on fish (Jowett & Davey, 2007; Murase et al., 2009; Swartzman et al., 1992; Walsh & Kleiber, 2001). GAMs use a smoothing function that allows for non-linear relationships to present themselves, which is useful in my dataset where there are many factors contributing to the relationship. Three GAMs were built using all fish abundance, biodiversity (Shannon-Wiener Index values), and important fishery species abundance as the dependent variables, and distance between mangroves and reef, length of mangrove edge, the area of the mangrove stand, MPA area, age of MPA, area of municipal waters, percent of municipal waters protected, population density, and percent live coral cover as independent variables (Table 3.1).

Table 3.1 *Variables and Data Sources*

Covariate (code)	***Description***	***Data Source***
Mangrove habitat index near (MIN)	Perimeter *(m)*/ Area *(m^2)* within the site boundaries	GMW
Mangrove habitat index far (MIF)	Perimeter *(m)*/ Area *(m^2)* within 20 miles of the site boundaries	GMW
Population density *(people/km^2)* (Population)	Proxy for anthropogenic impact	Census Data
MPA size *(ha)* (MPA_Area)	MPA area	Rare Data
MPA age *(years)* (Age)	Age of the MPA as of 2017	Rare Data
Percent of protected area *(%)* (PP)	Percent of municipal waters within an MPA	Calculated
Area of municipal water *(ha)* (Municipal_Area)	Fished area	Rare Data
Percent live coral cover *(%)* (LCC)	Reef habitat quality	Rare Data

GMW = Global Mangrove Watch

Each independent variable was tested separately in a one-factor model to determine the amount of deviance explained, which indicates how influential a variable is on the dependent variable, the significance, and Akaike Information Criterion (AIC) (Table 3.2). This information was used to then develop a stepwise GAM model where the order of adding variables was determined by the amount of deviation explained. Only variables that were significant to the 0.10 level were included in the stepwise model. I used an alpha equal to 0.10 because of the uncertainty within my data itself, especially regarding the loss of information due to aggregating everything to the year level.

Using a forward stepwise process within the GAMs, I identified and selected the best predictors (Solanki et al., 2017). The AIC was used to compare models, the model with the lowest AIC was selected as the relative best for prediction. The main drivers of abundance and biodiversity were tested by identifying the importance of each variable. The importance of each individual variable was determined by assessing the significance values of parametric and smoothing terms within the GAM output.

To ensure there was no autocorrelation or effect based on time, I simultaneously ran general additive mixed models using year as a random factor. I then compared the AIC of the assemblage of models and determined the GAM models without year were best for prediction.

Table 3.2 *Model Parameters*

Variable	Deviance Explained %	AIC	P value	edf	Rank
Biodiversity					
s(MIN)	14.8	63.65	<0.05	3.7	7
s(MIF)	24.1	74.67	<0.0001	2.90	3
s(PP)	24.4	59.51	<0.0001	0.99	2
s(MPA_Area)	18.2	67.35	<0.0001	1.7	4
s(Age)	15.9	71.23	<0.01	2.54	5
s(LCC_all)	31	54.11	<0.0001	1.96	1
s(Population)	15.7	70.57	<0.01	2.1	6
s(Municipal_area)	7.56	75.56	<0.05	0.86	8
Fish Abundance					
s(MIN)	2.16	1716.56	>0.05	1.0	-
s(MIF)	0.076	1714.86	>0.05	1.0	-
s(PP)	27.4	1694.42	<0.0001	2.85	1
s(MPA_Area)	5.23	1711.84	<0.0001	0.78	5
s(Age)	4.87	1713.79	>0.05	1.6	-
s(LCC_all)	11.7	1712.09	<0.1	3.76	3
s(Population)	9.81	1710.2	<0.05	1.97	4
s(Municipal_Area)	16.7	1704	<0.01	2.07	2
Fishery Abundance					
s(MIN)	11.5	982.86	<0.01	1.87	5
s(MIF)	14.5	980.19	<0.01	1.94	4
s(PP)	23.1	971.55	<0.0001	1.92	2
s(MPA_Area)	25.3	970.67	<0.0001	2.64	1
s(Age)	2.01	989.89	>0.05	1.28	-
s(LCC_all)	6.8	986.90	<0.1	1.81	6
s(Population)	12.5	987.71	>0.05	4.75	-
s(Municipal_Area)	20.8	975.77	<0.001	2.82	3

This table describes the parameters of explained deviance, AIC value, P value, effective degree of freedom (edf) and Rank based on the deviance explained of the independent variables for each dependent variable (biodiversity, fish abundance, fishery abundance) in the model. LCC = percent live coral coverage, MIN = mangrove habitat index within a site, MIF = mangrove habitat index within 20 miles of a site, MPA_Area= the area of the marine reserve, Municipal_Area = the area of municipal waters, PP= the percent of municipal waters that are under protection of a marine reserve, Age = the age of the marine reserve in 2017, Population = the population density

3.4 Results

3.4.1 Biodiversity

For biodiversity, percent of protected area (24.4% deviance explained; $P < 0.0001$) and percent of live coral cover (31% deviance explained; $P < 0.0001$) were influential variables for predicting biodiversity, both having a negative relationship (Table 3.2; Figure 3.7). When only looking at individual variables, the effect on biodiversity is complex. The mangrove habitat index within the 20-mile radius explained more of the deviance (24.1% deviance explained; $P < 0.001$) than the index within the site (14.8% deviance explained; $P < 0.05$). For mangrove habitat within 20-miles, there is a negative parabolic curve, where area is more important for biodiversity initially, but then after a certain threshold it changes, and edge becomes more important. Mangrove habitat within the site appeared to have the opposite effect where edge is initially more important than area to a certain threshold and then turns negative, indicating the increased importance of area habitat. Additionally, biodiversity declined with age of reserve (15.9% deviance explained; $P < 0.01$) initially, but then increased as age increased.

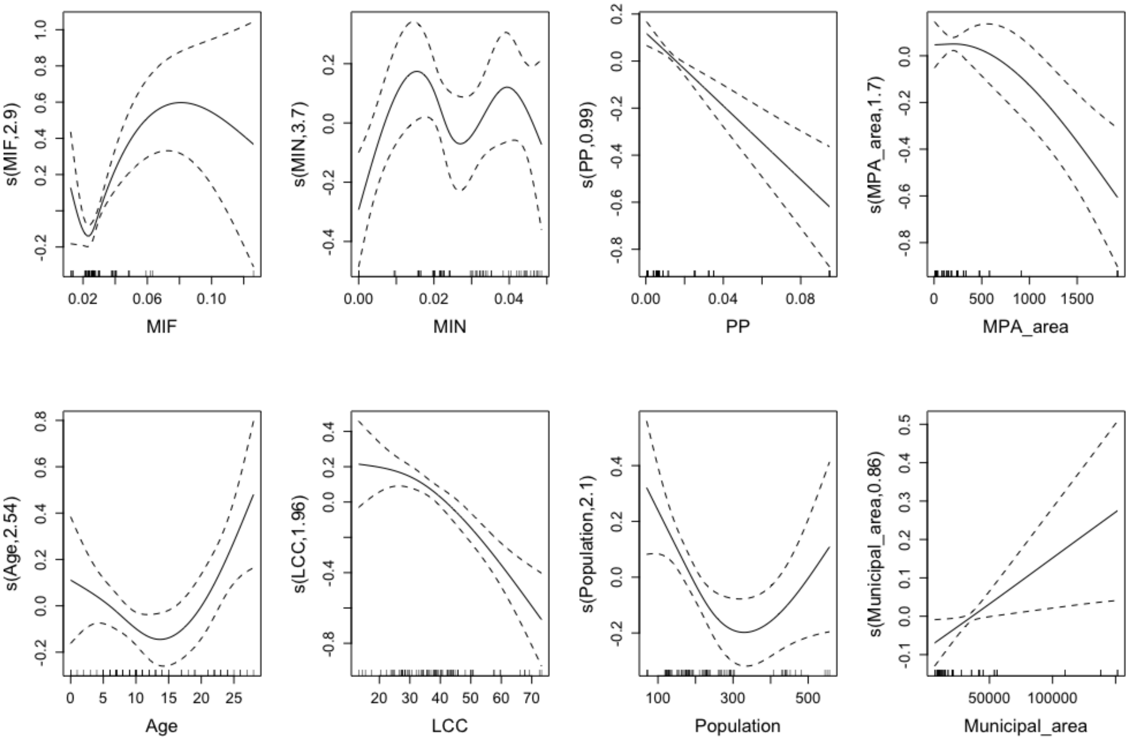

Figure 3.7 *One-factor GAM plots for biodiversity*

LCC = percent live coral coverage, MIN = mangrove habitat index within a site, MIF = mangrove habitat index within 20 miles of a site, MPA_Area= the area of the marine reserve, Municipal_Area = the area of municipal waters, PP= the percent of municipal waters that are under protection of a marine reserve, Age = the age of the marine reserve in 2017, Population = the population density.

All of the variables were significant predictors for biodiversity and were included in the stepwise process. After the stepwise models were developed (Table 3.3), Model 9 (deviance explained = 89.9%; AIC = -72.0; df =18.73; Figure 3.8) had the lowest AIC value, and was chosen as the best model:

biodiversity ~ s(PP) + s(MIF) + s(MPA_Area) + s(Age) + s(MIN) + s(Municipal_area)

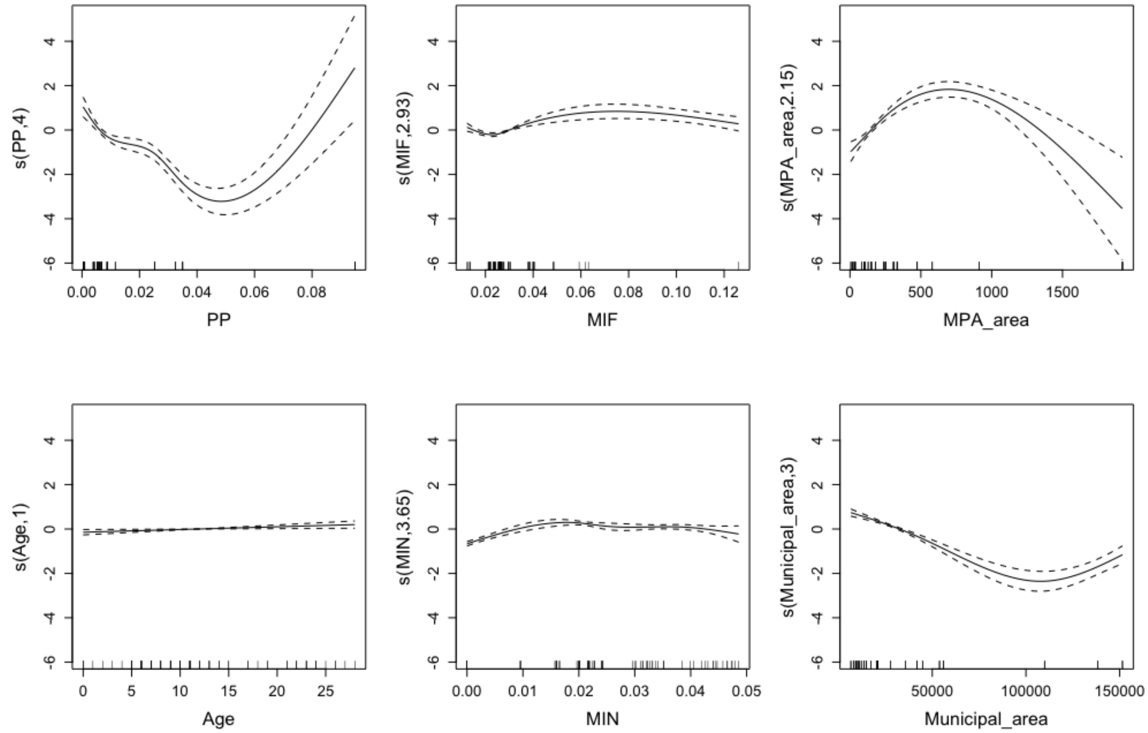

Figure 3.8 *Model 9 GAM plots for biodiversity*

LCC = percent live coral coverage, MIN = mangrove habitat index within a site, MIF = mangrove habitat index within 20 miles of a site, MPA_Area= the area of the marine reserve, Municipal_Area = the area of municipal waters, PP= the percent of municipal waters that are under protection of a marine reserve, Age = the age of the marine reserve in 2017, Population = the population density.

Table 3.3 *Biodiversity Stepwise GAM Model Development*

Model	Biodiversity	Deviance Explained %	AIC	R^2	df
1	s(LCC)	31	54.11	0.29	3.96
2	s(LCC) + s(PP)	34.2	50.9	0.323	4.3
3	s(LCC) + s(PP) + s(MIF)	43.7	41.77	0.407	6.03
4	s(LCC) + s(PP) + s(MIF) + s(MPA_Area)	43.9	42.52	0.405	6.6
5	s(LCC) + s(PP) + s(MIF) + s(MPA_Area) +s(Age)	48.9	38.25	0.446	8.18
6	s(LCC) + s(PP) + s(MIF) + s(MPA_Area) +s(Age) + s(Population)	64.1	18.06	0.587	12.37
7	s(LCC) + s(PP) + s(MIF) + s(MPA_Area) +s(Age) + s(Population) + s(MIN)	82	-21.45	0.766	20..72
8	s(LCC) + s(PP) + s(MIF) + s(MPA_Area) +s(Age) + s(Population) + s(MIN) + s(Municipal_area)	90.6	-69.95	0.873	22.54
9	**s(PP) + s(MIF) + s(MPA_Area) +s(Age) + s(MIN) + s(Municipal_area)**	**89.9**	**-72**	**0.872**	**18.73**

LCC = percent live coral coverage, MIN = mangrove habitat index within a site, MIF = mangrove habitat index within 20 miles of a site, MPA_Area= the area of the marine reserve, Municipal_Area = the area of municipal waters, PP= the percent of municipal waters that are under protection of a marine reserve, Age = the age of the marine reserve in 2017, Population = the population density, df= degrees of freedom, AIC = Akaike information criterion

The variables in Model 9 influenced biodiversity differently than when looked at individually. For example, both near and far mangrove habitat's relationship was flattened, indicating that both area and edge of the mangroves are equally important. While municipal area had a positive relationship in the one-factor models, in the final model, it had a negative relationship with biodiversity. Area of the reserve had a positive parabolic relationship with biodiversity within the aggregate model, while it was a negative relationship in the individual model. In both cases, the strong slope positive or negative could be influenced based on a single datapoint, so the relationship is likely less strongly correlated than it appears. Age of the reserve also had a slight positive or flat relationship with biodiversity as age increased.

3.4.2 Fish Abundance

With fish abundance, the percentage of area protected within municipal waters explained the highest amount of deviance (27.4%; $P < 0.0001$), where fish abundance increased with increase of the percent of protected area until it leveled off. Area of municipal waters was also an influential parameter with 16.7% of deviance explained ($P < 0.01$), where fish abundance decreases with an increase of municipal waters initially up to the point when the relationship with large municipal areas turned positive (Figure 3.9). Neither of the mangrove habitat variables, within the site or within 20-miles, were significant when evaluated individually. Age of the reserve was also not significant when analyzed individually, therefore, all three variables were removed from the stepwise GAM model (Table 3.4).

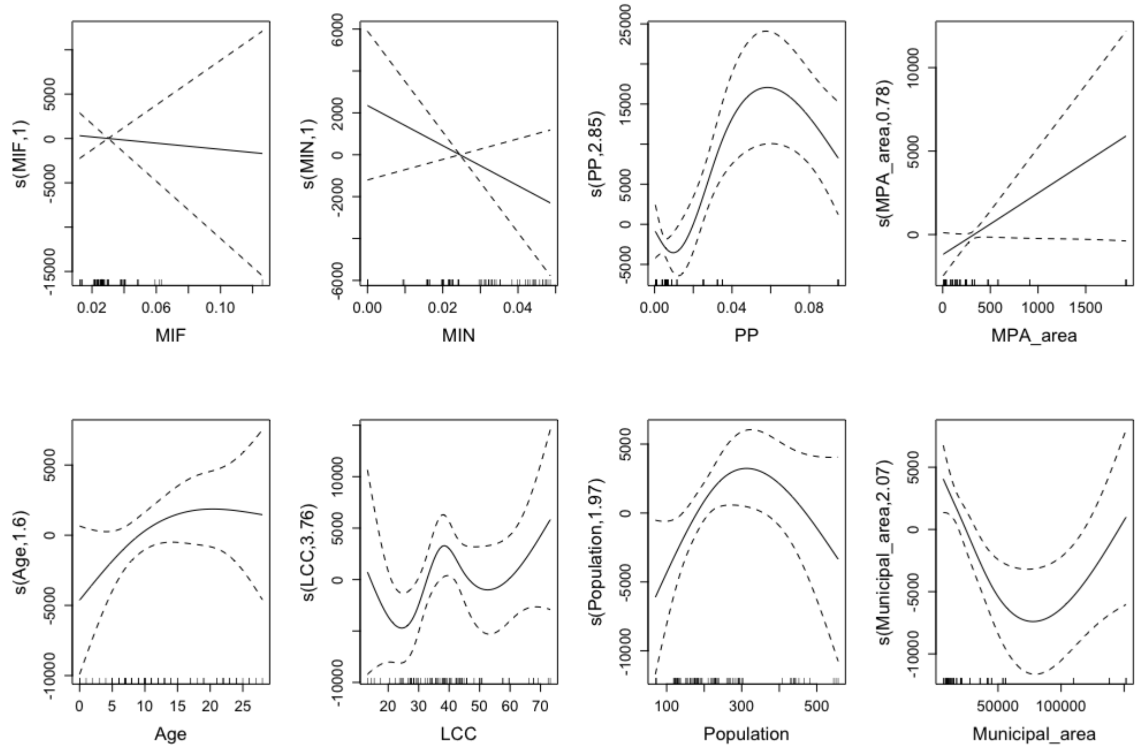

Figure 3.9 *One-factor GAM for fish abundance*

LCC = percent live coral coverage, MIN = mangrove habitat index within a site, MIF = mangrove habitat index within 20 miles of a site, MPA_Area= the area of the marine reserve, Municipal_Area = the area of municipal waters, PP= the percent of municipal waters that are under protection of a marine reserve, Age = the age of the marine reserve in 2017, Population = the population density.

Both Models 4 and 5 resulted in the same AIC value, and so Model 4 was chosen for the best model because the additional variable did not contribute to bettering the model. Model 4 (deviance explained = 44.9%; AIC = 1687.92; df = 12.80; Figure 3.10): fish abundance ~ s(PP) + s(Municipal_area) + s(LCC) + s(Population)

Table 3.4 *Fish Abundance Stepwise GAM Model Development*

Model	Fish Abundance	Deviance Explained %	AIC	R2	df
1	s(PP)	27.4	1694.42	0.25	2.85
2	s(PP) + s(Municipal_area)	36.8	1689.79	0.31	8.25
3	s(PP) + s(Municipal_area) + s(LCC)	37.3	1691.46	0.31	9.29
4	**s(PP) + s(Municipal_area) + s(LCC) + s(population)**	**44.9**	**1687.92**	**0.36**	**12.799**
5	s(PP) + s(Municipal_area) + s(LCC) + s(population) + s(MPA_Area)	44.9	1687.82	0.363	12.799

LCC = percent live coral coverage, Municipal_Area = the area of municipal waters, PP= the percent of municipal waters that are under protection of a marine reserve, Age = the age of the marine reserve in 2017, Population = the population density, df= degrees of freedom, AIC = Akaike information criterion

In Model 4, percent of the protected area had a strong positive relationship. Population density also had a positive relationship with fish abundance and then decreased with very dense populations. Mangrove habitat did not contribute to this model, while low live coral cover has a negative relationship with abundance, increased coral cover increases abundance and then declines again in high coral cover. This could also be due to bias in how fish surveys are conducted, where areas of high coral cover are harder to see and identify fish.

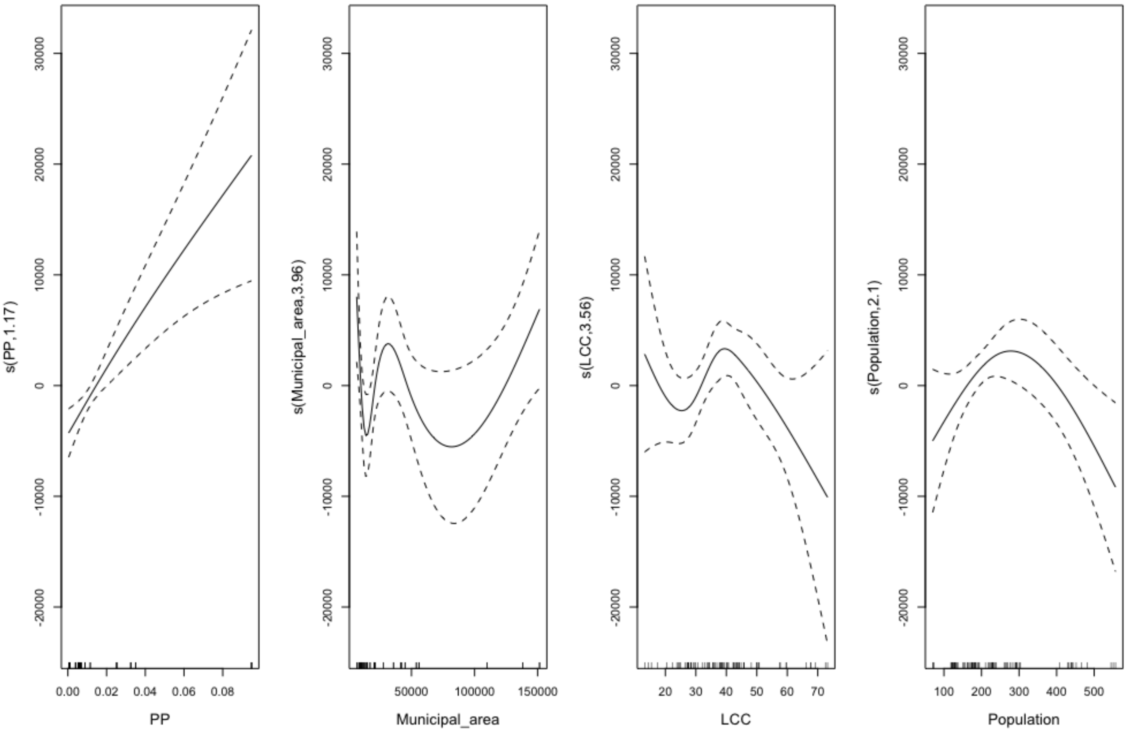

Figure 3.10 *Model 4 GAM plots for fish abundance*

LCC = percent live coral coverage, MIN = mangrove habitat index within a site, MIF = mangrove habitat index within 20 miles of a site, MPA_Area= the area of the marine reserve, Municipal_Area = the area of municipal waters, PP= the percent of municipal waters that are under protection of a marine reserve, Age = the age of the marine reserve in 2017, Population = the population density.

3.4.3 Key Fisheries Species Abundance

Then abundance of species important to artisanal fisheries within Rare sites was disaggregated from overall abundance. These included any species within the following families or subfamilies: *Lutjanidae, Mullidae, Epinephelinae,* and *Carangidae*, all of which have mangrove dependent species. Area of the reserve explained the most deviance (25.3%; $P < 0.0001$; Table 3.2). There was a positive relationship between key fisheries species abundance and size of the reserve (Figure 3.11). The percent of protected area also had a strong influence on abundance with approximately 23.1% of the deviance explained (P < 0.0001). Of the mangrove variables, mangrove habitat within 20-miles from the site had the most influence over key fisheries abundance (14.5% of deviance explained; P<0.01) and increased as the habitat index increased, meaning edge of mangrove was more important, before leveling off. Mangrove habitat within the site of the site (11.5% deviance explained; P < 0.01) is related to an initial decline in important fisheries species and then an increase.

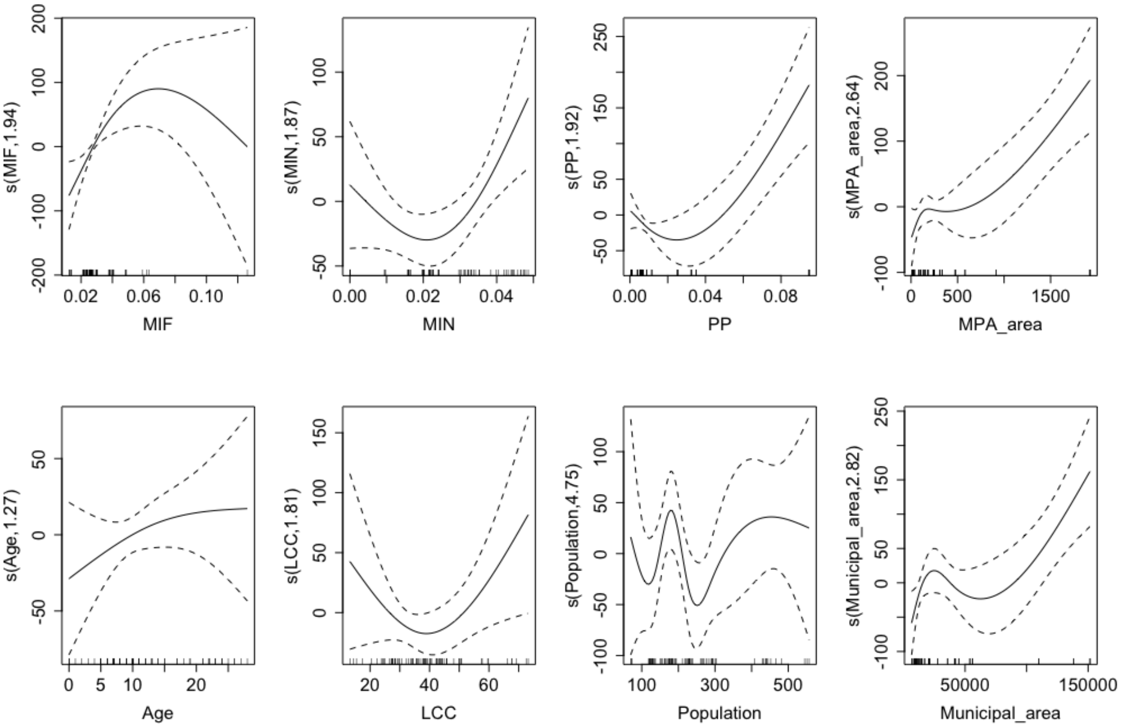

Figure 3.11 *One-factor GAM models for key fished species abundance*

LCC = percent live coral coverage, MIN = mangrove habitat index within a site, MIF = mangrove habitat index within 20 miles of a site, MPA_Area= the area of the marine reserve, Municipal_Area = the area of municipal waters, PP= the percent of municipal waters that are under protection of a marine reserve, Age = the age of the marine reserve in 2017, Population = the population density.

Two variables, population density and age of the reserve, were removed from the stepwise GAM because they were not significant individually (Table 3.5). The best model to come out of the stepwise process was Model 6 (deviance explained = 57.8; AIC =936.43; df = 10.65):

key_fishery_abundance ~ s(MPA_area) + s(PP) + s(Municipal_area) + s(MIF) + s(MIN) + s(LCC)

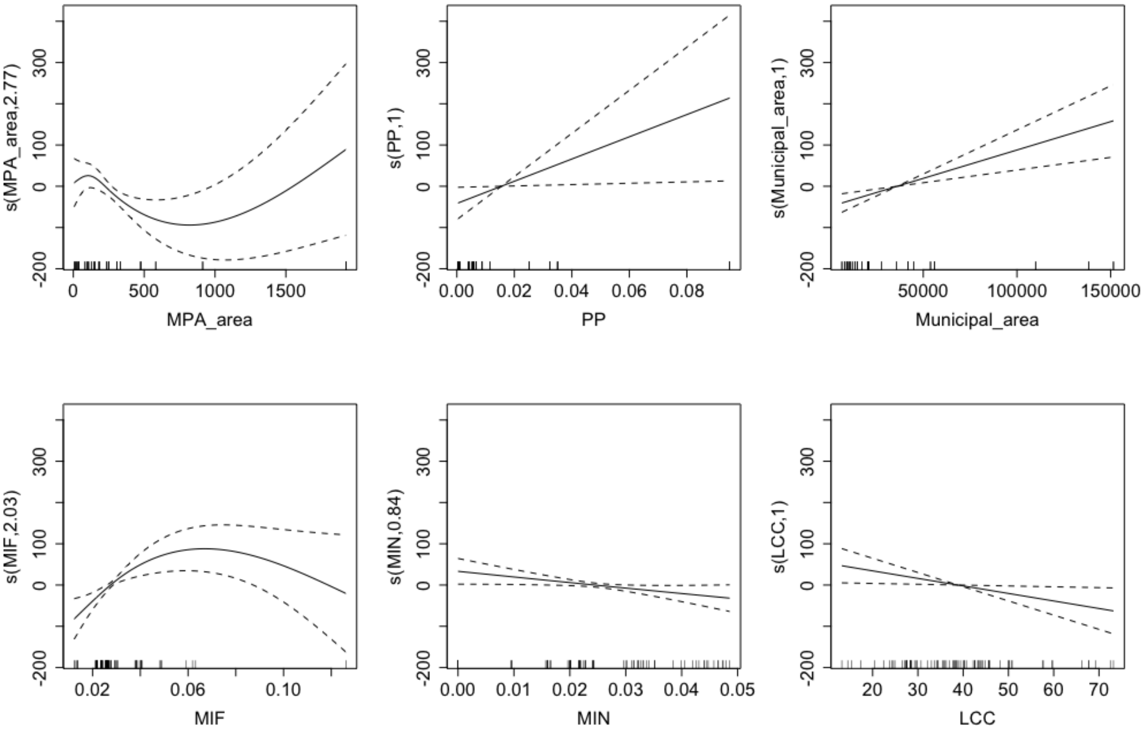

Figure 3.12 *GAM plots for Model 6 fishery abundance*

LCC = percent live coral coverage, MIN = mangrove habitat index within a site, MIF = mangrove habitat index within 20 miles of a site, MPA_Area= the area of the marine reserve, Municipal_Area = the area of municipal waters, PP= the percent of municipal waters that are under protection of a marine reserve, Age = the age of the marine reserve in 2017, Population = the population density.

Table 3.5 *Stepwise GAM model building for fishery abundance*

Model	Fishery Abundance	Deviance Explained %	AIC	R2	df
1	s(MPA_area)	25.3	970.67	0.227	4.63
2	s(MPA_area) +s(PP)	41.6	957.18	0.37	7.87
3	s(MPA_area) + s(PP) + s(Municipal_Area)	44.6	950.86	0.41	6.83
4	s(MPA_area) + s(PP) + s(Municipal_Area) + s(MIF)	50.6	945.21	0.46	8.7
5	s(MPA_area) + s(PP) + s(Municipal_area) + s(MIF) + s(MIN)	54.7	940.12	0.5	9.67
6	**s(MPA_area) + s(PP) + s(Municipal_area) + s(MIF) + s(MIN) + s(LCC)**	**57.8**	**936.43**	**0.53**	**10.65**

LCC = percent live coral coverage, MIN = mangrove habitat index within a site, MIF = mangrove habitat index within 20 miles of a site, MPA_Area= the area of the marine reserve, Municipal_Area = the area of municipal waters, PP= the percent of municipal waters that are under protection of a marine reserve, Age = the age of the marine reserve in 2017, Population = the population density, df= degrees of freedom, AIC = Akaike information criterion

In Model 6, percent of the area protected showed a relationship of increasing key fisheries species when the percent of protected area increased (Figure 3.12). However, the area of the reserve itself had a negative relationship with key fisheries species abundance, indicating that the size itself may not be as important as the relationship of the size to the fishing area. The mangrove habitat within the 20-mile radius had an asymptotic relationship with key fisheries species, while mangrove habitat within the site was slightly negative. Within 20-miles of the site, high abundance of key fished species is related to an increased importance of edge habitat.

3.5 Discussion

This chapter evaluated the relationships between biodiversity, fish abundance, and key fisheries species abundance with the ratio of mangrove edge to area, population density, coral cover, and MPA characteristics. Each dependent variable evaluated had different predictors that were most influential and, in some cases, responded differently to the same independent variables. For example, increasing the area of reserves has been a common recommendation in order to increase protections for fish communities (Allison et al., 1998; Claudet et al., 2008; Vandeperre et al., 2011). My model for biodiversity indicated that reserve size may have a positive impact on biodiversity up to a certain threshold. Halpern (2003) found that the effect of the reserve was independent of reserve size and the relationship does pull negatively at large reserve sizes, though that may be due to the influence of a singular datapoint. Similarly, key fishery abundance also has a slight positive relationship with MPA area and then turned negative. This may be due to the differences in life history of those four families of fish, where MPAs typically benefit animals with small home ranges, fish included in the model, such as jacks and mullet are more mobile (Hilborn et al., 2004; Vandeperre et al., 2011). Additionally, while the fish chosen are found in the reef habitats, were picked due to their life histories of migrating two and from mangrove habitat, meaning they become vulnerable to fishing when they leave the protected area. Alternatively, it may be because larger reserves could be more difficult to enforce, resulting in less compliance and more violations of the marine reserve (Wilhelm et al., 2014), though none of these reserves would be considered "large scale." This would show up as an impact more on fishery species than overall abundance or biodiversity, which may still be protected with larger reserves. Implementing large marine reserves may cause harm to fishers' livelihoods by reducing the area that they are legally allowed to fish in (Mascia et al., 2010; Ovando et al., 2016), however, networks of smaller marine reserves may offer a balance by providing good protection for marine species and space for fishers to continue to support themselves (Rolim et al., 2019). Overall, one size does not fit all in regards to marine reserves; while they do have an impact on fish abundance, site specific factors influence the magnitude of the impact (Eddy et al., 2014; Samoilys et al., 2007), therefore reserves should be designed with intention and sufficient social-ecological knowledge for the specific location.

However, the percent of protected marine area relative to the area of municipal waters had a positive relationship with abundance of fish overall and key fisheries species, indicating that the raw size of the protected area may be less important than the percentage of protected to fished area. The percent area protected at my study sites ranged from 0.04% to 9.5%, all falling short of the Aichi Biodiversity Target 11 of protecting 10% of coastal marine areas (CBD, 2011). Implementing marine reserves in the future should take into consideration the unique features of a community and should be designed to cover a percentage of the fished area, rather than designating an ideal size. Ipil was the site that had the highest percentage of municipal waters in marine reserve (9.5%). That site also showed there was interactions with the implementation of community-based management and had differences in fish community structure before and after versus a site like Libertad which only has 0.04% of their municipal waters under protection and did not show any differences with community-based management (Marriott et al., 2021). Getting certain percentages of protection has been a target of a variety of international conventions. Aichi Biodiversity Targets called for 10% of coastal marine areas to be protected by 2020 and as of 2022, the United Nations has agreed on a measure to protect 30% of land and sea by 2030 (Ainsworth, 2022; Einhorn, 2022). The Philippines also designates in their Fisheries Code that 15% of municipal waters is under some form of protection (Fisheries Code, 1998). Understanding the impact of marine reserves on a local level and designing those reserves bespoke to a region is imperative to achieving future targets. While protecting 30% of a local community's fished area may be unrealistic or harmful to fishing communities, reaching 10% protection may provide benefits to fishers as well as fish abundance (Cinner et al., 2014; Mascia et al., 2010).

Population density had an initially positive relationship with fish abundance up until a certain threshold, after which it turned into a negative relationship. Nutrients from human processes (pollution, sewage, etc.) could provide more food sources for fish in an oligotrophic environment, but after a certain level, that pollution is either too much or the fishing pressure is too high in densely populated areas (Piroddi et al., 2021). Nutrients alone are not necessarily bad for fish abundance due to the secondary production it can stimulate (Nixon & Buckley, 2002). Because reefs are generally nutrient poor, the concern for excess nutrients or eutrophication of the nearshore marine environment is that coral reefs will phase into macroalgae dominated environments (Adam et al., 2021; McManus & Polsenberg, 2004; Prouty et al., 2017). However, other research has shown that a ‘phase-shift’ is only a risk if herbivorous fish populations are low (McCook, 1999). Herbivorous fish are threatened (Edwards et al., 2014), and in the Philippines, common herbivorous fish such as rabbitfish (*Siganidae*), parrotfish (*Scaridae*), and surgeonfish (*Acanthuridae*) are frequently captured in the artisanal fishery. Thus, there could be some scenarios in which areas of high population density have high nutrient input but low fishing pressure resulting in a positive impact on fish abundance. Or, cases where there may be both high nutrient input and high fishing pressure resulting in a negative impact on fish abundance.

Mangrove habitat did not have the hypothesized relationships with the different dependent variables. While the relationship was significant ($P < 0.05$) with biodiversity and abundance of key fisheries species when evaluated individually, the direction of the relationships varied. They mangrove edge/area variable was not significant in the fish abundance model. When the relationship with the edge/area is positive, edge is more important, and when the relationship is negative, area is more important. While mangrove edge may provide the habitat necessary for juvenile and adult fish, habitat fragmentation could result in shapes that have long edge habitat but narrow coverage (Figure 3.1), which this ratio is meant to account for. If edge and area were equally important this could appear as a flat line or end up with no significant relationship. When assessed in one-factor models, mangrove habitat within a 20-mile radius was a highly influential variable on biodiversity; and in the final model it appeared that both edge and area were equally important resulting in a mostly flat line. However, within that 20-mile radius mangrove area was more important at lower levels of abundance, while edge habitat was more important at higher levels of abundance for key fished species. While with local mangrove habitat, area is slightly more important to higher abundance of key fished species. Mangroves provide more ecosystem services than just habitat (Barbier et al., 2011) and it is possible that the loss of the coverage has more impact than the availability of edge habitat. Such ecosystem or ecological services are mangrove's ability to purify water and remove excess nutrients (De Valck & Rolfe, 2018). Additionally, mangroves provide erosion control that reduce the amount of sediment on reefs (Carlson et al., 2019; Duke & Wolanski, 2001). Sediment pollution can cause obstructions to the gills of reef fish and result in poor metabolic performance (Hess et al., 2017). Wider mangrove stands may be able to trap sediments more effectively than narrow or longer mangrove stands.

Fish have been found to use narrow mangrove habitat more frequently than wide mangrove habitat (Dunbar et al. 2017), however, use does not necessarily translate into increased biodiversity at the reefs where the Rare surveys were completed. Edge availability was found to be related to key fisheries abundance, which may indicate that key fish species abundance may be a better metric to evaluate use of mangrove habitat by fish than biodiversity. Additionally, in another study, mangroves on an island-wide scale had a positive relationship with a non-fished fish species (Halpern, 2004). Similarly, this study found key fishery families, which are mangrove dependent, had a positive asymptotic relationship with mangrove habitat within 20-miles of the site. These results show that mangrove edge habitat across wide reaches of the Philippines can be influential in increasing abundance of fish that are important to the fishery. However, conserving edge habitat alone will not provide full benefits to biodiversity, for which both edge and area were equally important.

3.5.1 Limitations and Considerations

One of the main limitations of my data was the lack of longitudinal data for mangrove edge and area, which were not available for every year my fisheries data were. This required using last or next available years to fill in missing data. It should be noted that mangrove cover can appear to be changed in satellite imagery due to storm activity through defoliation, hydrological changes, loss of tree biomass and more (Amaral et al., 2022). Between the years 2010 and 2015 there were devastating storms, with 2013 having the most damaging typhoon, Haiyan, on record in the Philippines that could have impacted year over year extent or edge. Because of Typhoon Haiyan in 2013, I used 2015 data to fill in gaps for 2014, since there is a potential for significant change to mangrove habitat from 2010. Additionally, the mangrove data itself is only as good as the satellite imagery and algorithms it came from. While gathering data layers for this research, I noticed that the mangrove shapefiles did not always align with what was pictured in a satellite image. The lack of well-developed shapefiles for the Philippines made true edge habitat difficult to extract because in some cases land and sea boundaries did not align.

Another consideration is that this study only used habitat data from coral reefs and mangroves; there is extensive research suggesting that seagrass beds are also important nursery habitat for reef fishes (Barbier et al., 2011; Dorenbosch et al., 2005). Abundance and biodiversity may be impacted by seagrass habitat as well as there may be some interactions between mangroves, seagrass, and coral reefs that is not captured in this study.

Due to the nature of gathering and using data at different scales, climate change variables such as sea surface temperature and precipitation were difficult to integrate into the dataset. However, incorporating climate variables could be a helpful addition to this research, which would account for other external factors that may be impacting fish biodiversity and abundance.

3.6 Conclusion

This study characterized the relationship between mangrove habitat with biodiversity, fish abundance, and abundance of important fishery species. Mangrove habitat was significant as a driver of fish biodiversity and abundance of key fisheries species, but not always in the predicted ways. Mangrove edge, predictably, provides more swimmable habitat for fishes and is an important and influential driver for key fisheries abundance. However, for biodiversity, edge and area were equally important variables, indicating that mangrove forest as a whole is providing essential ecosystem services.

Additionally, mangrove habitat far from the site may be having an impact on biodiversity and key fisheries abundance, meaning mangrove protection and restoration efforts should not be limited to areas directly next to MPAs. Mangrove habitat is a threatened coastal ecosystem and care should be taken when developing coastal areas to ensure habitat left or restored is still providing necessary ecosystem services to be ecologically functional.

This research also demonstrated that biodiversity and key fisheries abundance does not always have a positive relationship with marine reserve size and the percent of fished area may be a more important variable to predict if a marine reserve will be successful. Additionally, population density does not necessarily have a negative impact on biodiversity or fish abundance, with excess nutrients common near high population centers, potentially benefitting nearby fish populations. Fisheries exist in complex social-ecological systems and no singular variable perfectly predicts the outcome of the success of a marine reserve. When designing future reserves, the local conditions need to be taken in to account in order to have the best chance of achieving both conservation and fishery goals.

CHAPTER IV – FISHER PERCEPTIONS AT DIFFERENT COMMUNITY-BASED MANAGED MARINE RESERVE SITES

4.1 Introduction

Marine resource governance in the Philippines is punctuated by major events in their history. Prior to Spanish colonization in the 16th century, the people who inhabited the now Philippines had a rich culture of traditional fishing rights and local jurisdiction over marine resources (La Viña, 1999). During the Spanish reign, management over marine resources was transitioned to the central government, or the Crown, which continued broadly through American rule (1898-1946; La Viña, 1999). This tumultuous history of marine resource governance being taken from local villages and handed to the central government, fostered a mistrust among its citizens (Brillantes & Fernandez, 2011). After independence from the United States, the Philippines started to return to forms of community-based management, codifying the decentralization of marine resource governance to the local level in their Local Government Code of 1991(Pomeroy & Courtney, 2018; Pomeroy, 1995). Some fishers in the Philippines prefer community-based management (Hamilton, 2012) and top-down government approaches for marine resource governance are likely ineffective due to the dispersive nature of the fishery. Co-management of fisheries can be challenging when implementing in populations where there is extreme poverty or other incentives to overexploit resources and there is a need for institutional framework and infrastructure to be in place to allow for effective communication between communities and managers (Cinner et al., 2012). Community management, including self-monitoring, can be a beneficial governance strategy because self-organizing can increase likelihood of social trust and compliance to rules (Ostrom, 2000).

In addition to community-based management, MPAs are prevalent in the Philippines for marine conservation, with over 1400 reserves established and the first one being implemented in 1940 (Horigue et al., 2012). As mentioned throughout this dissertation, MPAs protect marine habitat from direct anthropogenic impacts, such as fishing. However, in a review of MPAs in the Philippines, many of these reserves were not considered effective in reaching their conservation goals (Arceo et al., 2008; Cabral et al., 2014; Campos & Aliño, 2008). There are a variety of factors, such as population size, perceived crisis in fish populations, availability of alternative livelihoods, and high community participation, that communities may have that impact the success of MPAs (Pollnac et al., 2001). Additionally, compliance and enforcement of MPAs are critical to their success, in this case being defined by increase of fish biodiversity. The goal of this chapter is to investigate the social components between sites where fish biodiversity increased and those where it did not, and fishers' perceptions on compliance and enforcement through qualitative analysis.

Rare's Fish Forever Program has a framework to track governance progression of a site that includes site management, consultation, co-management, and tenure with community management to address that concern. The program defines these terms as follows: 1) site management is defined as a larger government body having governing authority over an area, 2) consultation still has centralized government authority but is in the process of forming limited co-management with communities, by inviting stakeholders to give their input, 3) co-management areas allow the government to have rights over the area but give the village legal authority to manage the marine area, and 4) tenure and community management mean that the local government owns the area while giving legal authority to the local villages to self-manage. Rare uses this framework to facilitate the transition of MPA management from centralized government to community management.

Rare collected longitudinal data through knowledge, attitude, and perception surveys and found that there was an improvement in compliance after the implementation of the Fish Forever Program in the Philippines (McDonald et al., 2020). Their research found that there was variation in both social and ecological impacts among their program sites. Similarly, an analysis of fish community and biodiversity among these same sites found ecological differences between sites (Marriott et al. 2021). While the longitudinal quantitative survey data is important for understanding the impact of the Fish Forever program, this chapter dives deeper into what differences between community-based managed sites there are that can be uncovered through qualitative interviews. Positive perceptions of MPAs have been linked to increasing compliance (Leleu et al., 2012; Twichell et al., 2018), though positive perceptions do not always result in high compliance and enforcement still needs to take place (McClanahan et al. 2005) . Additionally, because compliance and enforcement efforts can be expensive or undesirable to fishers to continuously monitor (NMFS OLE, 2015; Plet-Hansen et al., 2017; Stewart & Walshe, 2008), interviewing those on the water unlocks insights on those topics, as well as providing an opportunity to for fishers to delve into perceived reasons for violations.

4.1.1 Theoretical Framework

In fisheries models, understanding mortality is vital for assessing the stocks overtime. Mortality is separated into fishing mortality (F) and natural mortality (M), which together equal the entire mortality for the species. Natural mortality is hard to quantify, but scientists believe that we can more accurately quantify fishing mortality because it is counted at the dock (Beverton & Holt, 1957). It could be argued that it does not matter how the social components of fishing drive extraction, because all of that is captured into fishing mortality. However, in developing countries, particularly ones where small-scale fishing is common, there are no good tracking methods of fishes caught, and therefore F is severely underestimated (Pauly and Zeller, 2016). Because the math is less deterministic in these regions, we need a more holistic view of what the interactions are within the fishery. Fisheries link social and ecological systems because there is the scientific component of population dynamics and life history of fish, but also the social components of governance, fishers' livelihoods, and economics.

Social-Ecological Systems (SES) are those where there are complex interactions between the "natural" and "human" worlds. This concept broadly has been around for decades. Folke, a prominent resilience and SES scientist, describes linking ecology and economy since the mid-1980s. Additionally, Pickett et al. (1997) wrote about SES in the context of urban ecology, which has obvious links between the human and natural world because of the anthropogenic engineering of land and habitat. The connection between resilience and SES is heavy in the literature, but the overall concepts of humans and nature interacting with and impacting each other has been well-established for decades (Berkes & Folke, 1995). Community resilience and sustainable use of resources are inextricably linked, given that the ability to have resilience requires the stability of basic needs such as food (Bullock et al., 2017). As the field has developed, there has been a growth of understanding of the connection of many different types of ecological systems to social systems.

The social-ecological system framework (Ostrom, 2009) explains that in order to understand any system or activity that includes both social and ecological components and how they are connected, a holistic approach must be taken. Ostrom’s (2009) framework includes four “first level” core subsystems: Resource Units (what the ecosystem produces, such as fish), Resource Systems (the ecosystem), Governance Systems (the rules and institutions), and Users (those who harvest or benefit from the resource system, such as fishers). Each subsystem is then composed of many other “second-level” variables, which can include qualitative and quantitative data. Ostrom’s framework aims to identify both what those subsystems are as well as how they interact with other subsystems. The other two pieces of the framework are the external Social, Economic, and Political Settings and external Related Ecosystems that the SES operates within. For the purposes of this paper, I used a subset of the second-level variables for analysis (Figure 4.1). This framework has been used in the literature to describe community resilience (Berkes & Folke, 1995), fishery systems (Basurto et al., 2013;

Cinner et al., 2009), and the relationship between fisheries and marine reserves (Pollnac et al., 2010; Quintana et al., 2021). Kittinger et al. (2013) called for additional research on to understand the social capital required in developing community-based management programs, based in SES frameworks. This paper builds on previous literature by looking at community-based MPA management through a SES lens and investigating the social capital aspects of that management, such as enforcement, education and networks, to further the progress of management design and implementation.

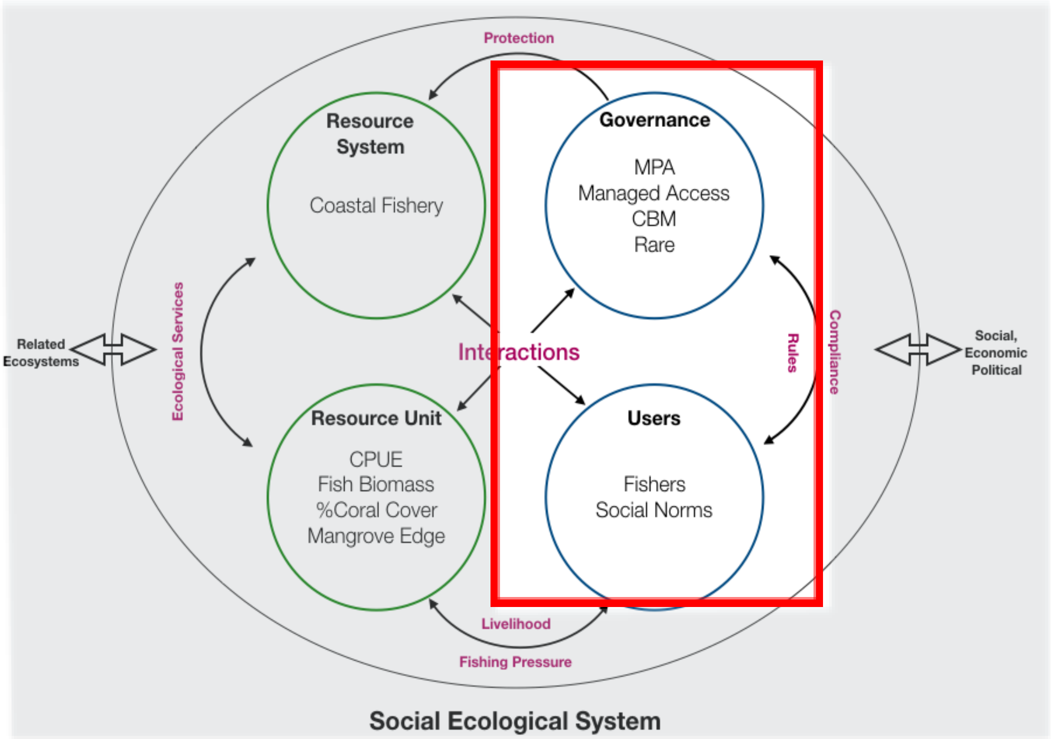

Figure 4.1 *Conceptual diagram of the social-ecological system described in Chapter 4*

In red is the portion of the framework, governance and users, addressed by Chapter 4. Adapted from Ostrom (2009).

4.2 Research Question

In Chapter Two, I found that there was variation effectiveness of the MPAs, where some did not change community structure after CBM was implemented and some did have a change. In Chapter Three, I investigated some of the ecological variables that may be influencing fish abundance and biodiversity at these sites. This chapter is looking at some of the social reasons that may have led to variation in biological response. This chapter is looking to answer, what are the differences in fishers' perceptions of the marine reserve, catch, compliance and enforcement between ecologically successful and unsuccessful CBM marine reserves? Because compliance and enforcement are such vital parts of the effectiveness of marine reserves, I would expect different perceptions as to the compliance or enforcement levels at sites that were successful versus unsuccessful.

4.3 Methods

4.3.1 Study Area

All interviews took place at four of the 21 Fish Forever program sites (Figure 4.2). Sites were chosen based on ecological outcomes from Chapter Two. Ayungon and Manjuyod had an increase in biodiversity after the implementation of community-based management of marine reserves, while Tayasan and Bindoy did not have an increase in biodiversity after the implementation of community-based management of marine reserves (Marriott et al., 2021). Choosing sites with known ecological outcomes was important because perceived ecological health is not always a good indicator of an increase in biomass (Warner & Pomeroy, 2012). All four sites are adjacent to each other along the Tañon Strait in the province of Negros Oriental. As of 2017, there were approximately 1,200 fishers in Ayungon, 1,500 fishers in Bindoy, 1,000 fishers in Manjuyod, and 400 fishers in Tayasan working within the region that Rare was implementing their program. All of the sites as of 2017 were operating under “consultation,” transitioning to “co-management” as defined by Rare’s Fish Forever program.

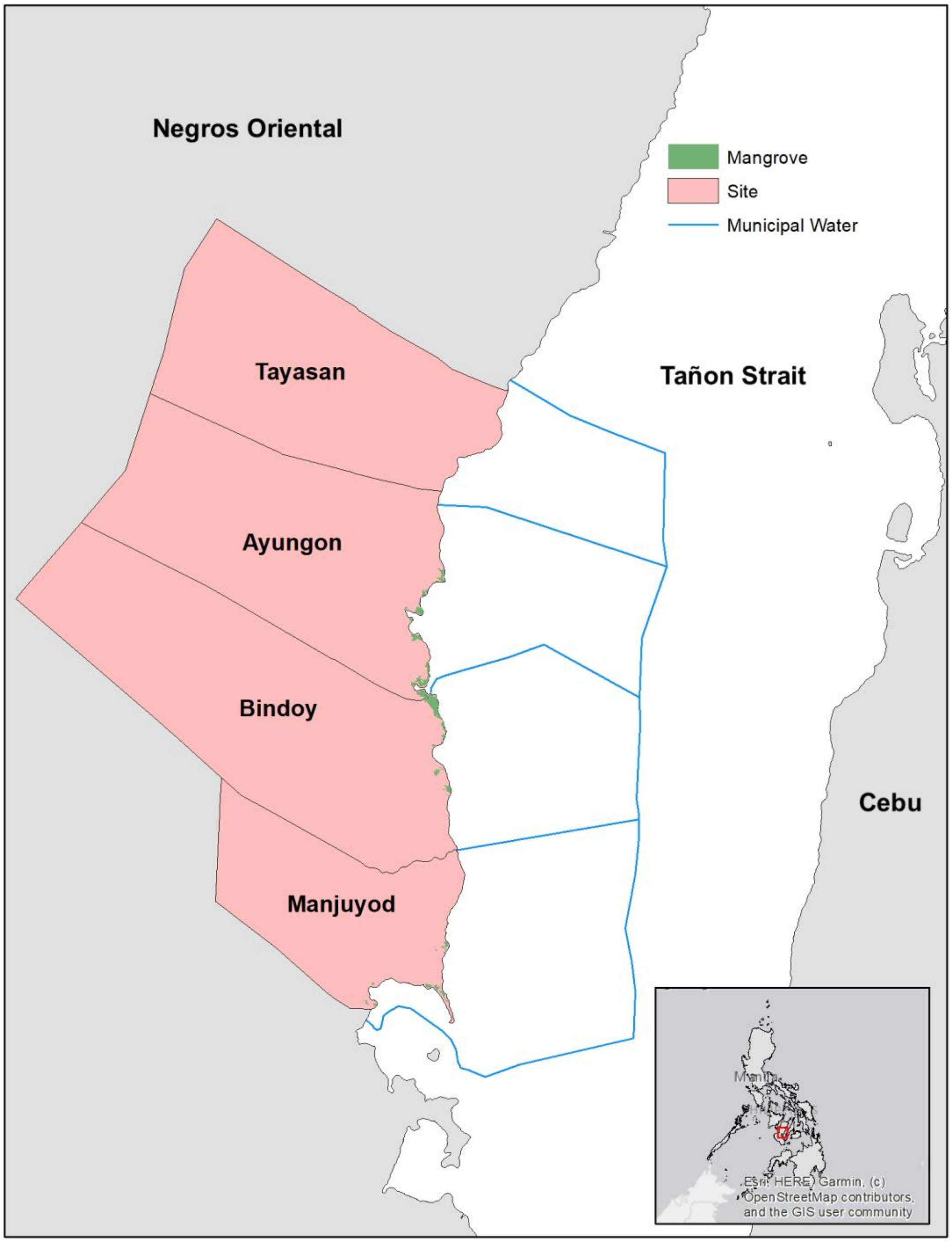

Figure 4.2 *Site Map for Interviews*

Data Source: GADM, Rare, Global Mangrove Watch
Spatial Reference: GCS WGS 1984

4.3.2 Approach

I conducted semi-structured interviews (Table B.1) with fishers, targeting two sites where biodiversity was higher after CBM was implemented (Ayungon and Manjuyod) and two sites where biodiversity was lower or unchanged after CBM was implemented (Bindoy and Tayasan). A semi-structured interview style allowed for a core set of questions to be asked to all participants, while still allowing for flexibility to ask follow-up questions, when needed. These interview questions were developed with the assistance of the Rare Philippines office. Interview responses and notes were recorded by hand as well as by a recorder to capture all meaning. Analysis of the interviews was through both deductive and inductive thematic analysis, which breaks down raw text into themes (Erlingsson & Brysiewicz, 2017), using Provalis software. I had a goal to discuss the topics or themes of marine reserve perception, compliance, enforcement, and community engagement. However, there were also emergent themes that occurred during the interviews.

Interviews took place in the Philippines in March 2022. I conducted a total of 32 interviews with a total of 37 people (22 men and 15 women) who were associated with the fishing community (24 fishers, eight Bantay Dagat or protected area rangers, one fish landing manager, two elected officials, one conservation fellow, one local NGO representative). Individuals were recruited through a partnership with local governments and Rare Conservation fellows. Most interviews were conducted individually, however, at a few sites, interviews were conducted in groups. All interviews were approximately 15 minutes in length and conducted in English with a translator into Visaya, the local language. The participants were associated or familiar with Rare prior to the interviews, therefore their perceptions may not be representative of the entire community due to recruitment bias. All but two participants interviewed for this study were recruited with the assistance of Rare and are highly active in the fishery decision-making process, which provides some limitations for the conclusions of this study. Those who highly participate in the management process of the marine reserve, either formally or informally, have more positive perceptions (Twichell et al., 2018) and therefore the majority of those interviewed may have an underlying recruitment bias of being active with Rare and therefore having more positive views. There was a potential for participants to answer questions with what they thought I wanted to hear, or “social desirability bias” (Grimm, 2010). We attempted to reduce social desirability bias by asking questions that may be sensitive in nature indirectly (Bergen & Labonté, 2020), such as instead of, “have you ever violated the reserve” we asked, “have you ever witnessed someone violating the marine reserve.”

Even though these perceptions may be limited through recruitment bias, because all of the sites have been involved with Rare for many years with the same intervention program, it allows for comparisons to be drawn with each other. These data provide insight on what the fishers perceive the state of their community-based marine reserve is and what potential ways are to improve effectiveness in the future. This type of information can be used by NGOs, like Rare, when facilitating a community’s management of their marine reserve.

4.3.3 Participant Descriptions

In Ayungon, I met with eight fishers who were all on the fisheries council or otherwise involved more formally with fisheries management. I also traveled to the beach and interviewed two other fishers who were not prearranged or affiliated with Rare. Most individuals I spoke with here were primarily fishers, but some fished for a secondary income. All but two people had secondary employment. In Manjuyod, I interviewed eight people involved in fisheries, of which four were women and four were men. Of those interviewed, five were fishers, one was a barangay captain (a town leader), one was affiliated with an NGO, and one was a political official.

In Tayasan, I interviewed eight people involved in fisheries of which there were five women and two men. Most people who I interviewed were Bantay Dagat or otherwise involved with the fishery. Again, all but two individuals had secondary employment in a variety of fields, including a carpenter, a tricycle driver, and a healthcare worker. In Bindoy, I conducted six interviews with 10 people; one interview included five fishers. All fishers interviewed here were male. Many of them also had other work such as carpentry or mango harvesting.

4.4 Results

4.4.1 Themes

The interviews included topics regarding perceptions on the marine reserves, compliance, enforcement, and community engagement. Some of the themes that emerged from the interviews were that MPAs were generally helpful, compliance is high within the local communities, violations that occur are mostly from people outside the community, challenges with fisheries management are due to forces external to the community, and that there is high respect and trust in Bantay Dagat (Table 4.1). This section is structured as follows: first, I will describe the themes that were present in both ecologically successful (Ayungon and Manyujod) and unsuccessful sites (Tayasan and Bindoy), then I will describe those present primarily in the ecologically successful sites, and finally, I will describe those present primarily in the ecologically unsuccessful sites.

Table 4.1 *Themes resulting from the interviews present at all sites, only the successful sites, and only the unsuccessful sites*

Themes	**All Sites**	**Successful Sites**	**Unsuccessful Sites**
Marine Reserve Effectiveness	Helpful	-	-
Catch Trends	-	Increasing	Decreasing
Compliance	High	Self-enforcement	-
Knowledge and Education	-	Sufficient: successful education campaigns	Insufficient: violators lack knowledge
External Challenges	Garbage Pollution Political Corruption Typhoon Odette Illegal Fishers	-	-
Respect and Trust in Bantay Dagat	High	-	-

4.4.1.2 Themes Common in All Sites

4.4.1.2.1 Marine Reserves are Helpful

At all of the sites, community members had positive sentiments on marine reserves. Regardless of if they also said their catch had been reduced, they intimately understood the potential ecological benefits of having an implemented marine reserve. Primarily they mentioned spillover effect where fish in the marine reserve will exit the marine reserve and become catchable as well as the marine reserve providing necessary spawning habitat so that fish can reproduce safely.

> *"It is a big help the marine sanctuary is the ground of small fishes and fishes will grow big and go outside the sanctuary and we will be the ones to catch the fish." -Fisher from Manjuyod*

Additionally, a sub-theme that kept occurring was that there was a perceived change in perception over time. Before the marine reserve was implemented, fishers discussed a hesitation about the designation or enforcement of the reserve. However, as time passed and education campaigns continued, led by local champions, the fishers perceived an increase of acceptance and their perceptions of the marine reserve have become positive.

> *"It is a big help that the marine reserves protect our marine resources. Before the marine sanctuary was established, many fishermen didn't know that it was good or beneficial to them, but later on until now, they have lots of information that the sanctuary is good for them and is a big help."*
> *- Bantay Dagat from Tayasan*
>
> *"Before they were against the establishment of the sanctuary, but now they have seen the benefits, they are now pro-sanctuary." - Fisher from Ayungon*

While most of the fishers and community members interviewed are familiar with Rare and were recruited by Rare to be a part of the interview process, two fishers, who were not associated in any way, were recruited and interviewed at the coastline. These fishers said they were never consulted in the marine reserve implementation process, however, they still had positive perceptions of the marine reserve and its role to help restore fish populations.

Even though community members interviewed had positive views of marine reserves, in some places, implementing new marine reserves was a challenge. Manjuyod has a unique feature that the other sites do not have, which is a large white sand sandbar. This sandbar attracts local and foreign tourists but is currently not protected. Within Manjuyod, there are some local villages with implemented marine reserves and some with marine reserves that are delineated on a map but not implemented with regulations (similar to a "paper park") (Di Cintio et al., 2023; Pinat & Green, 2004). One of the interviewees who lives in one of the villages without a marine reserve discussed her desire for them to implement and enforce a marine reserve fully, especially near the white sandbar, so that her community could benefit from ecological enhancements and maintain their tourist destination.

> *"Maybe it is [Rare] to help to pursue additional MPAs for Fish Forever, but sad to say it is not the priority of our barangay so it is hard to adopt. Because of that we are very willing to adopt the project because it is near our big white sandbar. That's why we are praying that we have NGOs who look forward to the project implementation." - Local NGO Affiliate*

There is an implication within this response that village priorities are not with implementing a new marine reserve even though she perceives that the community wants one implemented. The barangay (a municipality) may not view it as a priority due to the other marine reserves in the region or because there was a recent typhoon that reprioritized their resources to relief efforts. Additionally, while the marine reserves are managed at the community level, there is still a cost associated with monitoring them. The Bantay Dagat are fishers who volunteer their time to monitor and enforce the MPA, but some barangays pay a small stipend of 1,500-3,000PHP (or $30-60 USD) per month, which may be unaffordable for some local governments. Increasing the number of Bantay Dagat that require stipends by the local government because of the implementation of a new MPA may depend on financing from NGOs like Rare.

4.4.1.2.2 Compliance is High within Communities

In terms of perception of compliance, a theme that repeatedly occurred throughout all sites was that compliance was high within the community. Often, interviewees would respond passionately that everyone follows the rules, sometimes even confused that I would even ask that question. However, when further probed about if they have ever witnessed a violation, the answers diverged. Themes of violations did occur in both categories of sites, but the cause or origin of those violations were different between successful and unsuccessful sites.

> *"Here in Tayasan, fishers follow the rules, regulations, and policies about fishing management and law in Tayasan."* - Fisher in Tayasan

Compliance was often paired with the presence of designated boundaries for the marine reserve. Many respondents discussed that they witnessed more violations prior to the boundaries being demarcated as opposed to after the installation of the buoys.

Additionally, fishers perceived the increased presence of Bantay Dagat as a way to improve compliance.

4.4.1.2.3 Challenges are External

Fishers and community members discussed the perceived challenges their local fisheries face. They perceived that compliance was high within communities and viewed their challenges as coming from external factors such as illegal fishing or gears, political corruption, or pollution. There are two different types of outside fishers that were present. The first type are other small-scale fishers from neighboring barangays who may not be entirely aware of the regulations or do not participate in the management process. The second are commercial fishers in Tanon Strait who are illegally fishing in the area but wield political capital to avoid repercussions. For example, in Manjuyod, conflict with fishers from outside Manjuyod and the use of illegal gears such as compressors and poison was repeatedly mentioned. In the broader Tañon Strait, the body of water located between the islands of Negros and Cebu, there was conversation in both Bindoy and Manjuyod about commercial fishing vessels illegally fishing and intruding on municipal waters. The commercial fishing vessels were rumored to be owned by high-ranking political officials in the Philippines able to evade enforcement due to their positions of power.

> *"Tañon Strait is a protected seascape, but sad to say the violators of these national laws that was passed during the declaration of the Tañon Strait are the big politicians because they have their own commercial fishing boats. ... When their boats were being caught and reprimanded, the operators of the boat just calls the governor 'Our fishing boat is being reprimanded and being caught by this Bantay Dagat.' He is going to*

> *intervene. It will need very high-ranking government officials, higher than the governor, to implement and enforce without favor. That is the biggest challenge." - Politician from Manjuyod*

Another conflict that was mentioned in both Manjuyod and Ayungon was with the people and industry upland from the coastal communities. People from the upland communities will fish in the municipal waters, often using illegal gear and poisons. While the Bantay Dagat are able to apprehend and penalize the violators, not all the marine reserves in Manjuyod are protected 24/7 by the rangers, which leave windows of opportunity for transient fishers to illegally encroach on the marine reserve.

> *"Fishers from other barangays, in the upland barangays, they will come and fish. Depends upon the season, April, May, June, July. They come every night." - Fisher from Ayungon*

A milling corporation is also located upland from the marine reserve that can cause a lot of pollution washing into their municipal waters and seemingly causing water quality to decline during the rainy season. The conditions were described as smelling horrible and discoloring the water to dark brown to the point where they did not catch any fish. The respondent was concerned that the company held too much power within the local government and would not listen to the concerns of small-scale fishers. In Bindoy, garbage pollution was also mentioned as a reason for ecosystem health decline. There was blame put on these externalities for the decline in both fish and income of local fishers. The fishers interviewed held concern for environmental degradation and its impact on their livelihood.

4.4.1.2.4 Sub-theme: Typhoon Odette

One of the emergent themes that continuously came up in conversation was about the Typhoon, locally known as Odette, and the potential impact it would have on the marine reserve itself and the reef fish. Typhoon Odette made a direct hit in December 2021 to the communities I was interviewing and caused mass devastation both in terms of human lives lost and ecosystems. It was the equivalent of a Category 5 hurricane and is the second most costly typhoon ever to hit the Philippines. There was evidence of the typhoon in every community, between downed trees and damaged buildings. The community members I spoke with felt the typhoon has devastated their reefs and caused the fish to disappear, which has caused them a lot of stress.

> *"After Typhoon Odette [the coral reef] was devastated, big corals were washed out onto the shore. And there was a lot of damage to the marine sanctuary." - Former fisher from Tayasan*

The typhoon was on everyone's mind. Individuals reported seeing immense amounts of broken coral on the beaches after the typhoon and wanted to know what the long-term outcomes would be for the ecosystem and fishers there. The conservation fellow at one of the sites wanted a rapid assessment completed of the corals and fish abundance so there was adequate data to understand ecosystems impacts of the typhoon and if the community should consider moving their marine reserve to a less damaged area, if one existed. Additionally, because many vessels were destroyed in the storm, fishers had to pick up other employment. In Bindoy, fishers talked about how their fish aggregating devices they use to fish were destroyed during the typhoon, which resulted in reduced catch.

4.4.1.2.5 High Respect for Bantay Dagat

The rules of the marine reserve tend to be enforced primarily by “Bantay Dagat” or protected area rangers and other fishers. There was no distinct pattern of the perceived presence of Bantay Dagat amongst the sites, meaning that both types of sites had reports of 24/7 Bantay Dagat presence and times where they were absent. Though, there was an immense amount of respect for them as enforcers. Fishers and Bantay Dagat are empowered to apprehend violators and report them to the municipality. The penalties may be a verbal warning, gear confiscation, monetary, or even community service if they cannot pay the fine. In some cases, fishers are incentivized to apprehend violators because they will get half of the fine. In other cases across sites, there were calls to increase pay or the honorarium for Bantay Dagat so that there would be more coverage or better incentive for enforcement. Though, one fisher strongly maintained that Bantay Dagat who are volunteers enforce just as strongly as those who are paid because of their desire to protect the resources.

> *“The rules have been followed because the Bantay Dagat have been continuously patrolling. Foot and seaborn patrol.” Fisher from Ayungon*

In Bindoy, even though there is a perception of a high presence of violations of the marine reserve and conflict, there is confidence in the Bantay Dagat to enforce the regulations, and pride in being Bantay Dagat. The Bantay Dagat are not present all of the time at all of the marine reserves and that is when the fishers perceive most of the current violations occur.

> *“As long as [Bantay Dagat] are here to enforce the marine resources, our biggest challenge is those violators. But as long as [Bantay Dagat] are here, there is no challenge for them.” -Fisher in Bindoy*

In Manjuyod, there was a similar story, where a fisher became a volunteer Bantay Dagat in order to reduce the number of violations on the marine reserve, and in his view, Bantay Dagat were integral to that. This fisher became a municipal Bantay Dagat after some time volunteering but would have continued to volunteer because of his perception that having protection of the marine reserve was important.

> *"Because I saw that if there are no* Bantay Dagat *in our coastal areas, there are intruders, so it is not okay with him as a fisherman, even if it is voluntary, it is okay, but it is important that there was protection." - Bantay Dagat in Manjuyod*

4.4.1.3 Themes In Successful Sites

4.4.1.3.1 Catch Increasing

In sites that had an increase of biodiversity after the implementation of community-based management of their marine reserves also had the perception of increased catch. The fishers and respondents believe that the marine reserve in particular has been integral in the subsequent increase of catch.

> *"[Before the marine reserve was established] there had been a decline in fish catch, when the sanctuary was established there has been an increase in catch. There has been an increase in my fish catch, before I could only get 2 kg but now it has increased to 3 kg." - Fisher from Ayungon*

Specifically, interviewees reported that effective education campaigns and the addition of self-enforcement related to the marine reserves led to the increase of catch.

4.4.1.3.2 Compliance Sub-theme: Self Enforcement

In addition to the Bantay Dagat being the primary enforcers, at these sites, fishers would also enforce the rules and be able to implement penalties on violators. This is an important aspect of community-based management that also follows Rare's theory of change, of interpersonal communication, where, by fishers enforcing other fishers, they are creating social norms surrounding the concepts of respecting the boundaries of the marine reserves.

> *"Members of the associations are usually the ones who enforce and tell other fishers what the rules of the sanctuaries are."* - Fisher Ayungon

> *"They enforce themselves, the rules, violators, fishermen are also involved in enforcing the coastal fishery"* - Fisher in Ayugon

Self-enforcement also helps fill gaps where the Bantay Dagat are not on duty and prevents violations from occurring either from outside fishers or from fishers within the community.

4.4.1.3.3 Sufficient Knowledge and Education

As part of the Fish Forever program, Rare implemented Information and Education Campaigns to help educate fishers on the benefits of marine reserves. Knowledge is the first step in Rare's theory of change philosophy (Figure 1.1). Implemented by local advocates, Rare's signature "Pride Campaign" is designed to touch people's sense of place and feel pride over their resources and ecosystem. One way they do this is through having mascots at each barangay and host educational workshops for fishers. While all of Rare's program sites have a tailored Pride Campaign as the start of their community-based management system, the perception that these campaigns were important to the compliance and enforcement of the marine sanctuaries was a theme that emerged in the successful sites.

> *"In the beginning it was hard to implement the rules, but we* ***continue and continue to educate*** *other fisherman, to help protect and monitor the sanctuary."* - Fisher in Ayungon

> *"[The community] is also conducting information and education campaigns in the community to inform [fishers] that there is a marine sanctuary and it's benefits,* ***so there is a need to maintain it****." - Fisher Ayungon*

Notably, as stated by the fishers in the above quotes, these information campaigns cannot be a one-off workshop, but a continuous effort to educate fishers, especially new fishers who are entering the fishery.

4.4.1.4 Themes in Unsuccessful Sites

4.4.1.4.1 Catch Decreasing

In sites where biodiversity was not significantly different before and after the implementation of community-based marine reserves, there was a perceived decrease of catch. In Bindoy, no fishers said their catch had increased over the last few years. Some talked about how it was seasonal and others that their catch was enough but hadn't increased. A couple fishers mentioned that the community frequently uses fishing aggregating devices (FADs) to fish outside the marine reserve, though these FADs had been damaged or disappeared during Typhoon Odette and that has been the cause of reduced catch. They expressed the desire to acquire more of these devices and that would be a solution to their catch woes. Fishers also blamed overfishing as a reason their catch is declining but phrased it as the increase in number of fishers and illegal commercial fishing. Commercial fishing is completely illegal in the area surrounding these villages and is challenging for Bantay Dagat to enforce. While commercial fishing was present in both types of sites, the perception that this was causing a decline in catch was only present in unsuccessful sites.

> *"**Most of my catch is decreasing.** First there are lots of fishermen, every day every year there are more fishermen going to fish. Second is the garbage pollution. Third is the commercial illegal fishing." - Fisher in Bindoy*

4.4.1.4.2 Insufficient Knowledge and Education

When asked how to improve the fisheries here, many respondents spoke about further education campaigns to increase awareness of the marine reserves and the rules as well as improving enforcement. There was a difference in the perceptions from the successful sites on the success of the education campaigns in these sites. Participants discussed both the need for more information to be shared with a wider population. Interviewees reported that violations largely occur due to a lack of knowledge of the rules or where the marine reserve is located, which could be improved by more educational programs or targeting those who currently are unaware.

> *"Others are **not well informed** [on the rules of the marine reserve], so I would spread [information to] those other people and organizations." - Bantay Dagat from Tayasan*

At least one fisher mentioned that there are also informal pathways of communication and information sharing, such as when the Bantay Dagat give warnings to violators, they also explain the importance of the marine reserve and how it is beneficial.

> *"To those violators **who do not know** the [rules of the] marine sanctuary or the importance of the marine sanctuary, [Bantay Dagat] are the ones who tell [them] this is important." - Fisherman from Bindoy*

4.5 Discussion

The effectiveness of marine reserves depends on compliance of the rules or the ability to enforce the rules (Walmsley & White, 2003), however, it can be difficult to continuously empirically evaluate compliance or enforcement, especially in areas like the Philippines where there are over 1400 marine protected areas. Perceptions or local knowledge can be just as accurate as empirical methods (Brittain et al., 2022; Diedrich & García-Buades, 2009) and in the context of this study, perceptions on enforcement or compliance can be an indicator for real enforcement effort and violation events. This study used interviews to assess fisher perceptions of compliance and enforcement qualitatively at Fish Forever sites that had significantly higher (successful) and no significant difference (unsuccessful) in biodiversity after the implementation of community-based managed marine reserves. There were many overlapping themes between the successful and unsuccessful sites, which is to be expected given the proximity of these sites and participation in the Fish Forever program with Rare. However, there were also differences in the themes present, especially regarding how education and knowledge is perceived.

Overall, fishers in this study had positive perceptions of marine reserves and clearly understood their role in managing coastal fisheries, though interviewees noted the importance of continued learning, where they felt that fishers may not have agreed with the implementation of the reserves when the program was started, but overtime have grown to accept them. Positive perceptions of marine reserves have been discovered throughout other areas of the Philippines (Twitchell et al. 2018) and may be cultural due to their long history of MPAs or a result of long-term education campaigns on the benefits of the reserves facilitated through NGO involvement (Cabral et al., 2014; Pomeroy and Courtney, 2018). This is different from a study in Portugal where increased catch was documented, but fishers' acceptance of the marine reserve declined over time (Pita et al., 2020). However, the authors mention that marine reserves in Portugal are managed with top-down approaches, which may impact the perceptions of the marine reserves. Rare on the other hand engages communities on a local level through their theory of change model, using a participatory approach that allows fishers to be involved in the decision-making process (Butler, 2017). The participatory approach and co-management of marine reserves has been found to increase fishery benefits (Guidetti & Claudet, 2010) and improve perceptions of marine reserves amongst fishers (Twitchell et al., 2018). Fishers in our study had these perceptions regardless of whether they were being interviewed from an unsuccessful or successful site or whether they perceived their catch increasing or decreasing. This is consistent with Leleu et al. (2012) who found fishers; positive or negative perceptions on marine reserves were not indicators of the performance of the reserve.

Though all participants interviewed believed the marine reserve was helpful, they did not all believe their catch was increasing. This is particularly interesting because the metric of success between the sites was biodiversity, which does not consider biomass in the calculation. Often, research focuses on the impact of fishing pressure on biodiversity (Le Quesne & Jennings, 2012; Rochet et al., 2011; Thrush et al., 2016), though understanding the implications of conserved biodiversity on fisheries is critical to ecosystem-based management (Boehlert, 1996; Moullec et al., 2019). However, there are few cases where species richness and catch or biomass are related (Duffy et al., 2016; McIntyre et al., 2016). Worm et al. (2006) famously modeled that biodiversity loss would result in collapse of fisheries. Therefore, further research could include determining if catch trends were associated with biodiversity and how conserving biodiversity can stabilize fish catch for small-scale fishers.

The perception of decreasing catch in the unsuccessful sites was blamed on primarily external influences such as outside fishers or large environmental problems like pollution. Plastic pollution has been demonstrated to be consumed by important fishery species around the world and otherwise impact marine species through entanglement (Possatto et al., 2011; Thiel et al., 2018). However, there is limited research in how plastic pollution directly impacts fisheries in this part of the world. Nutrient pollution may be harmful to coral reefs and individual fish species (McManus & Polsenberg, 2004), but biomass may actually increase due to nutrient pollution providing a food source (Piroddi et al., 2021). The theme of outside fishers intruding and overfishing is also present in other surveys in the Philippines (Steinkoenig, 2018). Interviewees at unsuccessful sites perceived that catch is declining because of outside fishers, either fellow artisanal fishers from neighboring barangays or illegal commercial fishers. These external forces that may be impacting catch negatively give fishers an outlet to blame where they are not in control. Though, a partial solution to outside fishers is to increase enforcement efforts of the MPAs, that may only go so far when dealing with political corruption in the commercial fishing activity. More research into the relationships between the local governments, the federal government, and politicians and their roles in MPA enforcement or violations would allow for better understanding of the impact on artisanal fishermen.

On average, all 21 Philippine sites that participated in Rare's Fish Forever program, all indicators for knowledge and communication increased after the program's implementation of community-based management (McDonald et al., 2020). That study has a lack of granularity that would show differences in individual sites. While this study showed a difference in the perception of knowledge and education between successful and unsuccessful community-based managed sites. In the successful sites, education deemed sufficient and was lauded as a reason that fishers were accepting of the marine reserve and understood the rules. There is not usually a linear path from knowledge to behavior change (Ardoin et al., 2020; Marcinkowski & Reid, 2019; Pooley & O'Connor, 2000), and it is true that it is only the first step in the Rare theory of change model. Information and knowledge can be a powerful tool in influencing behavior, especially if paired with other steps in change models (Jenks et al., 2010; McKenzie-Mohr, 2000). In these sites, knowledge and continued education is perceived as working successfully by fishers to improve compliance. Meanwhile, unsuccessful sites perceived there was a lack of knowledge leading to an increase of violations. All of these sites are part of Rare's program and therefore have the same formula for education campaigns, where there is local mascot, conservation champion, and workshops, however, there is something occurring in the unsuccessful sites where that knowledge is not reaching everyone.

Knowledge about the marine reserve transfer occurs in all the sites formally and informally. Formally, there is a communication pathway from NGOs (including Rare) and local government units to fishers through workshops and public meetings to disseminate regulatory and ecological information (Figure 4.3a). Informally, there is education that occurs through fisher-to-fisher conversations creating a societal norm of how to behave within the marine reserve and surrounding areas (Figure 4.3b). This type of interpersonal communication can increase compliance of rules and create normative behaviors (Ostrom, 2000), for example, if fishers believe other people are complying, they are more likely to also follow the rules. Making sure knowledge about the rules is shared broadly is a challenge with fishers or violators from outside the local community who do not know about the rules or the reserve. In some cases, community-based enforcement is not sufficient to deal with nonresident fishers and require institutional intervention, such as police (Crawford et al., 2004). Though at my sites, interviewees spoke about how information about the marine reserve can be spread through Bantay Dagat, who act as educators of the regulations when they are delivering warnings to violators. Many participants said that warnings were the first line of penalty for violating the marine reserves and that as part of this warning, Bantay Dagat would tell the intruding fishers why the marine reserve was important, where the boundaries were, and not to fish in that area. This type of knowledge transfer, informally through fisher-to-fisher communication, has the potential to be more powerful because it is coming from peers rather than from an institution (Roux et al., 2006).

When looking at what makes MPAs successful, stakeholder engagement and strong social communication are some of the most important factors (Giakoumi et al., 2018). Rare’s program does have high levels of stakeholder engagement, hosting workshops and community meetings (Jenks et al., 2010; McDonald et al., 2020) and based on my conversations with fishers in the Philippines, they feel that they are participants in the decision-making process. Current education campaigns reach fishers within target villages, and many studies suggest that education is a vital part of establishing a successful marine reserve (Beger et al., 2004), but after educational events take place, there is no tracking in how that information is circulated beyond the community. Stakeholder engagement can be expanded into more opportunities for providing education to a wider range of potential resource users. In the context of this study, that could mean providing tools for more peer-to-peer knowledge sharing in informal settings, rather than NGO-led workshops. Future work could map social networks of the small-scale fishery here to better understand how communication across social groups impacts knowledge transfer. For example, recreational fishers in Australia believed that fishers within their social network were less likely to violate the rules than those outside their network (Bergseth & Roscher, 2018). Similarly, a social network analysis of Kenyan small-scale fisheries revealed that communication occurs most among fishers who use the same gear (Crona & Bodin, 2006). In the Philippines, fishers use a variety of gear types, sometimes individual fishers use multiple gears. The nature of the gear determines how fishers are using the resource temporally and spatially and may impact the amount of informal education and communication that occurs amongst these sites. In unsuccessful sites, the lack of knowledge was cited as a reason for outside fishers intruding in the reserve. Some of the interviewees in unsuccessful sites discussed how improving education may help reduce violations and improve the function of the marine reserve. However, it is possible that the gap in knowledge transfer across multiple actors or resource users, such as between local fishers or NGOs and illegal fishers (Figure 4.3b), is actually a breakdown in interpersonal communication because of gaps in social networks. Continuing research into the potential gaps in social networks is important to small-scale fisheries management because fishers are more likely to change their fishing behavior or report violations when they are linked to protected area rangers, like Bantay Dagat, through information sharing networks (Alexander et al., 2018; Stevens et al., 2015). When thinking about how to engage fishers who are using illegal gears or those who are not knowledgeable about the marine protected area, understanding how these networks in the different sites may offer additional insight on how to better target education campaigns so that these individuals are getting the information.

An undercurrent of many of the conversations revolving around the improvement of fisheries management was the need for economic investment in the communities. In many MPAs, one factor that indicated the success of marine reserves was the staff and budget capacity (Gill et al., 2017). For the sites in this study, the programs were all funded by the same organization using the same model, however, it was apparent that the communities also distributed funds independently based on their own unique needs. This resulted in a discrepancy of Bantay Dagat being completely voluntary or being paid a small stipend. While this study cannot conclude that the level of investment (local or otherwise) was a cause of catch decline or number of violations, it could have an impact on MPA success (Pollnac et al., 2001 and Gill et al., 2017). Investment in fishers came up when talking about Typhoon Odette when boats were destroyed but there was no outside assistance to help repair boats or gear. The ability to increase formal education campaigns to include educating the surrounding barangays to reduce violations would require investment. While the goal of community-based management implementation programs is to create a sustainable system that does not require the NGO to be omnipresent in the communities (Beger et al., 2004), a few people from different sites (both unsuccessful and successful) called on NGOs to continue to financially support these programs and invest in solutions to emerging problems.

There were two fishers that were interviewed who had no association with Rare, they also had positive sentiments of the reserve and also spoke knowledgeably about how marine reserves function. During this conversation in particular, I felt that their answers were skewed toward saying what they thought I wanted to hear, or “social desirability bias” (Grimm, 2010). Though the discomfort displayed in answering my questions may also be a result of having an unexpected group of people approach them to ask questions through a translator. Regardless of whether they were replying in a particular way to appease me, their aptitude about the marine reserve showed that the education and information campaigns implemented across, at least, Ayungon was effective at disseminating information beyond those familiar with Rare.

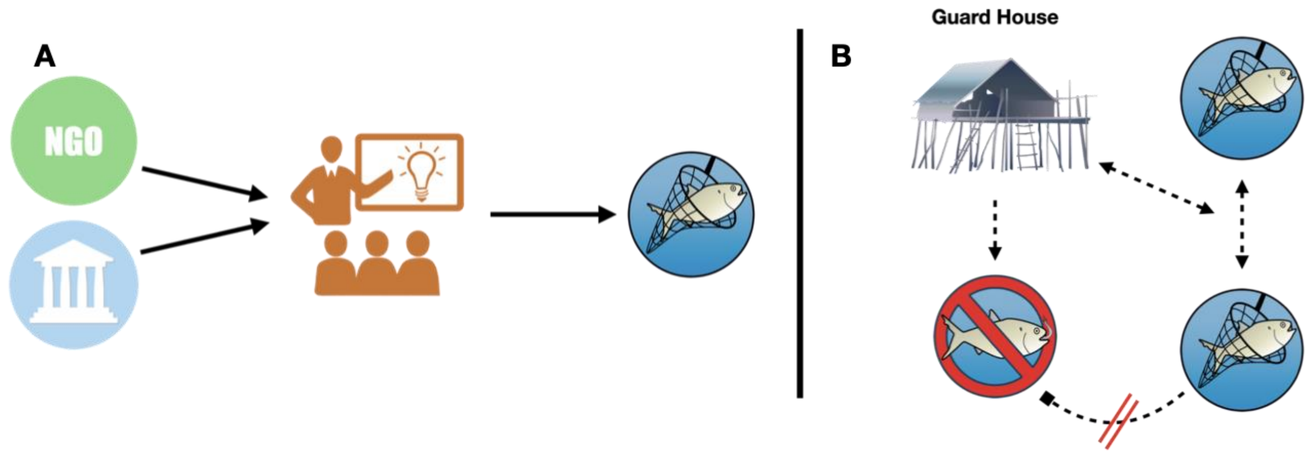

Figure 4.3 *Figure 4.3 Communication Pathway Diagram*

A) Formal communication pathway from local government and NGOs to fishers. B) Informal communication pathway between fishers, local fishers and Bantay Dagat, and Bantay Dagat and illegal fishers. Local fishers may not have effective peer-to-peer communication with illegal fishers.

4.6 Conclusion

This study found that the fishers interviewed had high regard and knowledge of marine reserve in terms of their benefits to both the ecosystem and the importance to their livelihood. There were many external factors that were designated as issues for sustaining fish catch including environmental factors such as pollution, habitat loss, climate change and typhoons and social factors such as political corruption and illegal fishers. Additionally, while self-organizing and volunteer efforts by Bantay Dagat are highly respected, increasing investment for enforcement will reduce gaps in coverage that would decrease the amount of un-monitored time violators could access the marine reserve.

This study was primarily interested in uncovering the differences in sites with successful CBM marine reserves and sites with unsuccessful CBM marine reserves. One difference is that sites that were determined to have no significant differences of biodiversity before and after CBM also perceived to have declining catch, while those in sites where biodiversity increased perceived increasing catch. One next step would be to triangulate their perceptions with catch data at each site. The primary difference was the perception of knowledge and education in either type of site. In the successful sites, respondents perceived there to be sufficient knowledge about the regulations surrounding the MPAs and their importance due to education campaigns and perceived compliance as being high due to them. While in the unsuccessful sites, respondents perceived that there was a lack of knowledge amongst those who did violate the marine reserve.

Often when marine reserves are being designed and evaluated, the biological aspects of how connected reserves are, and the social aspect of enforcement or compliance are heavily weighted. However, this research indicates that there may be a gap in how information is shared and transferred throughout fishing communities. This insight provides a starting point for local government units and NGOs to investigate how information is shared from formal venues as well as amongst fishers' social networks. Additionally, while many behavior change models are linear in nature, incorporating an intentional bidirectional link between interpersonal communication and knowledge sharing could result in a continuous education loop that may expand compliance among fishers.

CHAPTER V – SUMMARY AND CONCLUSION

5.1 Summary

This dissertation aims to provide greater understanding around the function of marine reserves through a social-ecological system (SES) lens. Ostrum (2009) describes a social-ecological system framework to include subsystems of a resource system, units, governance system, and users. Through this social-ecological systems framework, relevant variables can be identified and the relationships between different subsystems can be analyzed. Here, I situated small-scale fisheries management in the Philippines within a SES framework, identifying the variables and potential drivers of fish abundance and biodiversity (Figure 1.3). Each chapter of this dissertation centered around the relationships between different subsystems. Chapter Two focused on the relationship between resource units (fish community structure and biodiversity), resource system (coastal fishery), and governance systems (MPAs and community-based management). I found that governance, in the form of community-managed marine protected areas (MPAs), can be a driver of changing community structure within reef fish and biodiversity. After the implementation of community-based management there was a shift in fish assemblages inside the marine reserve indicating that there was a change in fishing behavior. Additionally, in some sites, biodiversity increased inside and outside the MPA after community-based management implementation. However, not every site had the same results, indicating that governance was not the only driver of change. This led to asking the question of what the differences between sites are that may result in fish response variation. For example, is there sufficient nursery habitat or does compliance or enforcement vary? Chapter Three took a deeper dive into how the surrounding ecological system, such as mangrove habitat, and factors of the MPA, such as age and size, impacted fish biodiversity and abundance. I found that mangrove habitat near and far were significant drivers of biodiversity and key fisheries species. Mangrove edge was more important for key fished species than mangrove area, which indicates that providing structural habitat for mangrove dependent fish continues to be important, and that these areas need to be protected to support the function of the MPAs and fishers who depend on these resources. Additionally, key fishery species, those that were important for artisanal fisheries in the region and dependent on mangroves, MPA area and the percent of area protected were the two most influential variables. Chapter Four meanwhile, investigated the perceptions of compliance and enforcement of resource users at sites where biodiversity increased after community-based management and those that did not. I found that one of the major differences between these two communities was not simply how they viewed absolute compliance or enforcement, but rather how they viewed information transfer amongst fishers, including those external to their community. Together, these three studies paint a picture of the SES of small-scale fisheries in the Philippines and connections can be made between the subsystems.

5.2 Synthesis

Compliance and enforcement are major variables when it comes to the success of protected areas (Arias et al., 2015; Bergseth et al., 2015). Understanding the pattern of compliance or enforcement could enhance the effectiveness of reserves and help meet the goals of implementation. Chapter Three of my dissertation showed that lack of compliance and enforcement may be exacerbated by or related to reserve size itself. Larger reserves may be difficult to enforce due to size, which would result in more violations of the marine reserve (Wilhelm et al., 2014). However, in Chapter Four when evaluating the sites where I interviewed, size of the MPA was not associated specifically with successful or unsuccessful sites. Nor were there overarching patterns where size of reserve was associated with implementation of community-based management in Chapter One, with very small reserves such as Manjuyod were successful and larger reserves such as Bindoy were not.

The relative size of reserves is more important than their absolute size; percentage of municipal waters in protection was positively related to biodiversity and abundance. This was demonstrated for example, by the fact Ipil, which has a relatively large percentage of protection in their municipal waters (9.5%), showed increased biodiversity after community-based management of marine reserves, while other cases, for example in Libertad, which only has 0.04% of their municipal waters under protection, did not show any differences with community-based management. In other cases, like in Manjuyod, there were still positive effects on biodiversity after community-based management was implemented, even though it had a very small amount (0.7%) of its municipal waters under protection. There were no patterns in perceptions of compliance, enforcement, or sentiments of the MPA in relation to the percent of protected area. The relationships between reserve size or percent protected with biodiversity and fish abundance were both nonlinear, which could be why MPA size and percent of area protected were influential variables in some cases but not others throughout the areas analyzed. The non-linearity is important to account for in future studies and implementation of reserves because often in ecological systems there can be time lags from implementation of a strategy to the biological response (i.e., increase of fish biomass), or there could be some type of tolerance threshold that results in a different response at a low-level input than a high-level input (i.e., population density or nutrients inputs).

Interestingly, one of the perceptions of fishers was that pollution was a factor in decreased fish abundance or catch. However, the GAM results showed that fish can be tolerant or even benefitted by proximity to dense human populations. While population density wasn’t a direct measure of nutrient or plastic pollution, where there are high densities of people, there is usually more pollutants of either source (Lestari & Trihadiningrum, 2019). This perception could be from their lived experience and witnessing plastic pollution on their coasts or from information from environmental NGOs or local governments being filtered down. While there are harmful effects of pollution on ecosystems (Shahidul Islam & Tanaka, 2004), it likely isn’t the primary cause of declining catch based on this research. That said, the interactions of multiple factors may synergistically compound impacts that were not studied in this chapter. For example, Zaneveld et al. (2016) found that nutrients and overfishing interact with temperature anomalies to impact coral health. Coral cover was a factor used in Chapter Three, and had mixed effects on biodiversity, fish abundance, and key fished species. Because of the synergistic effects between temperature, nutrients, and fishing pressure, future research should include climate variables and interactions between these different variables to uncover other impacts.

There are challenges in integrating social and ecological data, especially when data sources are acquired from third parties, because spatial or temporal scales often do not match. However, integrating these data into one framework and looking at what is going on socially and ecologically has allowed for a more holistic view on community-based managed marine reserves.

5.3 Recommendations and Next Steps

Often conservation efforts place a burden on the Global South (Sikor et al., 2014). Between the United Nations' and Philippines' goals to protect large swaths of marine environment, there will need to be a balance between the needs of fishers and conservation. People depend on the sea for its resources and regulating to the extent of harming livelihoods raises questions about ethics and equity (McClanahan et al., 2013; Richmond, 2013). Creating networks of smaller marine reserves can be that balance and has been shown to be successful (Gaines et al., 2010; Russ et al., 2008). Many of the reserves within the Philippines are closely associated with one another and may be functioning like a network already. Further, marine reserves should consider surrounding mangrove habitat for design or placement. Mangrove habitat has the potential to influence the abundance of important fishery species that fishers in the region depend on. Because of this, locally and nationally the Philippines should integrate mangrove restoration and conservation into MPA design. But beyond just designating marine reserves on a map, implementing a governance system that increases effectiveness of these reserves is vital. This research provided evidence that community-based management systems in the Philippines can increase the effectiveness of the marine reserves, even those that may have been designated for decades previously.

Additionally, the mechanisms as to how these community-based systems function are important to understand. I hypothesized at the start of this project that there would be a difference in the perceptions of compliance of the marine reserves at successful sites, those that had improved biodiversity after CBM was implemented, versus unsuccessful sites, those with no difference in biodiversity after CBM was implemented. What I found was that all of the fishing communities perceive high compliance from within their communities. I think what the most profound outcome of the interviews was, not that violations were occurring, but how communities perceive education and knowledge’s role in the success of their reserves. In successful sites, strong education campaigns were perceived to provide sufficient knowledge to community members and reduce violations, as opposed to the perceptions in unsuccessful sites that knowledge was insufficient and was a cause of violations occurring. This indicates that there is a gap in how education campaigns are conducted or a gap in understanding how informal knowledge is spread throughout a community. Development of social norms depend on both formal and informal transfer of knowledge.

Another aspect of knowledge transfer is inter-municipality collaboration. It appeared from the interviews that there is conflict or tension between residents of the coastal and non-coastal municipalities. Increasing collaboration or extending education campaigns beyond the coastal communities may reduce violations of the marine reserves. Providing some incentive for those outside the community may be needed to accomplish this, such as allowing them to register as fishers. By providing them with some legitimacy, it could result in more compliance with other rules, such as not fishing with poisons or spear-guns. For example, the implementation of fisheries registration in some villages has resulted in more effective monitoring and compliance of the fisheries (Peralta-Milan et al., 2012). Cross-community collaborative work has already begun with the local communities forming the BATMAN Alliance, which unifies the regulations and practices of the coastal communities of Bindoy, Ayungon, Tayasan, and Manjuyod. By forming governance practices that are the same across all of these communities, there is less ambiguity and conflict. It also sets clear boundaries what cooperative fishing agreements may or may not be acceptable. For example, Manjuyod and Tayasan do not allow fishing in each other's municipal waters, but Tayasan has an agreement with another municipality that does allow reciprocal fishing. This has resulted in those particular outside fishers adhering to the rules of the reserve. A similar relationship could be built with non-coastal municipalities as well.

As mentioned, fish abundance and biodiversity do not have a linear relationship with habitat availability or even level of protection of the reserve. Spatial ecosystem modeling can help inform how abiotic and biotic factors interact to support fish biomass in this area. There have been numerous ecosystem modeling efforts in the Philippines over the last few decades (Lachica-Aliño et al., 2006), such as modeling effects of loss of coral cover on fish biomass (Geronimo & Aliño, 2009) and impacts of illegal fishing on marine resources (Bacalso & Wolff, 2014). Both modeling examples also underscore the findings in this dissertation that habitat loss, such as areas of low mangrove area, does not always equate to a loss of abundance and that small-scale fisheries can have immense impact on the ecosystem.

While ecosystem models are important to advance scientific knowledge, using those models in a way that benefits both fishers and the ecosystem in ready to use formats is a continual need (Lachica-Aliño et al., 2006). Currently, there are thousands of marine reserves in the Philippines, potentially already acting like a network of marine reserves. However, there are gaps in the modeling framework that shows the connectivity between reserves and nursery habitats. Additionally, nursery habitats may support reef fish biomass from far beyond the nearest reach (Halpern, 2004). We should use socio-ecological system frameworks to incorporate social networks to understand how regulatory information flows through a community and the impact that has on the resources as part of the modeling system. Just as fishers may use social networks to share information about successful fishing areas (Turner et al., 2014), they can use social networks to share information about new or existing policies. Leveraging ecosystem modeling of marine reserve networks paired with information about social networks within local communities can lead to actionable solutions such as cooperative fishing agreements or inter-community regulatory actions to increase the effectiveness of existing or new marine reserves.

APPENDIX A – CHAPTER 2 SUPPLEMENTAL TABLES AND FIGURES

Table A.1 *Kruskal-Wallis statistic and P values for differences in biodiversity*

Site	n	statistic inside reserve	a. P reserve	statistic CBM	b. P CBM	statistic Interaction	c. P interaction
AYUNGON	49	14.14	0.0002*	0.40	0.525	14.69	0.002*
BINDOY_	48	3.11	0.078	1.32	0.250	4.25	0.235
CANTILA	73	0.14	0.710	7.55	0.006*	7.91	0.048*
CORTES_	83	3.79	0.051*	8.24	0.004*	10.89	0.012*
CULASI_	18	1.06	0.303	3.17	0.075	4.76	0.190
DAPACOR	30	2.96	0.085	0.28	0.598	4.62	0.202
DCARMEN	30	6.02	0.014*	1.31	0.253	8.03	0.045*
GUBATRA	50	6.97	0.008*	0.17	0.678	7.31	0.063
INABANG	59	2.15	0.143	3.80	0.051*	5.95	0.114
IPILBUL	51	1.94	0.163	0.86	0.354	3.03	0.386
LIBERTA	30	3.41	0.065	2.11	0.147	8.56	0.036*
LOOCBAH	30	1.60	0.206	0.33	0.567	3.87	0.276
LUBANG	30	3.26	0.071	0.01	0.930	3.27	0.352
MANJUYO	29	11.89	0.001*	1.53	0.215	13.57	0.004*
MASINLO	29	0.27	0.600	5.26	0.022*	6.63	0.085
MERCEDE	30	6.30	0.012*	0.05	0.826	6.35	0.096
SAGNAY_	47	0.12	0.733	1.08	0.298	1.15	0.765
SCARLOS	30	0.87	0.352	1.52	0.218	2.40	0.493
TAYASAN	24	0.85	0.356	1.82	0.178	2.78	0.428
TINAMBAC	89	0.33	0.560	6.58	0.010*	6.78	0.079

(a) tests reserve status (b) tests before or after CBM (c) tests the interactions between reserve status and CBM. * $P < 0.05$

Table A.2 *PERMANOVA results tested on the combination factors*

Site	**df**	**SS**	**Psuedo-F**	**P**	**perms**
AYUNGON	3	2.0418	1.918	0.0001	9754
BINDOY_	3	2.876	2.75	0.0001	9754
CANTILA	3	3.415	2.462	0.0001	9658
CORTES_	3	3.9008	2.563	0.0001	9730
CULASI_	3	2.15	1.748	0.0005	9831
DAPACOR	3	1.833	1.3127	0.0061	9738
DCARMEN	3	1.67	1.21	0.09	9809
GUBATRA	3	4.3305	2.8332	0.0001	9753
INABANG	3	2.9880	2.0102	0.0001	9720
IPILBUL	3	2.2795	1.8137	0.0001	9718
LIBERTA	3	1.6030	1.4806	0.0003	9687
LOOCBAH	3	2.4681	1.9531	0.0007	9815
LUBANG	3	3.1219	2.5431	0.0001	9804
MANJUYO	3	1.2406	1.2998	0.0065	9700
MASINLO	3	1.9240	1.6322	0.0003	9754
MERCEDE	3	2.4099	1.3887	0.0055	9767
SAGNAY_	3	1.761	1.3369	0.011	9776
SCARLOS	3	3.1592	2.8232	0.0001	9802
TAYASAN	3	1.3718	1.4787	0.0018	9755
TINAMBAC	3	3.4133	2.244	0.0001	9738

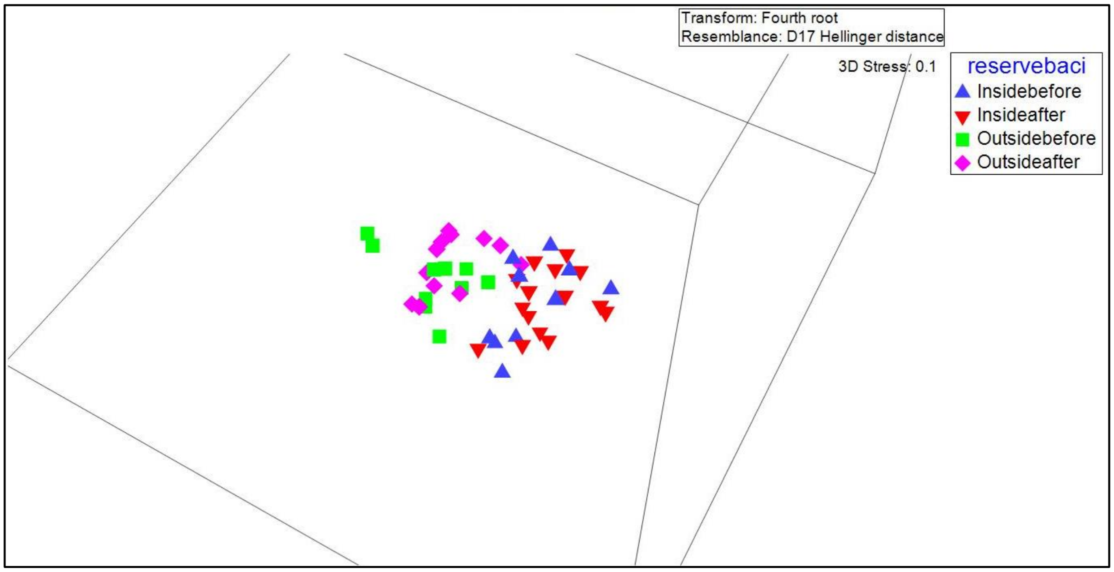

Figure A.1 *3D nMDS plot of fish species community structure similarities in Bindoy*

Triangles denote the community structure inside marine reserve (blue indicates before and red indicates after CBM implementation), and squares and diamonds outside of marine reserves, with squares indicating before, and diamonds indicating after CBM implementation.

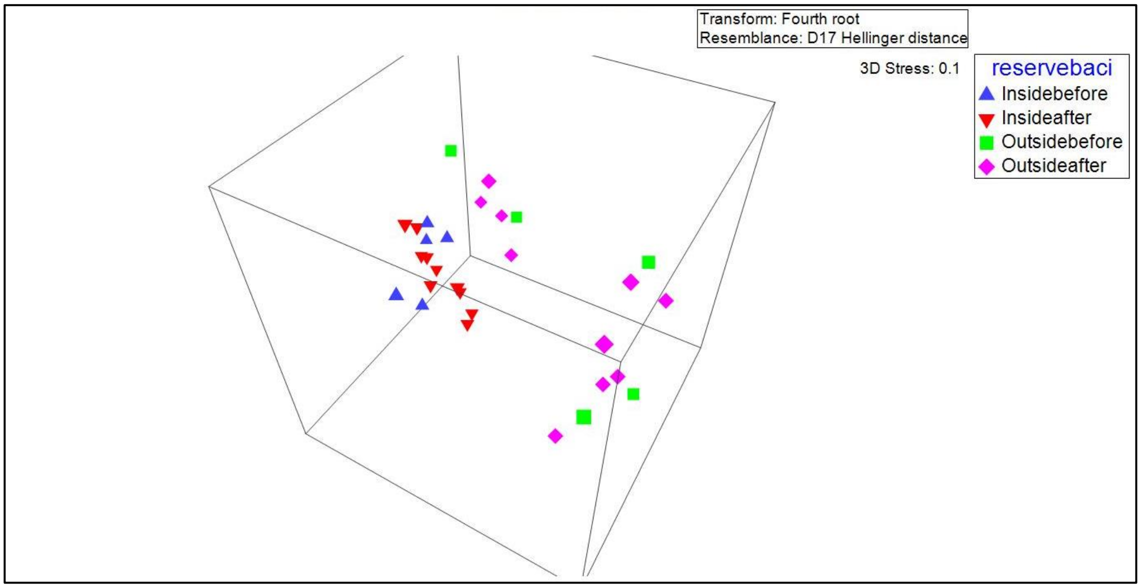

Figure A.2 *3D nMDS plot of fish species community structure similarities in Looc*

Triangles denote the community structure inside marine reserve (blue indicates before and red indicates after CBM implementation), and squares and diamonds outside of marine reserves, with squares indicating before, and diamonds indicating after CBM implementation.

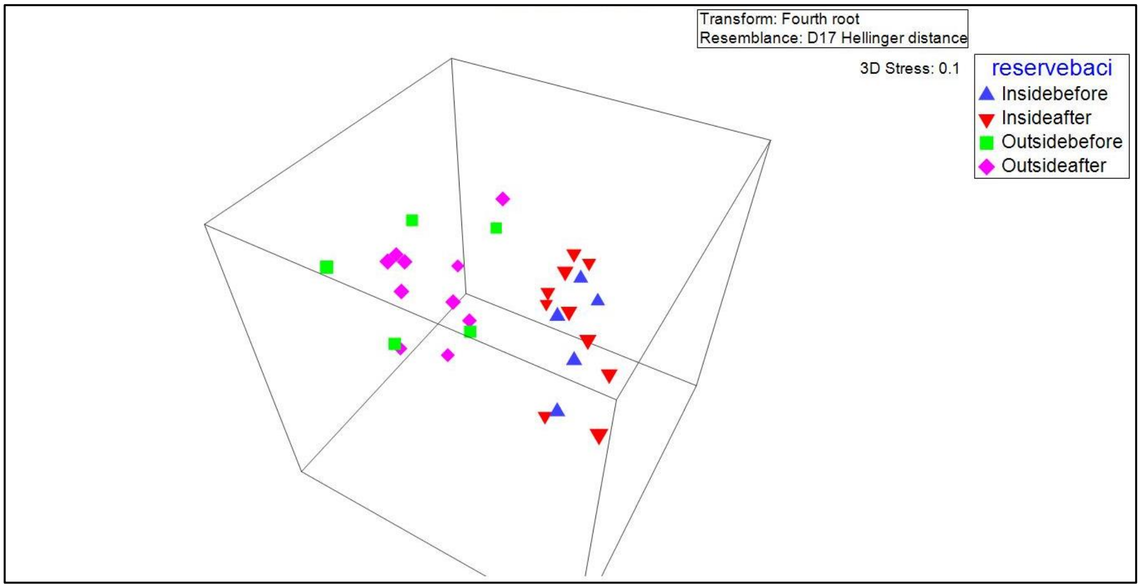

Figure A.3 *3D nMDS plot of fish species community structure similarities in Lubang*

Triangles denote the community structure inside marine reserve (blue indicates before and red indicates after CBM implementation), and squares and diamonds outside of marine reserves, with squares indicating before, and diamonds indicating after CBM implementation.

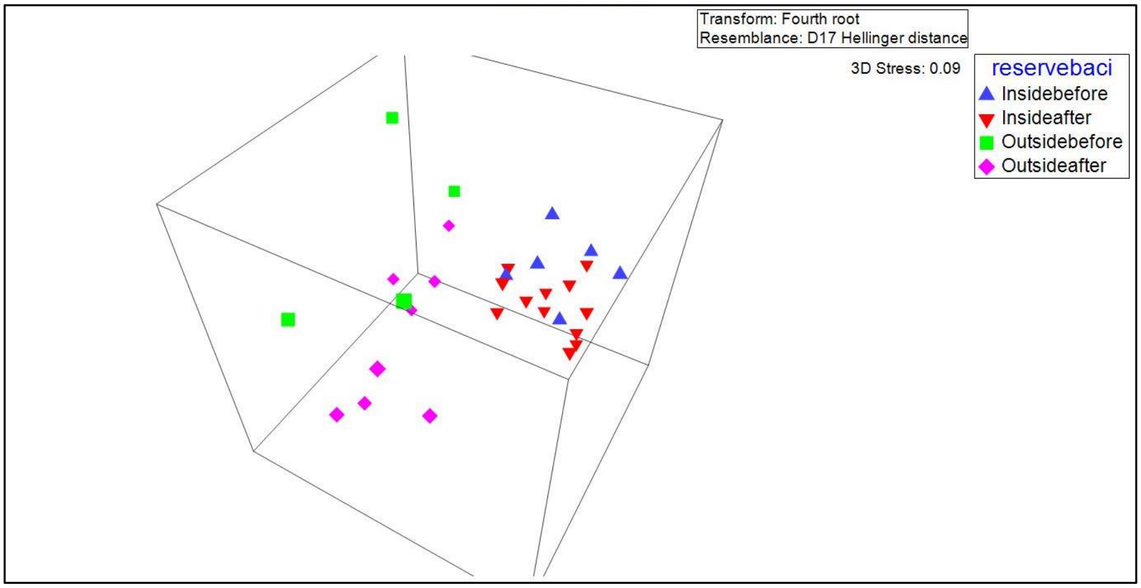

Figure A.4 *nMDS plot of fish species community structure similarities in San Carlos*

Triangles denote the community structure inside marine reserve (blue indicates before and red indicates after CBM implementation), and squares and diamonds outside of marine reserves, with squares indicating before, and diamonds indicating after CBM implementation.

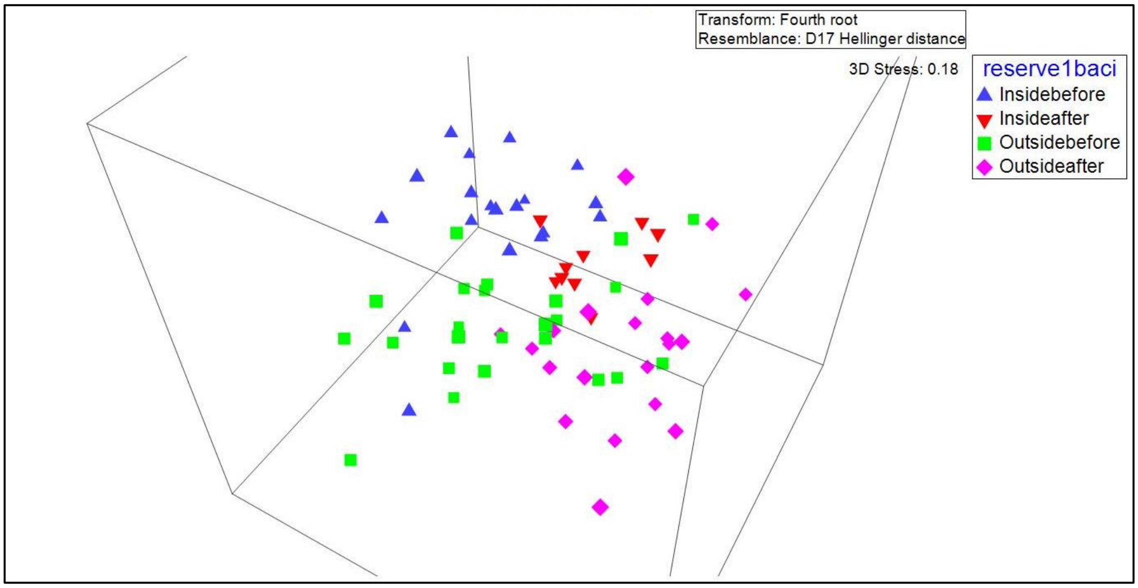

Figure A.5 *3D nMDS plot of fish species community structure similarities in Cantilan*

Triangles denote the community structure inside marine reserve (blue indicates before and red indicates after CBM implementation), and squares and diamonds outside of marine reserves, with squares indicating before, and diamonds indicating after CBM implementation.

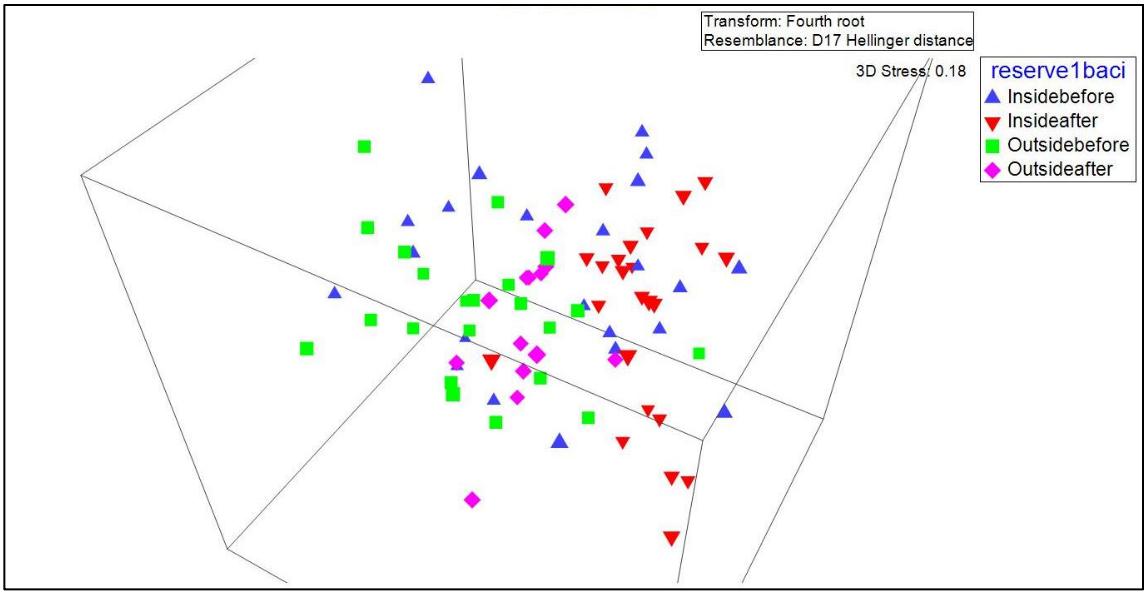

Figure A.6 *3D nMDS plot of fish species community structure similarities in Cortes*

Triangles denote the community structure inside marine reserve (blue indicates before and red indicates after CBM implementation), and squares and diamonds outside of marine reserves, with squares indicating before, and diamonds indicating after CBM implementation.

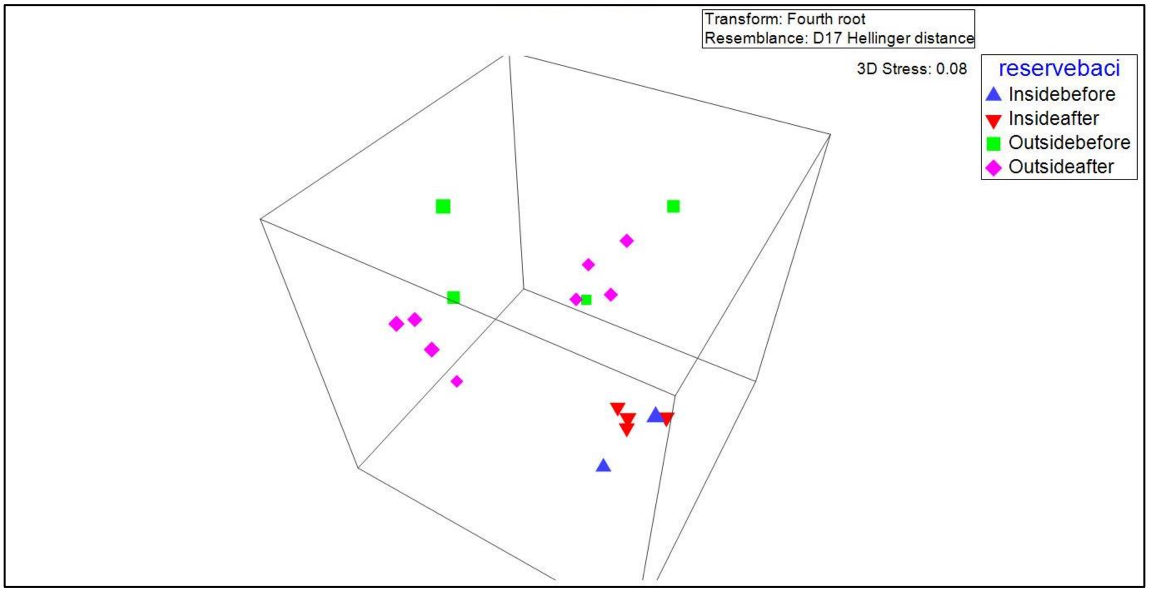

Figure A.7 *3D nMDS plot of fish species community structure similarities in Culasi*

Triangles denote the community structure inside marine reserve (blue indicates before and red indicates after CBM implementation), and squares and diamonds outside of marine reserves, with squares indicating before, and diamonds indicating after CBM implementation.

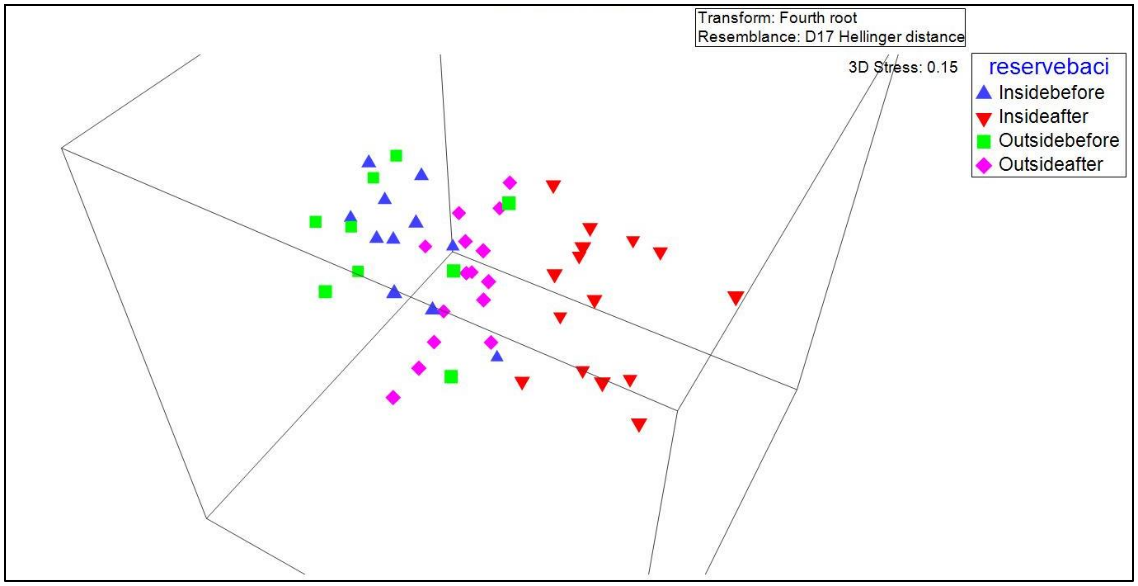

Figure A.8 *3D nMDS plot of fish species community structure similarities in Gubat*

Triangles denote the community structure inside marine reserve (blue indicates before and red indicates after CBM implementation), and squares and diamonds outside of marine reserves, with squares indicating before, and diamonds indicating after CBM implementation.

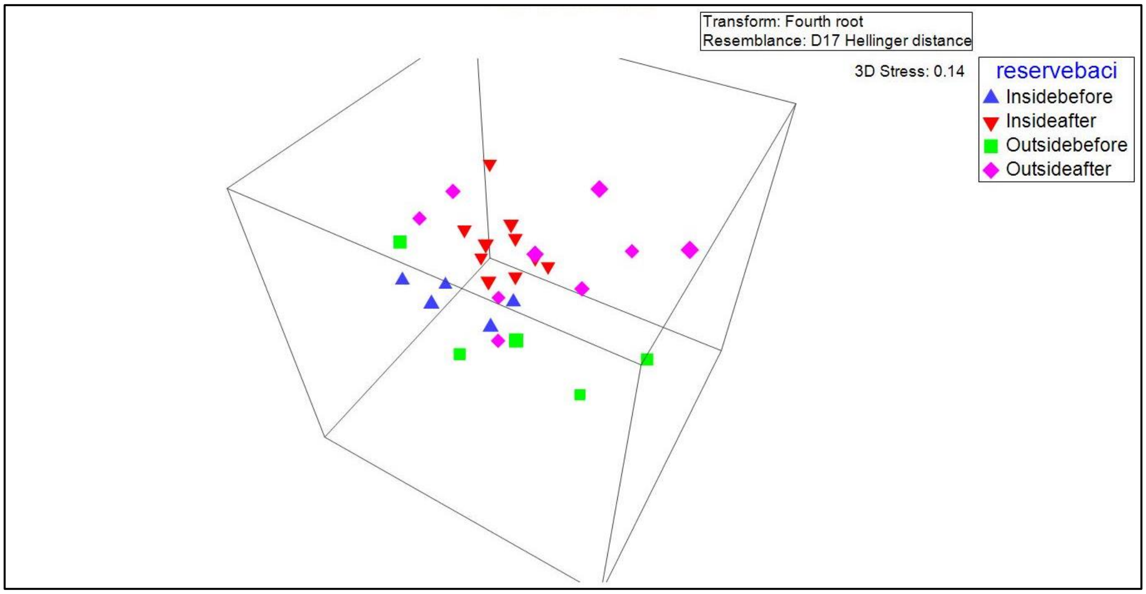

Figure A.9 *3D nMDS plot of fish species community structure similarities in Manjuyod*

Triangles denote the community structure inside marine reserve (blue indicates before and red indicates after CBM implementation), and squares and diamonds outside of marine reserves, with squares indicating before, and diamonds indicating after CBM implementation.

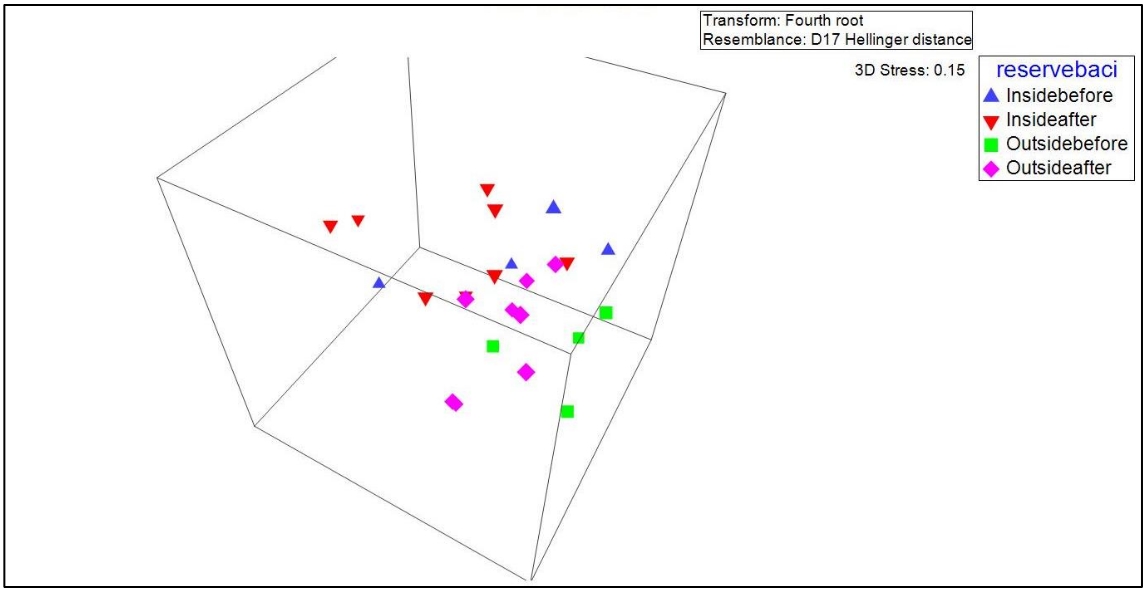

Figure A.10 *3D nMDS plot of fish species community structure similarities in Tayasan*

Triangles denote the community structure inside marine reserve (blue indicates before and red indicates after CBM implementation), and squares and diamonds outside of marine reserves, with squares indicating before, and diamonds indicating after CBM implementation.

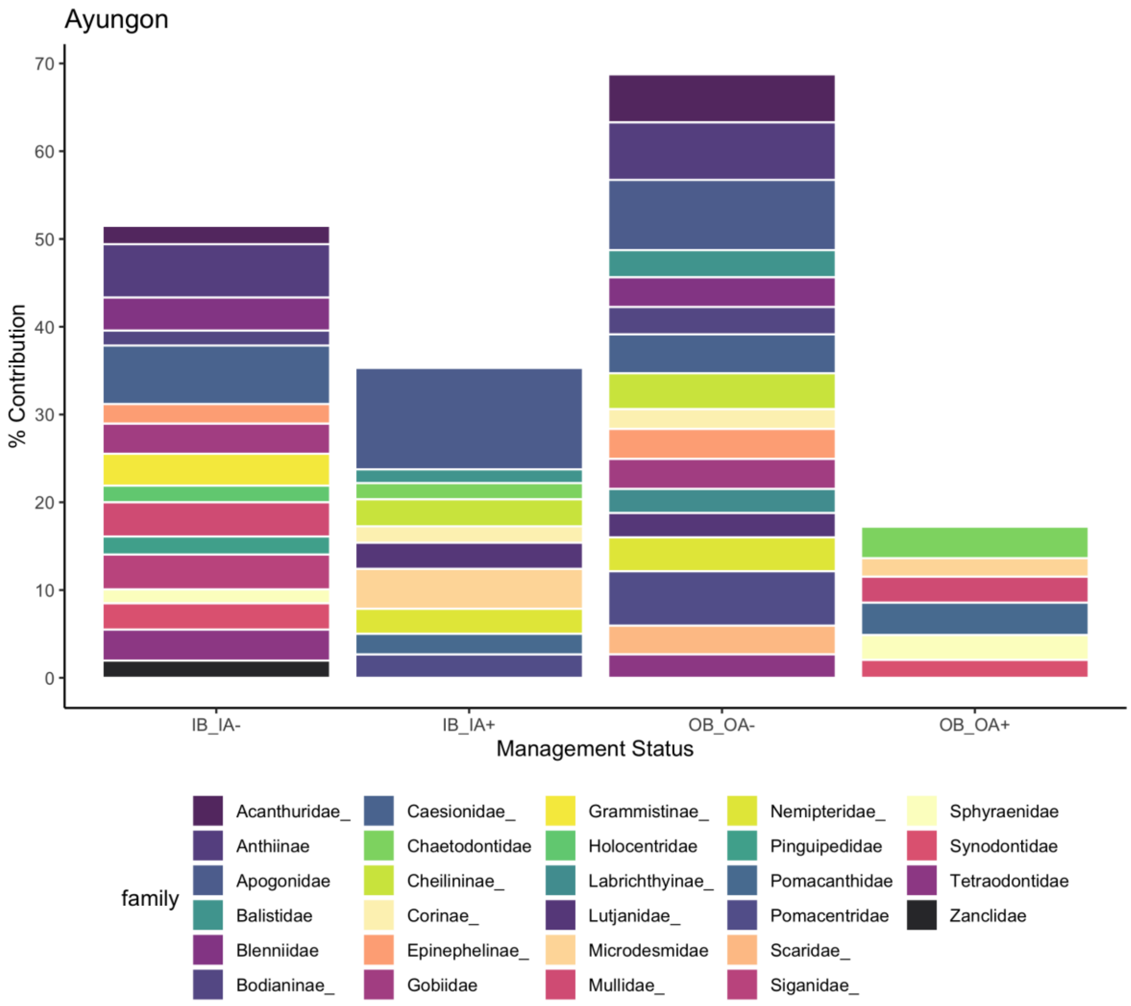

Figure A.11 *Percent contribution to the dissimilarity in Ayungon*

Between inside before and after (average dissimilarity 22.96) and outside marine reserves before and after (average dissimilarity 37.25) CBM, aggregated by family. OA = outside marine reserve, after CBM implementation, OB = outside marine reserve, before CBM implementation, IA = inside marine reserve, after CBM implementation, IB = inside marine reserve, before CBM implementation. + means that there was higher abundance after CBM, - means there was lower abundance after CBM.

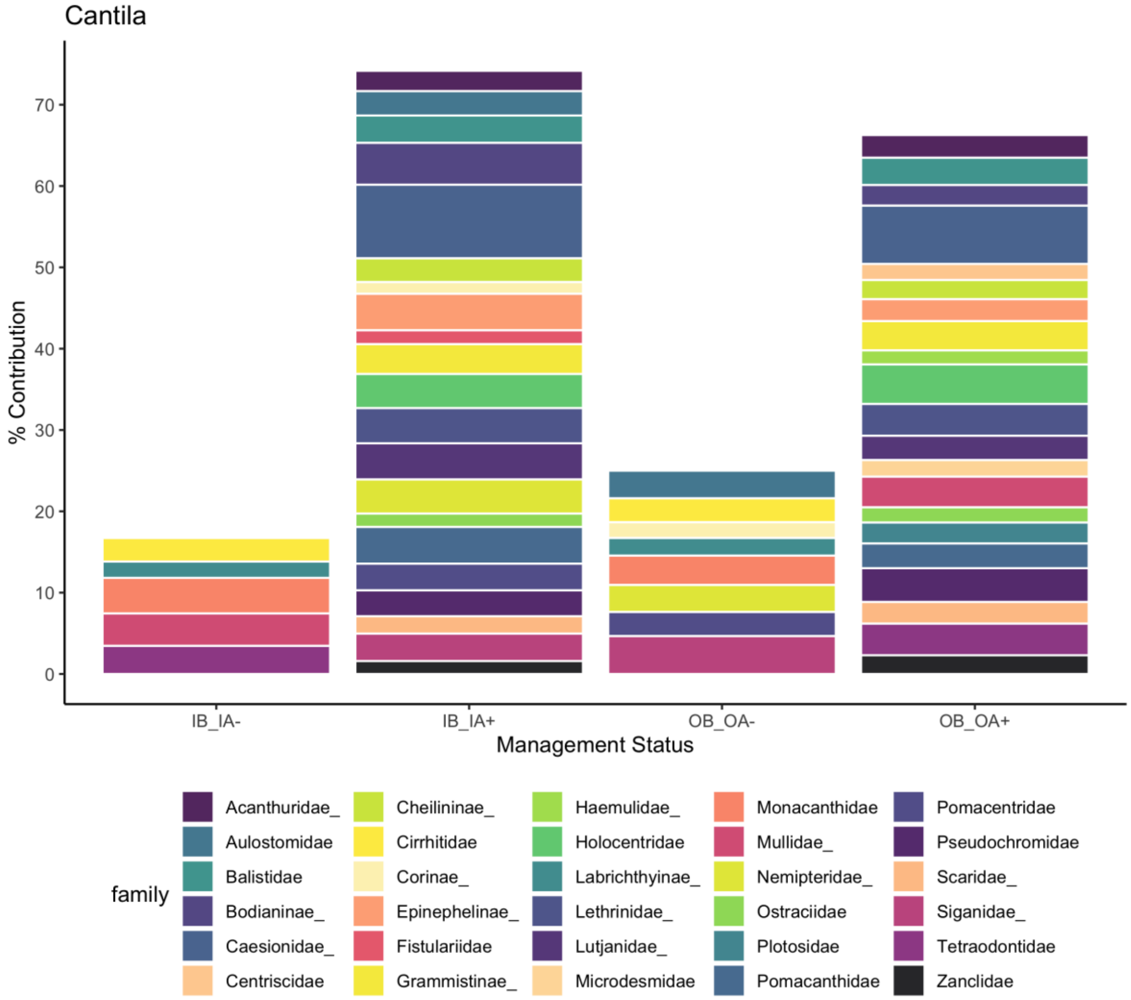

Figure A.12 *Percent contribution to the dissimilarity in Cantilan*

Between inside before and after (average dissimilarity 27.28) and outside marine reserves before and after (average dissimilarity 29.02) CBM, aggregated by family. OA = outside marine reserve, after CBM implementation, OB = outside marine reserve, before CBM implementation, IA = inside marine reserve, after CBM implementation, IB = inside marine reserve, before CBM implementation. + means that there was higher abundance after CBM, - means there was lower abundance after CBM.

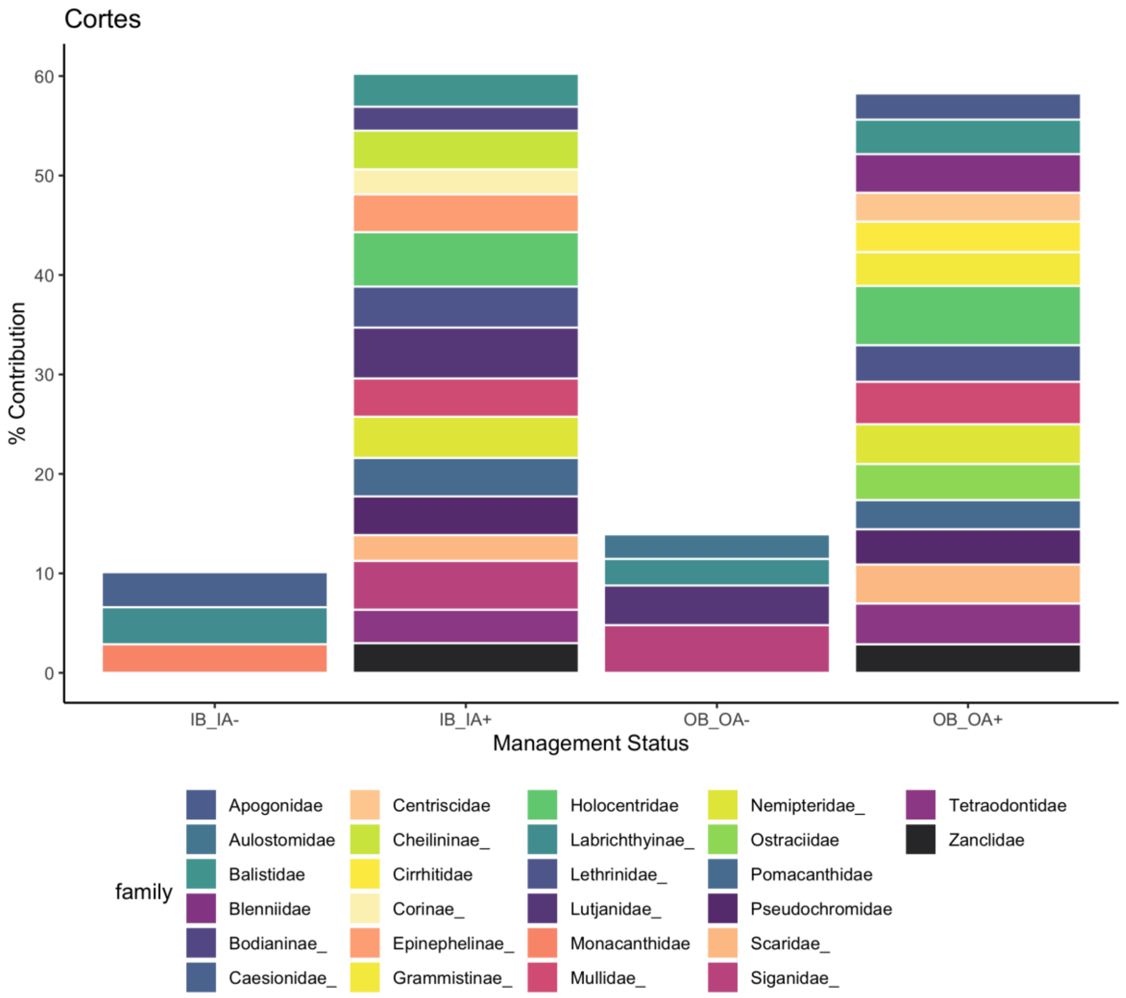

Figure A.13 *Percent contribution to the dissimilarity in Cortes*

Between inside before and after (average dissimilarity 33.31) and outside marine reserves before and after (average dissimilarity 32.26) CBM, aggregated by family. OA = outside marine reserve, after CBM implementation, OB = outside marine reserve, before CBM implementation, IA = inside marine reserve, after CBM implementation, IB = inside marine reserve, before CBM implementation. + means that there was higher abundance after CBM, - means there was lower abundance after CBM.

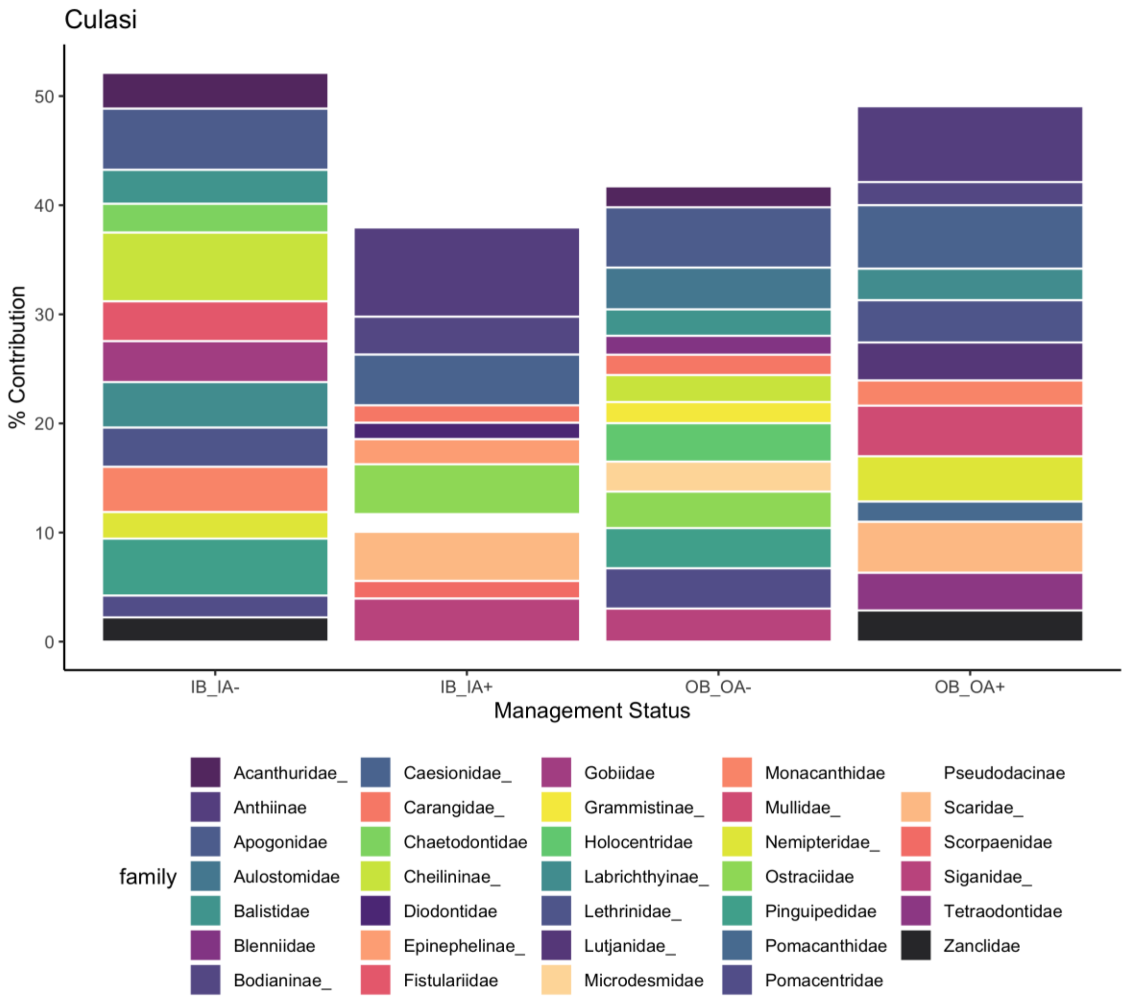

Figure A.14 *Percent contribution to the dissimilarity in Culasi*

Between inside before and after (average dissimilarity 20.11) and outside marine reserves before and after (average dissimilarity 26.82) CBM, aggregated by family. OA = outside marine reserve, after CBM implementation, OB = outside marine reserve, before CBM implementation, IA = inside marine reserve, after CBM implementation, IB = inside marine reserve, before CBM implementation. + means that there was higher abundance after CBM, - means there was lower abundance after CBM.

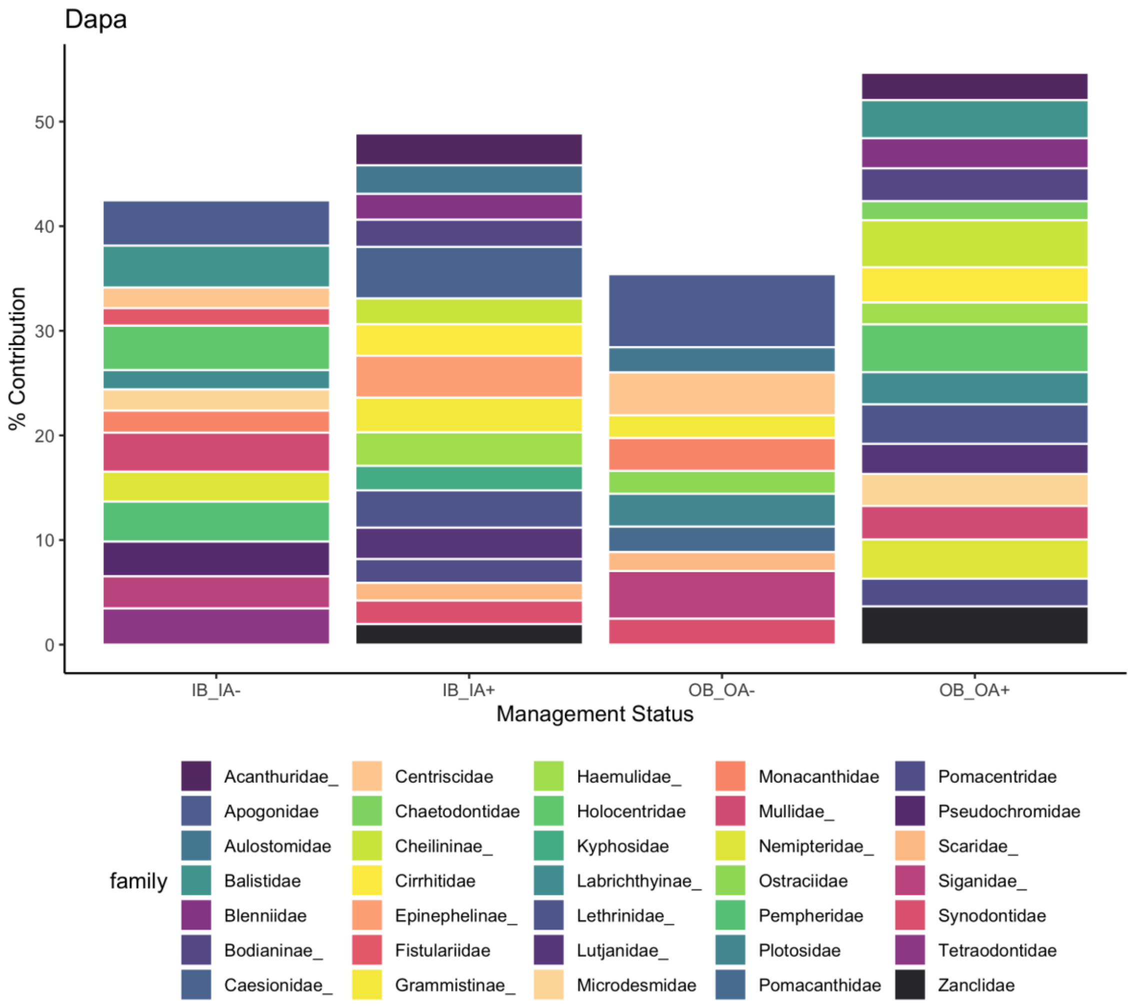

Figure A.15 *Percent contribution to the dissimilarity in Dapa.*

Between inside before and after (average dissimilarity 28.23) and outside marine reserves before and after (average dissimilarity 30.42) CBM in Dapa, aggregated by family. OA = outside marine reserve, after CBM implementation, OB = outside marine reserve, before CBM implementation, IA = inside marine reserve, after CBM implementation, IB = inside marine reserve, before CBM implementation. + means that there was higher abundance after CBM, - means there was lower abundance after CBM.

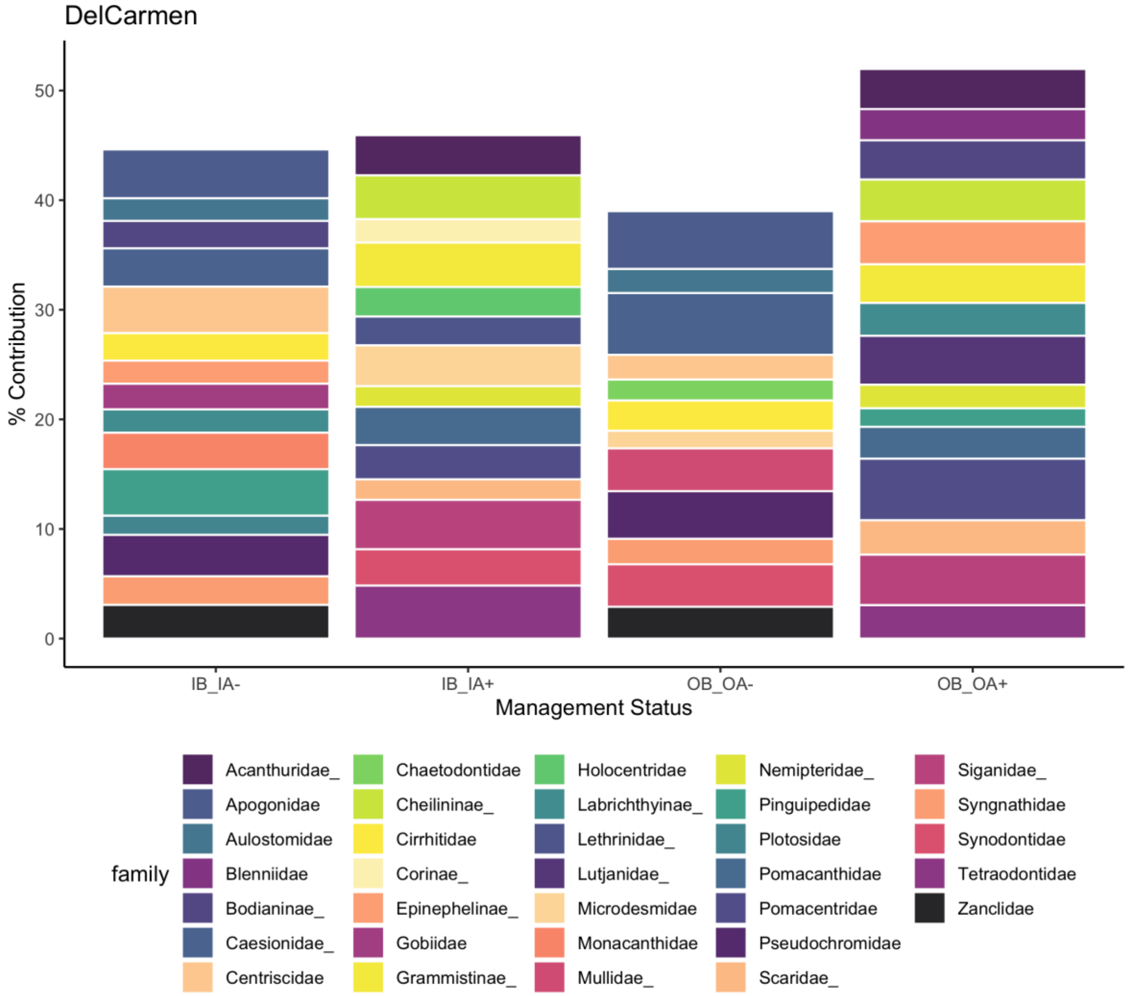

Figure A.16 *Percent contribution to the dissimilarity in Del Carmen*

Between inside before and after (average dissimilarity 26.69) and outside marine reserves before and after (average dissimilarity 28.71) CBM, aggregated by family. OA = outside marine reserve, after CBM implementation, OB = outside marine reserve, before CBM implementation, IA = inside marine reserve, after CBM implementation, IB = inside marine reserve, before CBM implementation. + means that there was higher abundance after CBM, - means there was lower abundance after CBM.

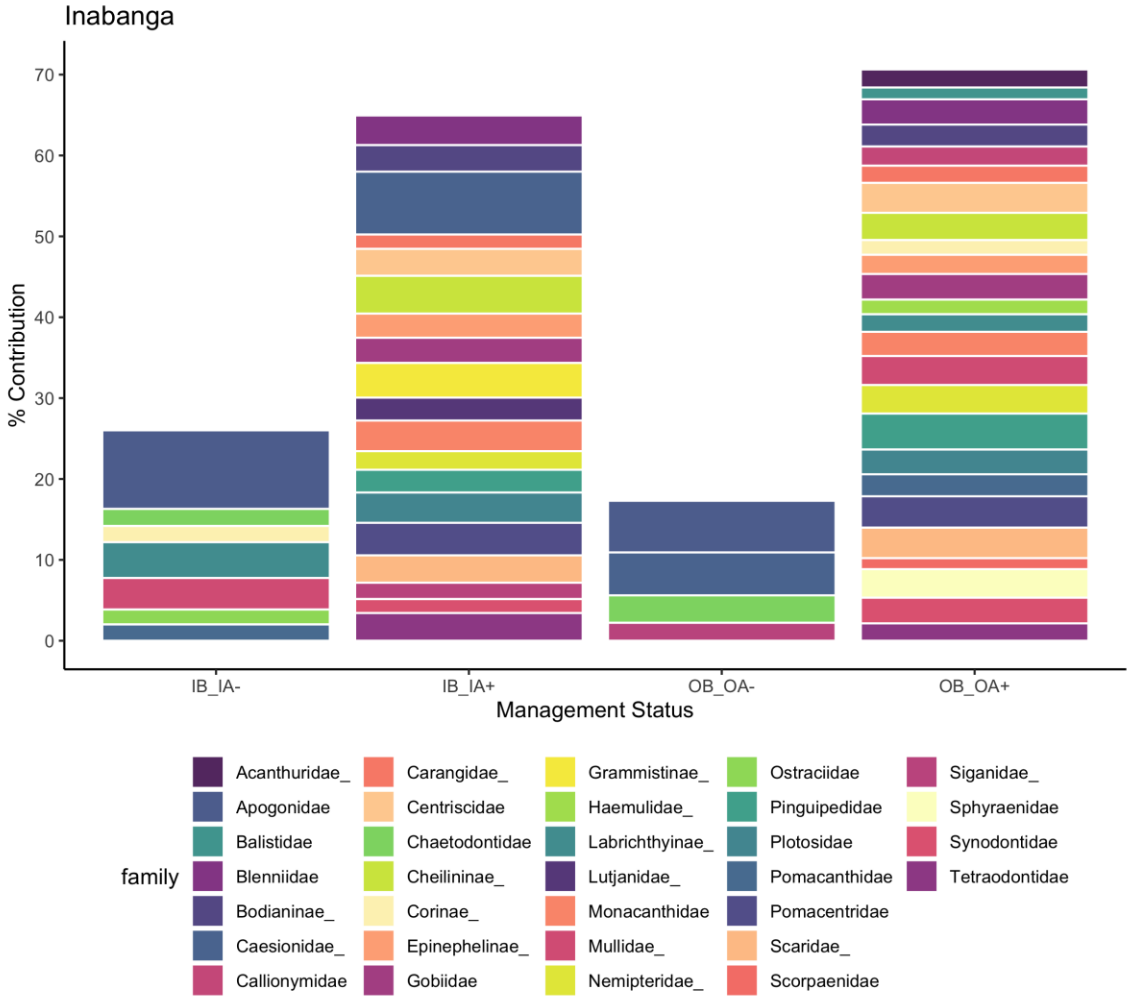

Figure A.17 *Percent contribution to the dissimilarity in Inabanga*

Between inside before and after (average dissimilarity 30.02) and outside marine reserves before and after (average dissimilarity 36.13) CBM, aggregated by family. OA = outside marine reserve, after CBM implementation, OB = outside marine reserve, before CBM implementation, IA = inside marine reserve, after CBM implementation, IB = inside marine reserve, before CBM implementation. + means that there was higher abundance after CBM, - means there was lower abundance after CBM.

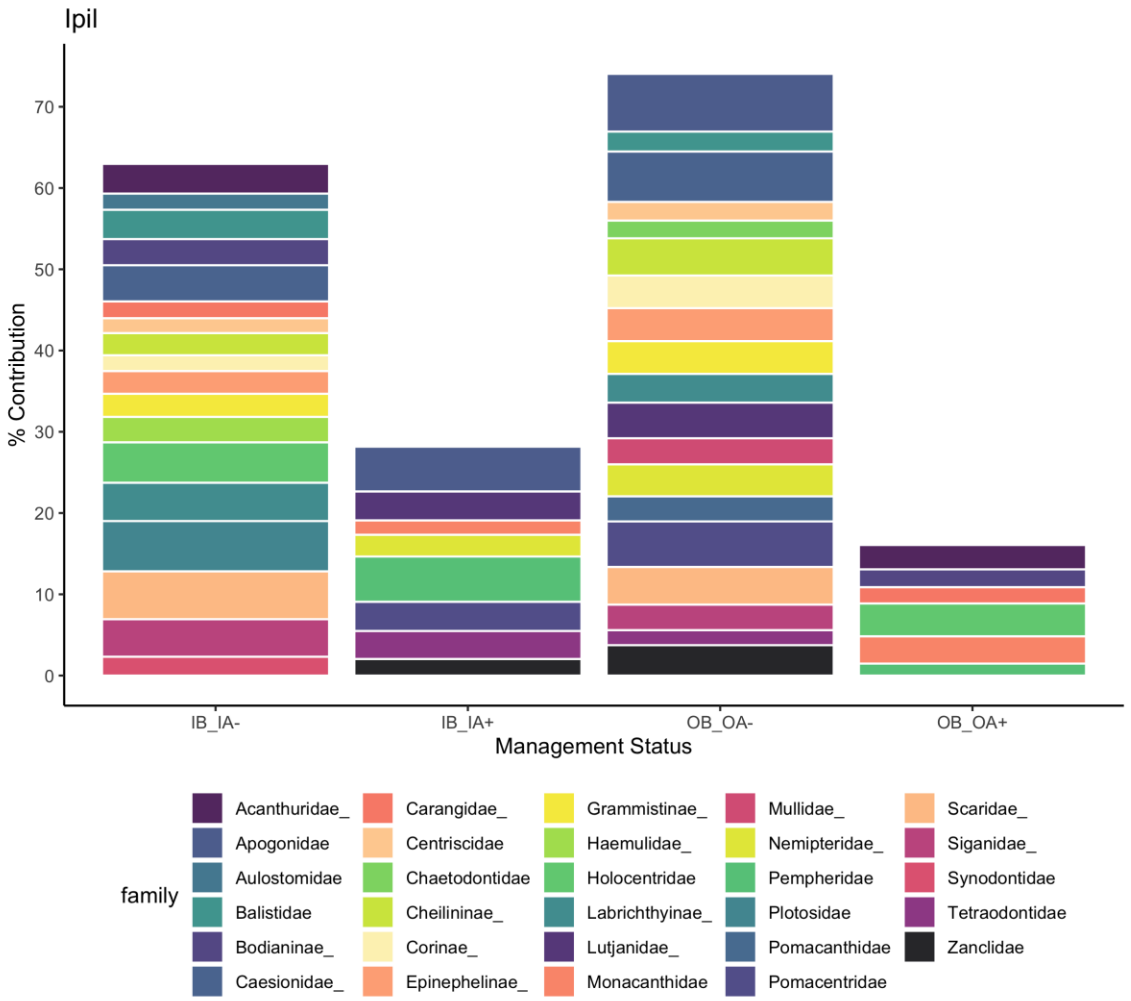

Figure A.18 *Percent contribution to the dissimilarity in Ipil*

Between inside before and after (average dissimilarity 25.33) and outside marine reserves before and after (average dissimilarity 37.29) CBM, aggregated by family. OA = outside marine reserve, after CBM implementation, OB = outside marine reserve, before CBM implementation, IA = inside marine reserve, after CBM implementation, IB = inside marine reserve, before CBM implementation. + means that there was higher abundance after CBM, - means there was lower abundance after CBM.

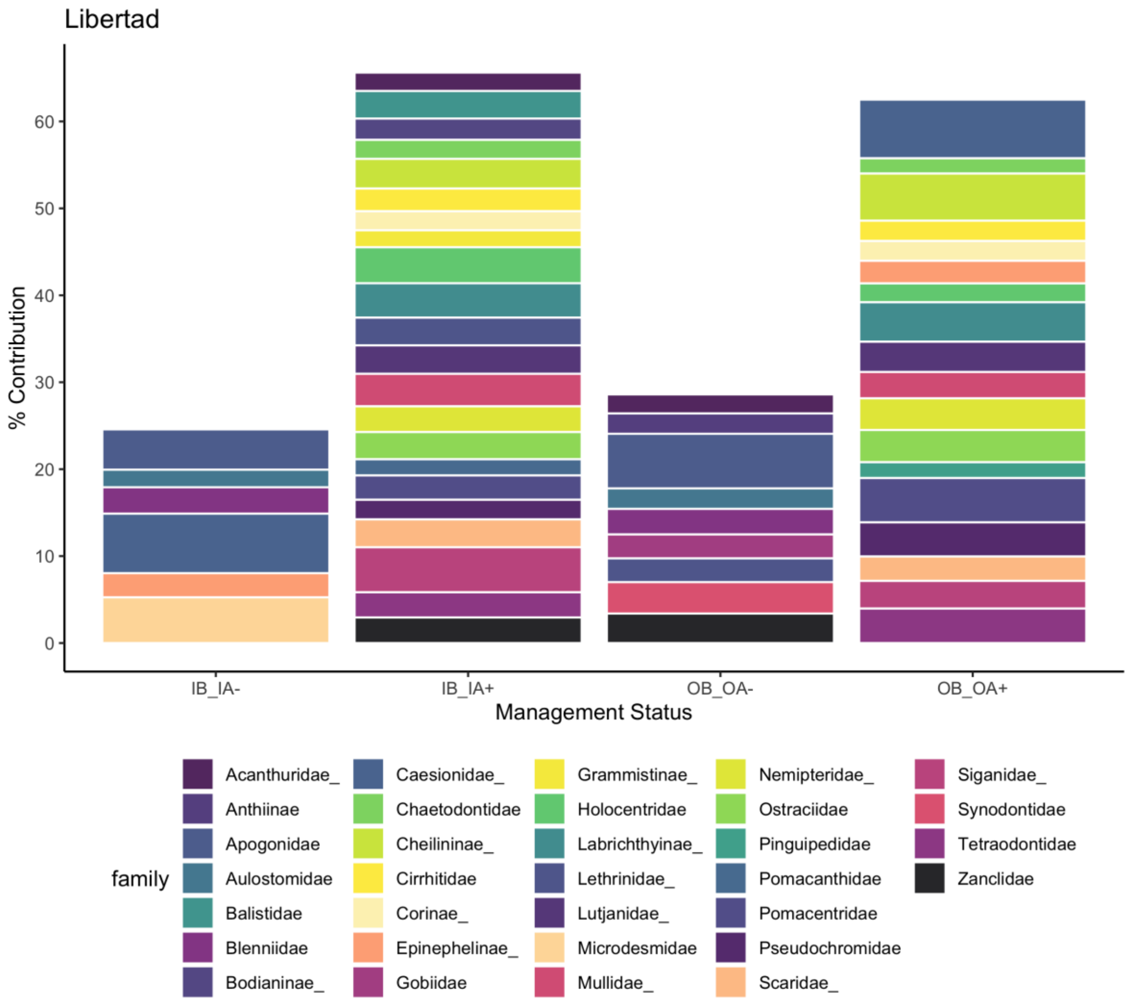

Figure A.19 *Percent contribution to the dissimilarity in Libertad*

Between inside before and after (average dissimilarity 32.38) and outside marine reserves before and after (average dissimilarity 28.41) CBM, aggregated by family. OA = outside marine reserve, after CBM implementation, OB = outside marine reserve, before CBM implementation, IA = inside marine reserve, after CBM implementation, IB = inside marine reserve, before CBM implementation. + means that there was higher abundance after CBM, - means there was lower abundance after CBM.

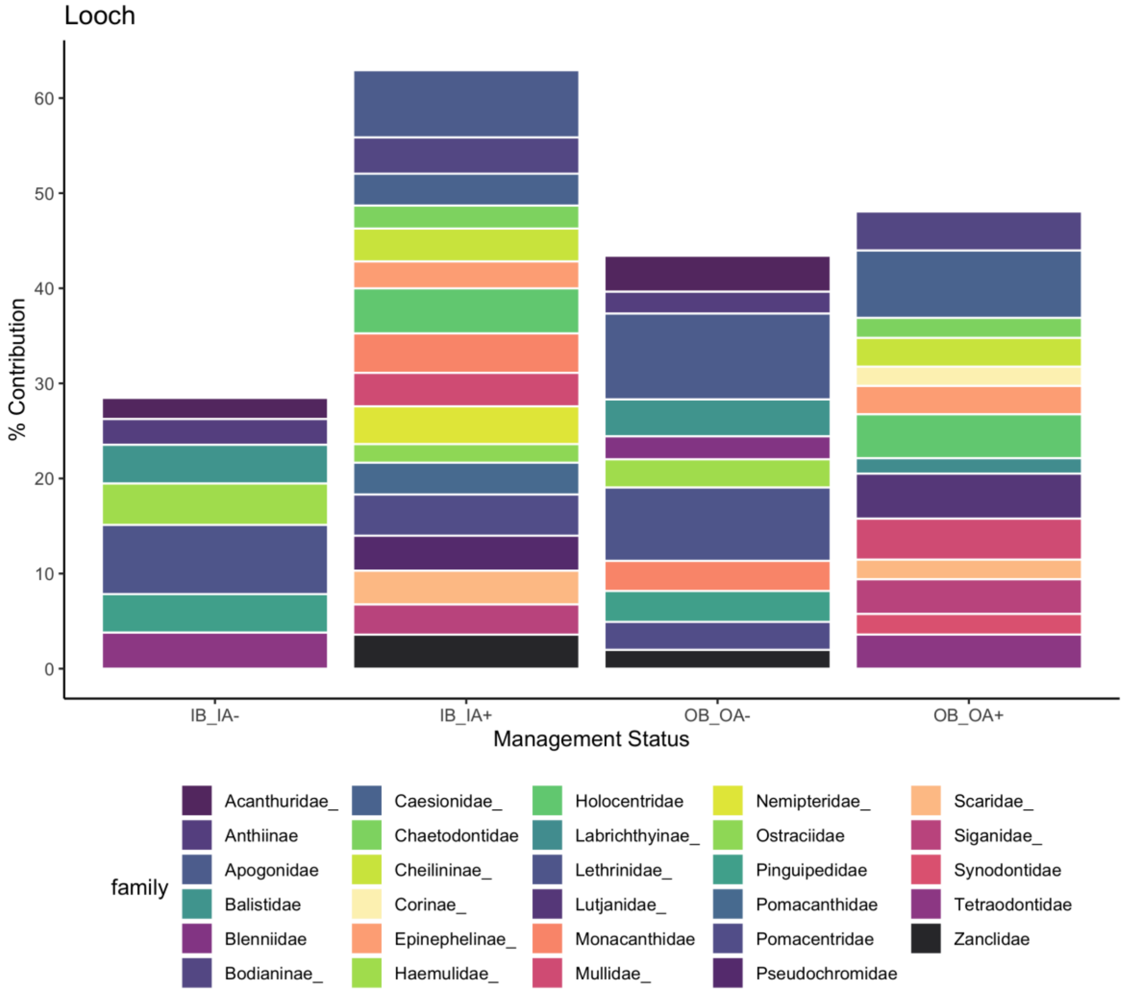

Figure A.20 *Percent contribution to the dissimilarity in Looc*

Between inside before and after (average dissimilarity 23.07) and outside marine reserves before and after (average dissimilarity 24.61) CBM, aggregated by family. OA = outside marine reserve, after CBM implementation, OB = outside marine reserve, before CBM implementation, IA = inside marine reserve, after CBM implementation, IB = inside marine reserve, before CBM implementation. + means that there was higher abundance after CBM, - means there was lower abundance after CBM.

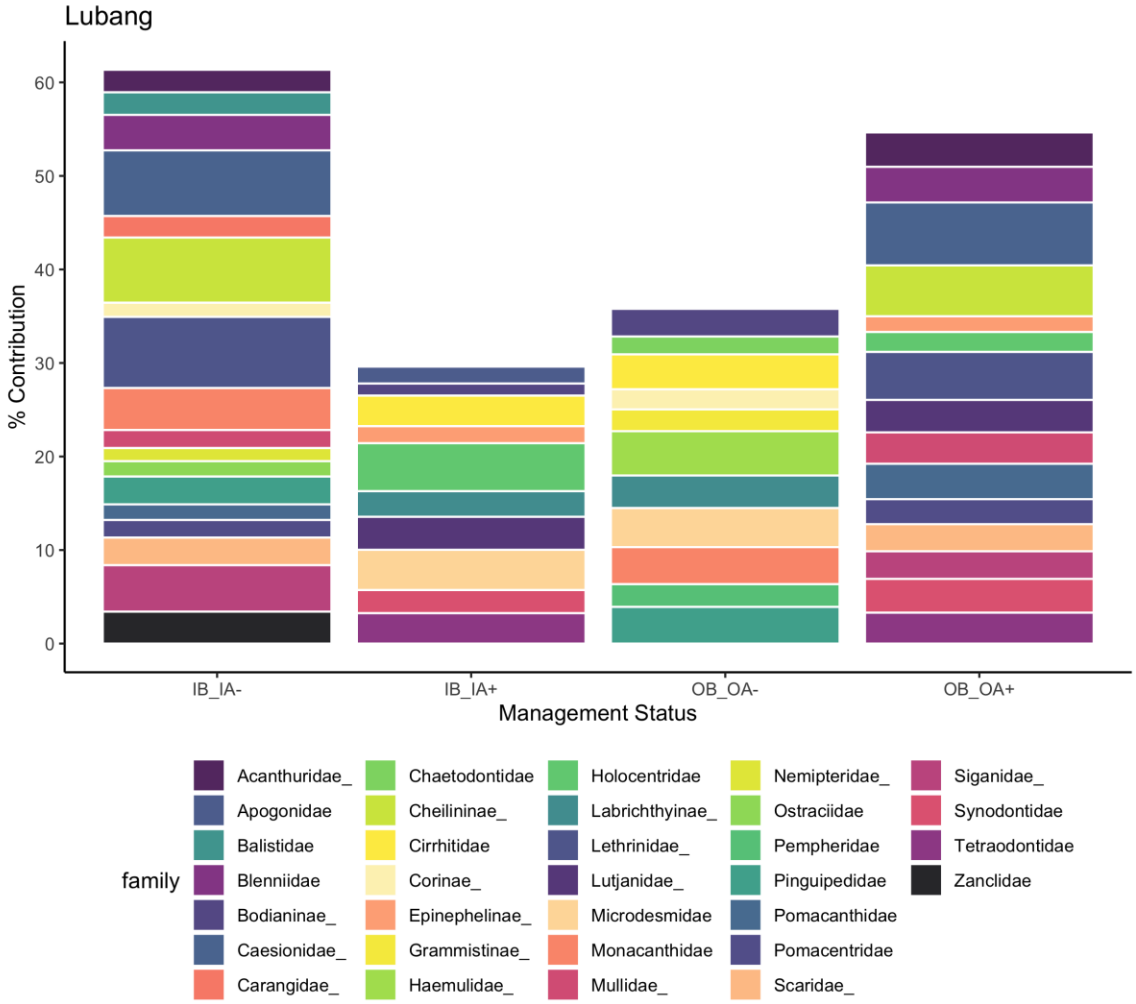

Figure A.21 *Percent contribution to the dissimilarity in Lubang*

Between inside before and after (average dissimilarity 21.31) and outside marine reserves before and after (average dissimilarity 26.38) CBM, aggregated by family. OA = outside marine reserve, after CBM implementation, OB = outside marine reserve, before CBM implementation, IA = inside marine reserve, after CBM implementation, IB = inside marine reserve, before CBM implementation. + means that there was higher abundance after CBM, - means there was lower abundance after CBM.

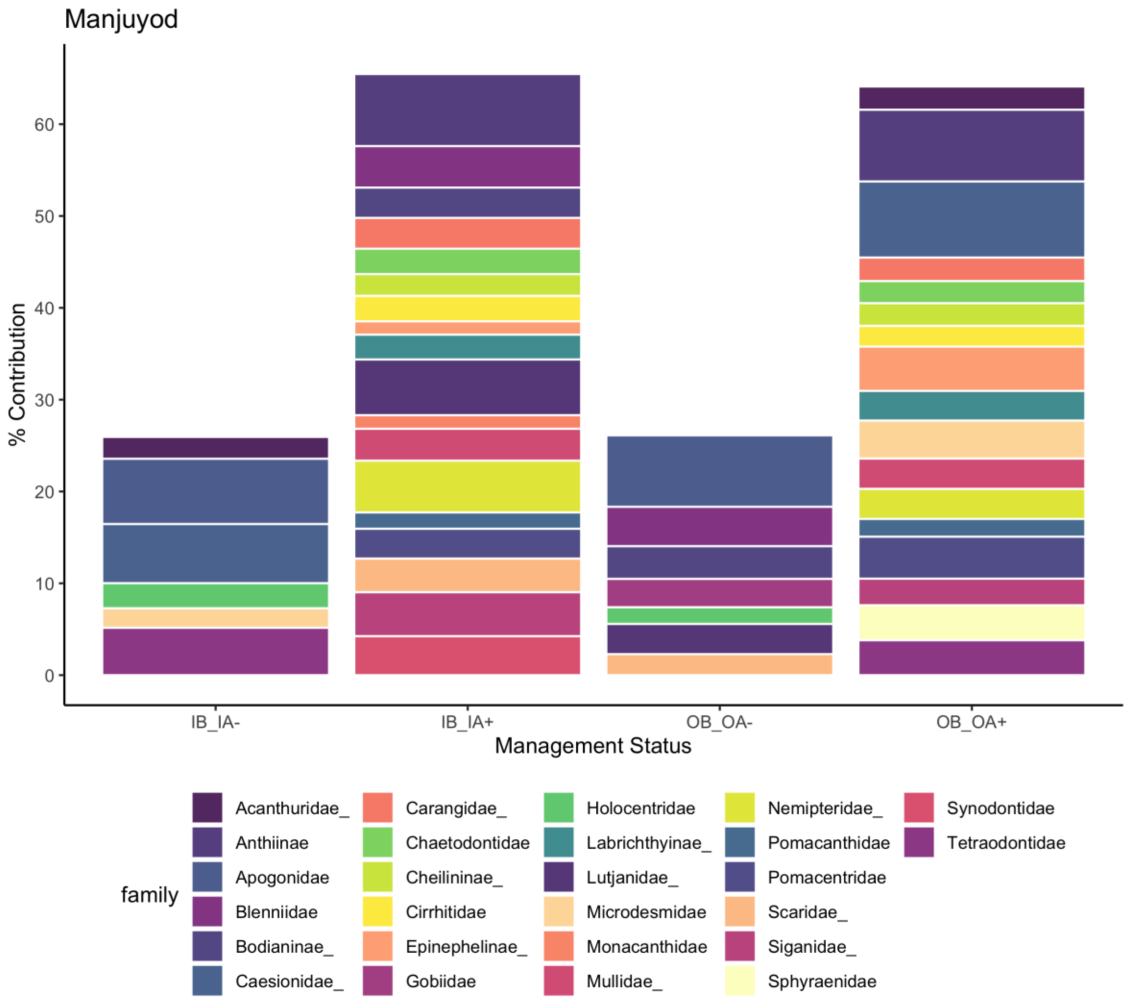

Figure A.22 *Percent contribution to the dissimilarity in Manjuyod*

Between inside before and after (average dissimilarity 20.14) and outside marine reserves before and after (average dissimilarity 22.31) CBM, aggregated by family. OA = outside marine reserve, after CBM implementation, OB = outside marine reserve, before CBM implementation, IA = inside marine reserve, after CBM implementation, IB = inside marine reserve, before CBM implementation. + means that there was higher abundance after CBM, - means there was lower abundance after CBM.

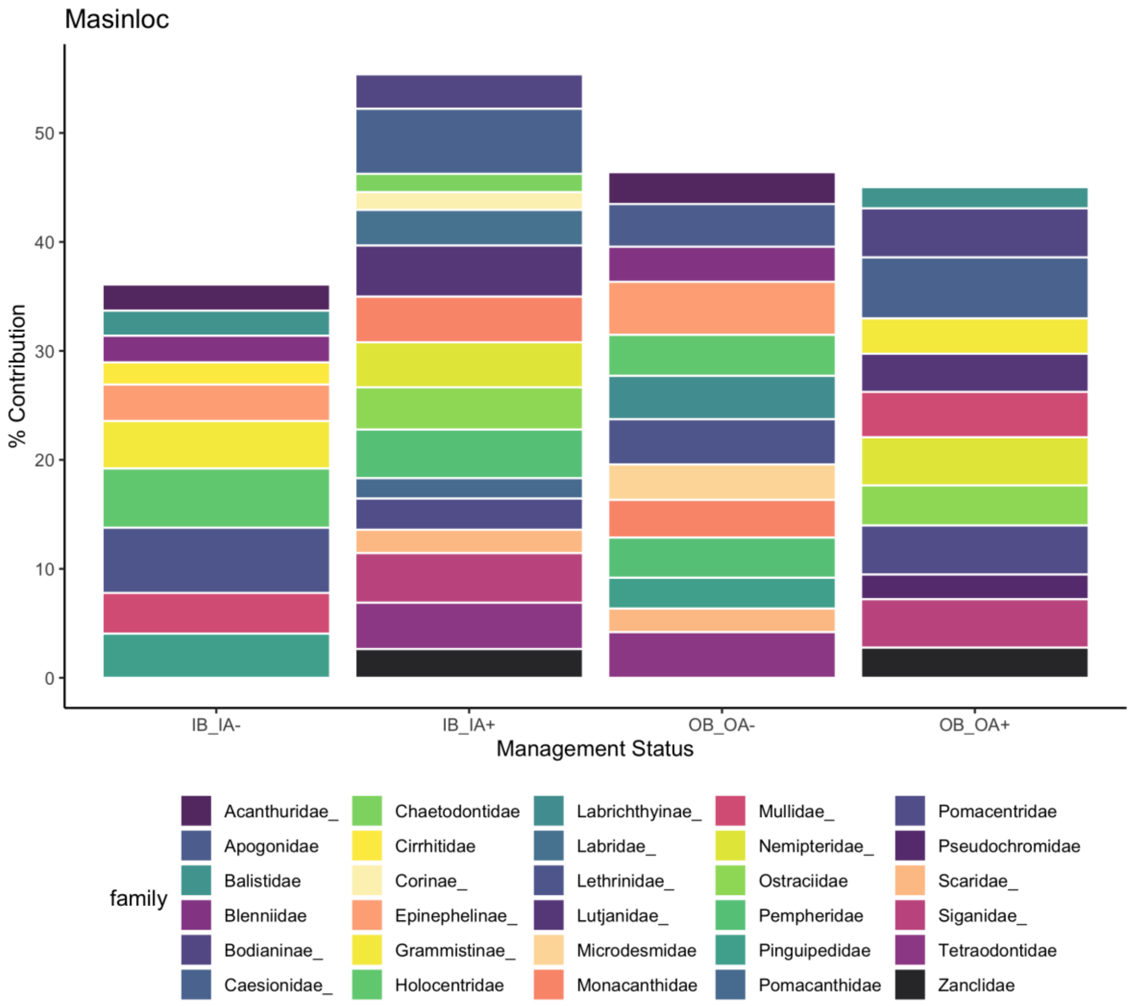

Figure A.23 *Percent contribution to the dissimilarity in Masinloc*

Between inside before and after (average dissimilarity 24.42) and outside marine reserves before and after (average dissimilarity 25.00) CBM, aggregated by family. OA = outside marine reserve, after CBM implementation, OB = outside marine reserve, before CBM implementation, IA = inside marine reserve, after CBM implementation, IB = inside marine reserve, before CBM implementation. + means that there was higher abundance after CBM, - means there was lower abundance after CBM.

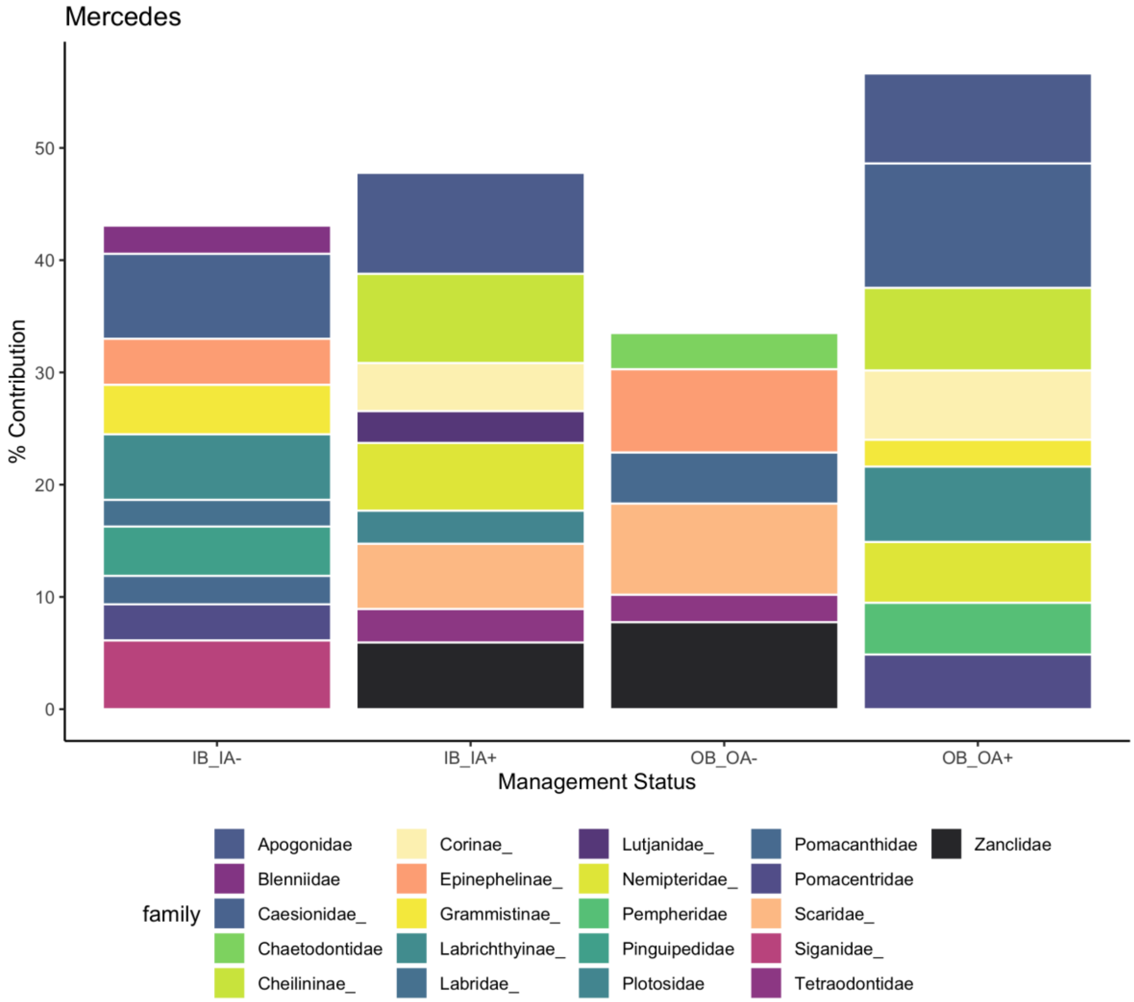

Figure A.24 *Percent contribution to the dissimilarity in Mercedes*

Between inside before and after (average dissimilarity 30.89) and outside marine reserves before and after (average dissimilarity 34.70) CBM, aggregated by family. OA = outside marine reserve, after CBM implementation, OB = outside marine reserve, before CBM implementation, IA = inside marine reserve, after CBM implementation, IB = inside marine reserve, before CBM implementation. + means that there was higher abundance after CBM, - means there was lower abundance after CBM.

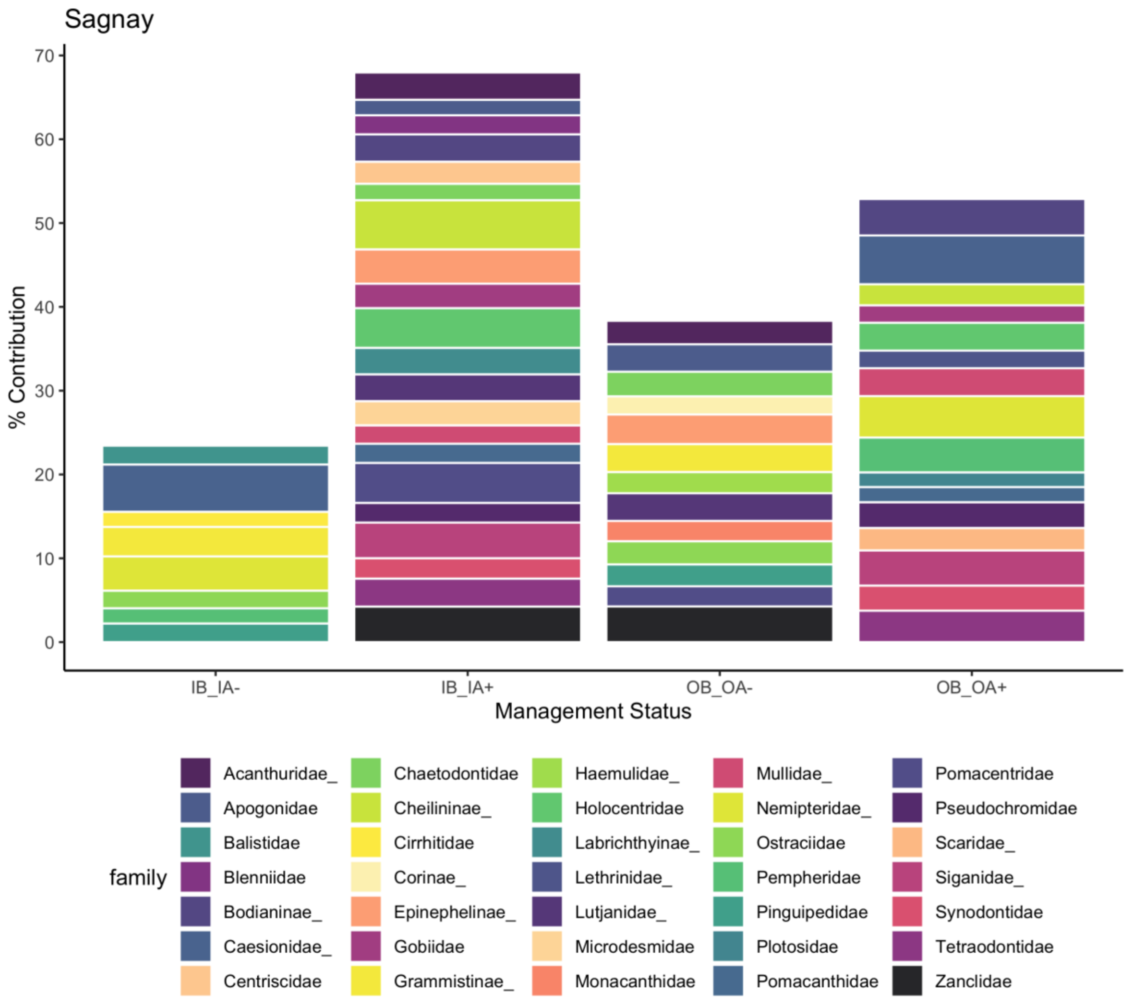

Figure A.25 *Percent contribution to the dissimilarity in Sagnay*

Between inside before and after (average dissimilarity 28.27) and outside marine reserves before and after (average dissimilarity 30.05) CBM, aggregated by family. OA = outside marine reserve, after CBM implementation, OB = outside marine reserve, before CBM implementation, IA = inside marine reserve, after CBM implementation, IB = inside marine reserve, before CBM implementation. + means that there was higher abundance after CBM, - means there was lower abundance after CBM.

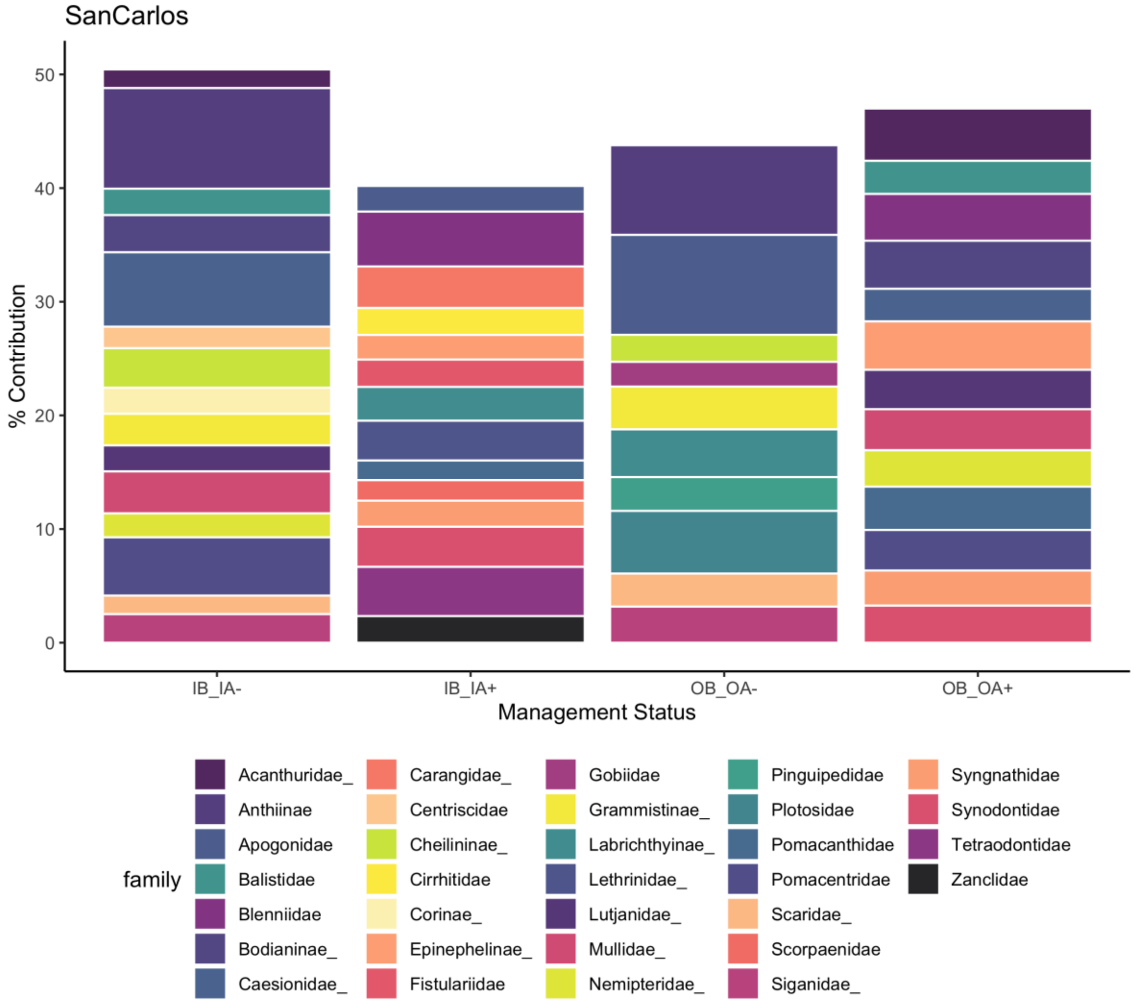

Figure A.26 *Percent contribution to the dissimilarity in San Carlos*

Between inside before and after (average dissimilarity 21.82) and outside marine reserves before and after (average dissimilarity 33.77) CBM, aggregated by family. OA = outside marine reserve, after CBM implementation, OB = outside marine reserve, before CBM implementation, IA = inside marine reserve, after CBM implementation, IB = inside marine reserve, before CBM implementation. + means that there was higher abundance after CBM, - means there was lower abundance after CBM.

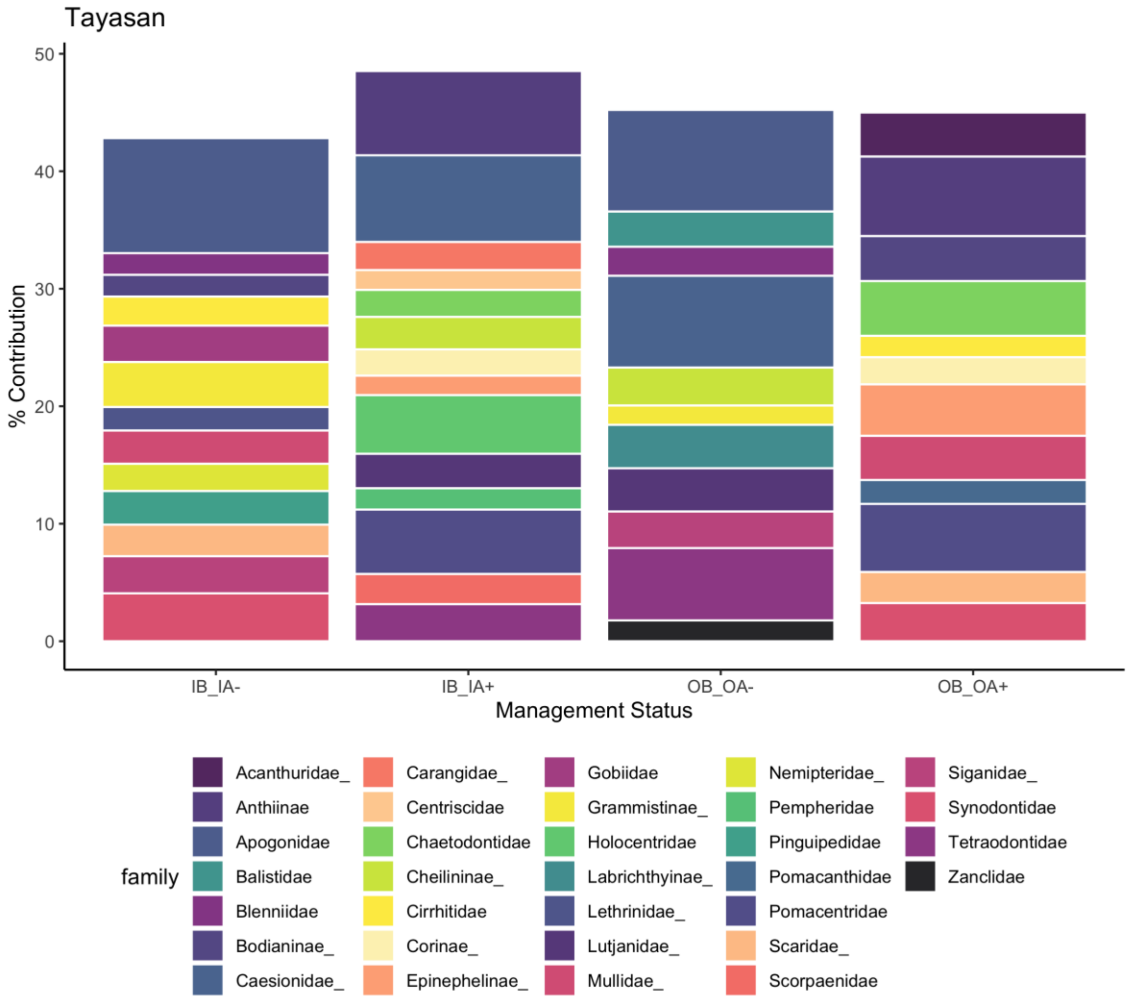

Figure A.27 *Percent contribution to the dissimilarity in Tayasan*

Between inside before and after (average dissimilarity 24.53) and outside marine reserves before and after (average dissimilarity 24.95) CBM, aggregated by family. OA = outside marine reserve, after CBM implementation, OB = outside marine reserve, before CBM implementation, IA = inside marine reserve, after CBM implementation, IB = inside marine reserve, before CBM implementation. + means that there was higher abundance after CBM, - means there was lower abundance after CBM.

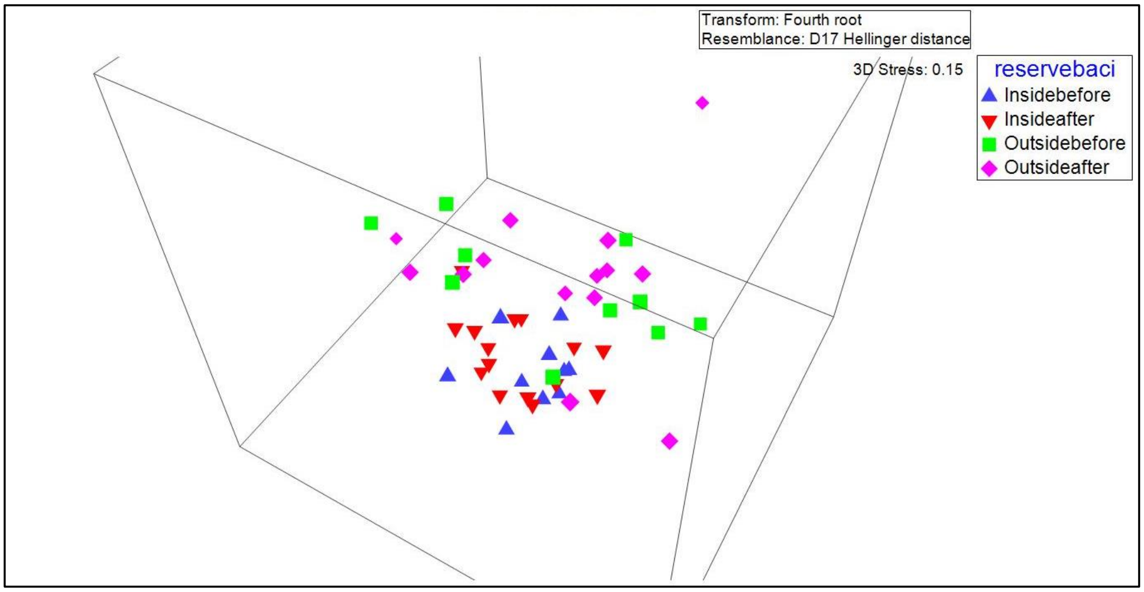

Figure A.28 *3D nMDS plot of fish species community structure similarities in Ayungon*

Triangles denote the community structure inside marine reserve (blue indicates before and red indicates after CBM implementation), and squares and diamonds outside of marine reserves, with squares indicating before, and diamonds indicating after CBM implementation.

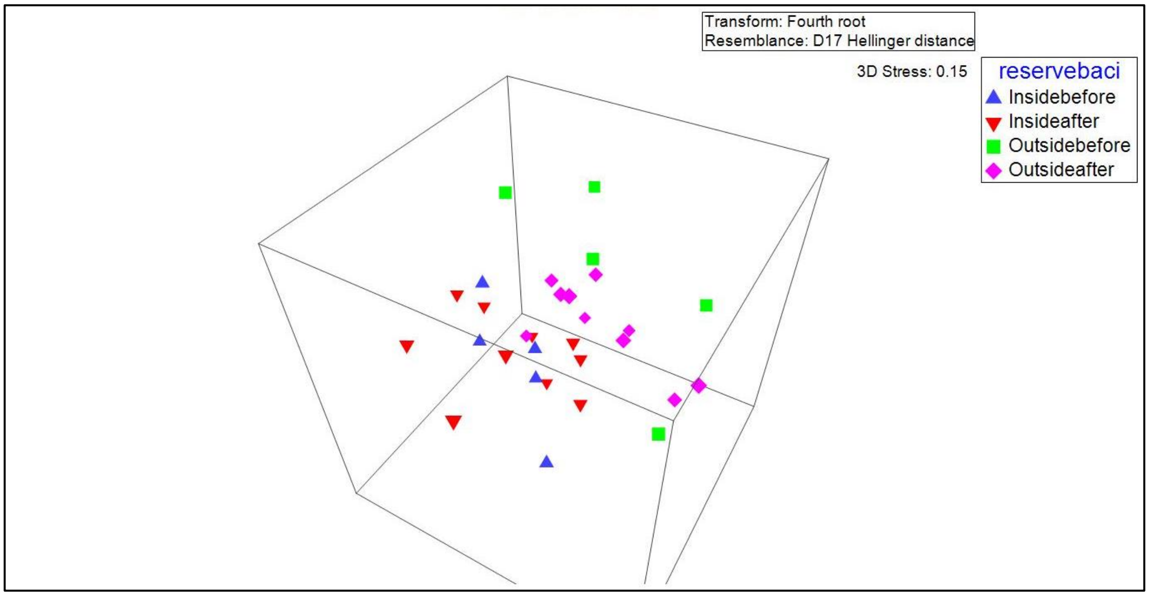

Figure A.29 *3D nMDS plot of fish species community structure similarities in Dapa*

Triangles denote the community structure inside marine reserve (blue indicates before and red indicates after CBM implementation), and squares and diamonds outside of marine reserves, with squares indicating before, and diamonds indicating after CBM implementation.

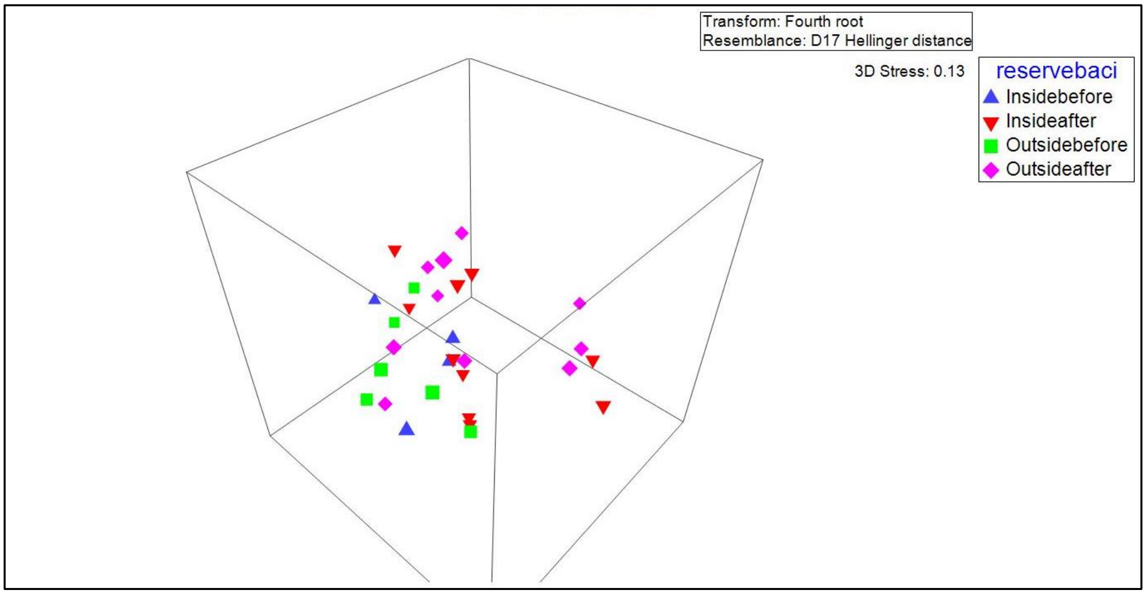

Figure A.30 *3D nMDS plot of fish species community structure similarities in Del Carmen*

Triangles denote the community structure inside marine reserve (blue indicates before and red indicates after CBM implementation), and squares and diamonds outside of marine reserves, with squares indicating before, and diamonds indicating after CBM implementation.

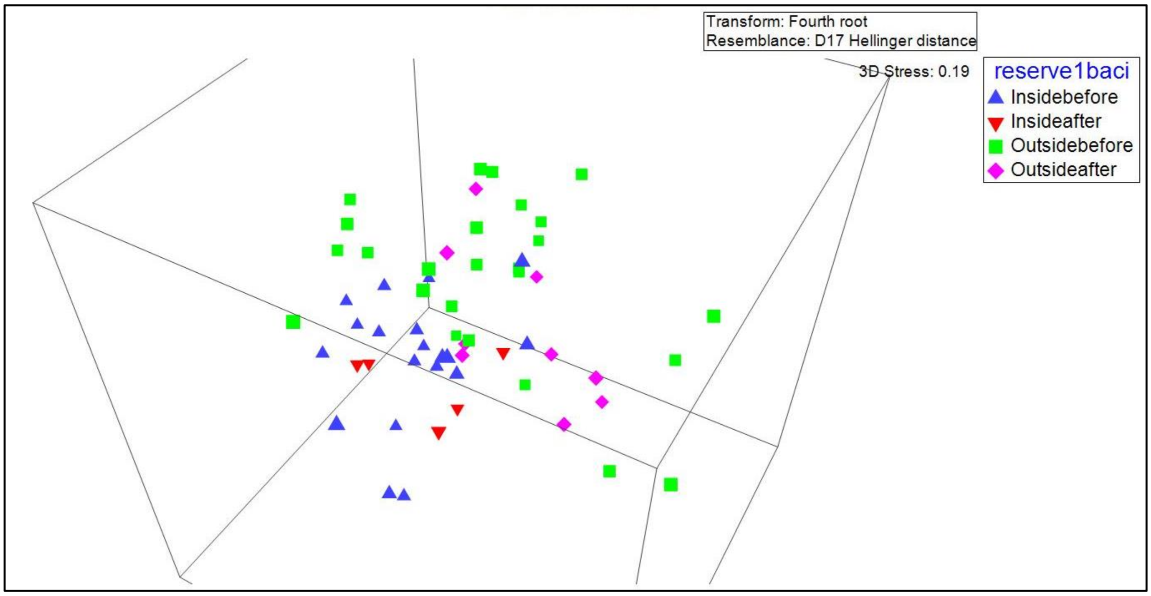

Figure A.31 *3D nMDS plot of fish species community structure similarities in Inabanga*

Triangles denote the community structure inside marine reserve (blue indicates before and red indicates after CBM implementation), and squares and diamonds outside of marine reserves, with squares indicating before, and diamonds indicating after CBM implementation.

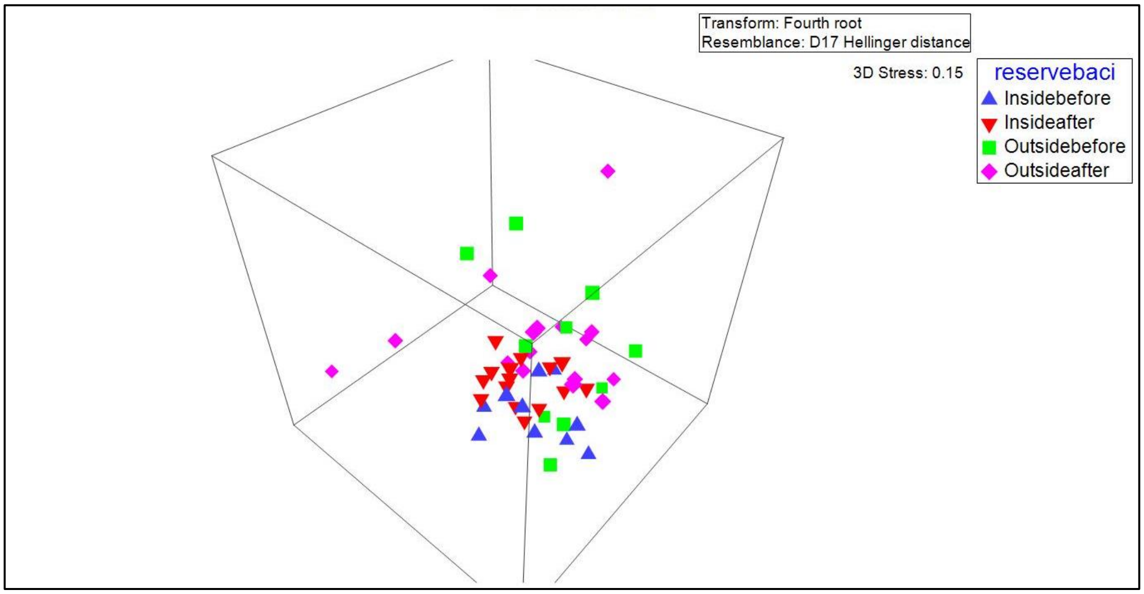

Figure A.32 *3D nMDS plot of fish species community structure similarities in Ipil*

Triangles denote the community structure inside marine reserve (blue indicates before and red indicates after CBM implementation), and squares and diamonds outside of marine reserves, with squares indicating before, and diamonds indicating after CBM implementation.

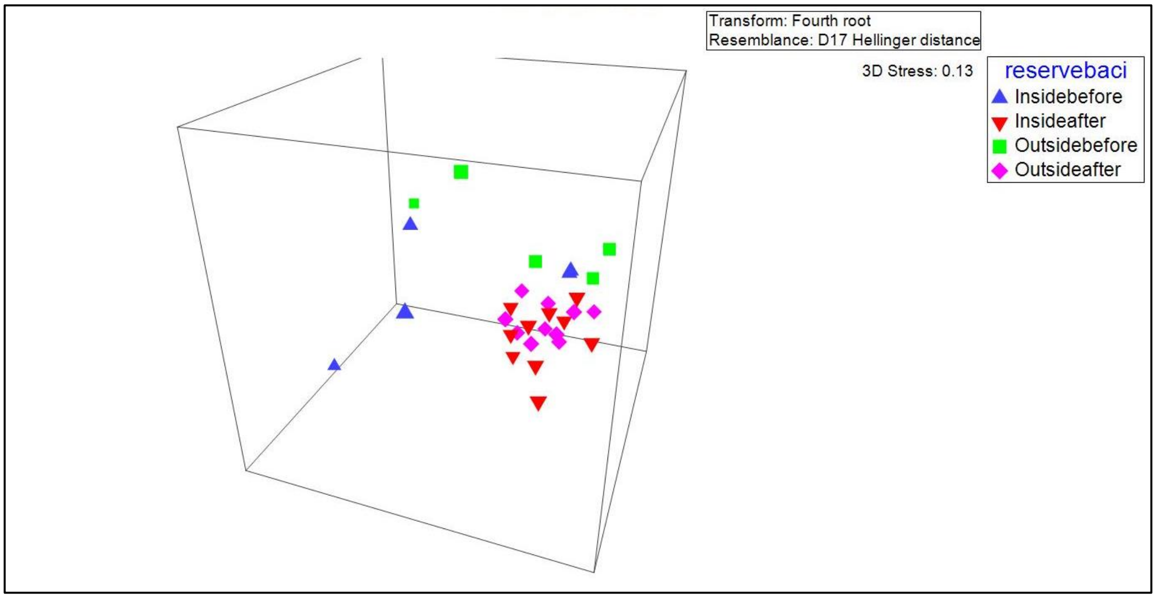

Figure A.33 *3D nMDS plot of fish species community structure similarities in Libertad*

Triangles denote the community structure inside marine reserve (blue indicates before and red indicates after CBM implementation), and squares and diamonds outside of marine reserves, with squares indicating before, and diamonds indicating after CBM implementation.

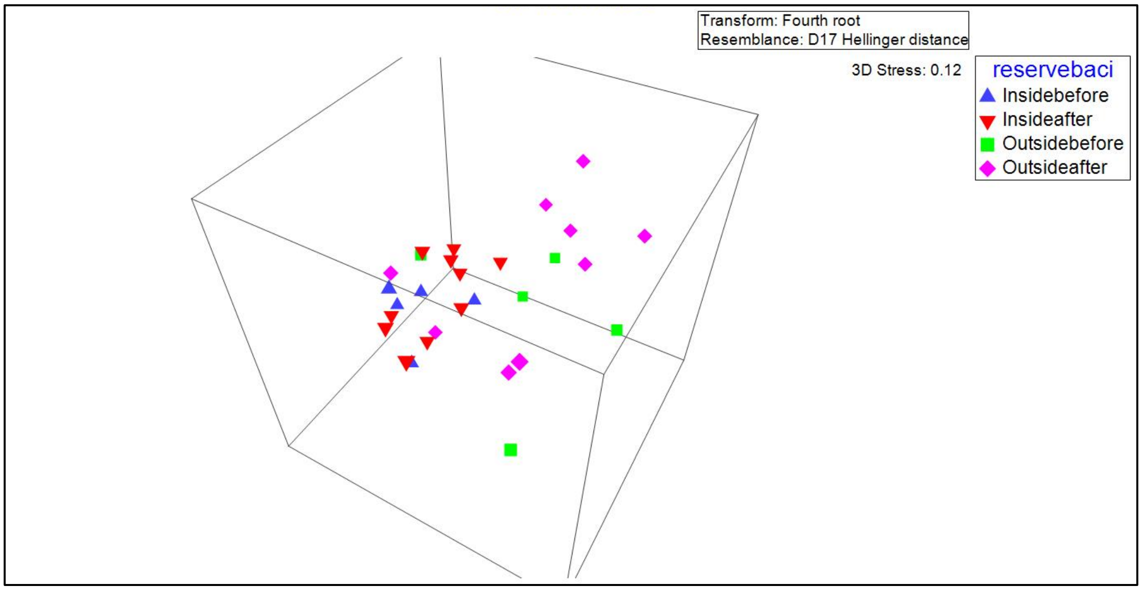

Figure A.34 *3D nMDS plot of fish species community structure similarities in Masinloc*

Triangles denote the community structure inside marine reserve (blue indicates before and red indicates after CBM implementation), and squares and diamonds outside of marine reserves, with squares indicating before, and diamonds indicating after CBM implementation.

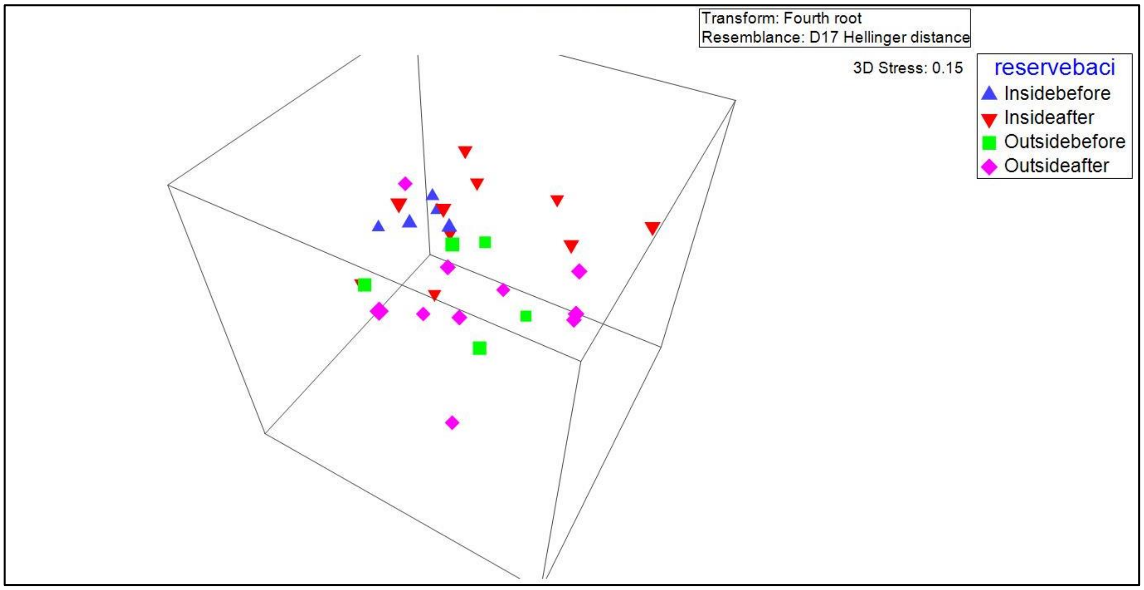

Figure A.35 *3D nMDS plot of fish species community structure similarities in Mercedes*

Triangles denote the community structure inside marine reserve (blue indicates before and red indicates after CBM implementation), and squares and diamonds outside of marine reserves, with squares indicating before, and diamonds indicating after CBM implementation.

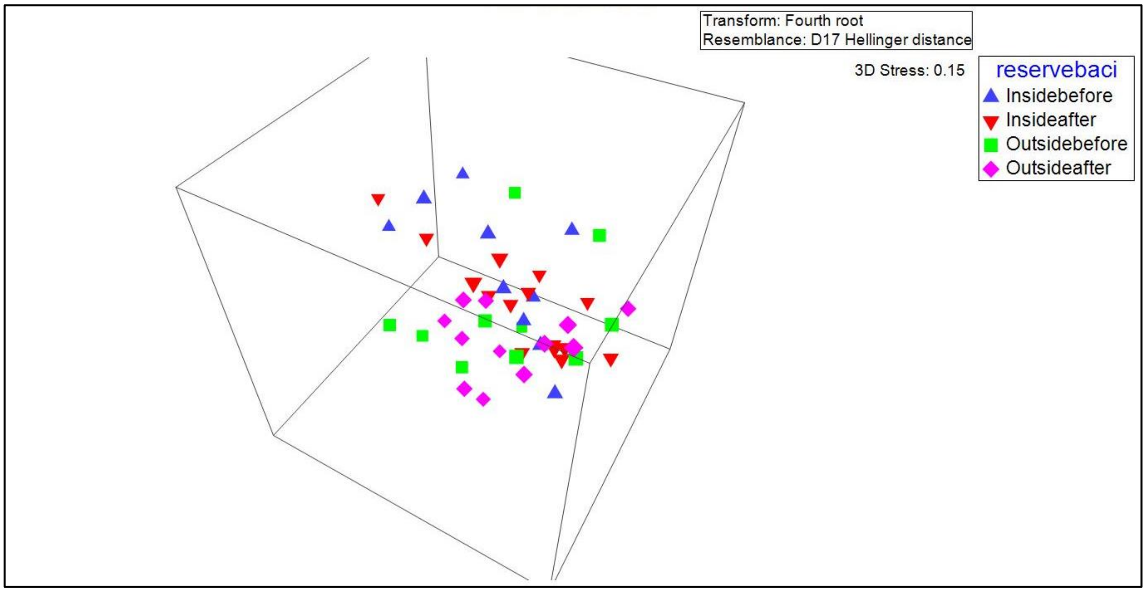

Figure A.36 *3D nMDS plot of fish species community structure similarities in Sagnay*

Triangles denote the community structure inside marine reserve (blue indicates before and red indicates after CBM implementation), and squares and diamonds outside of marine reserves, with squares indicating before, and diamonds indicating after CBM implementation.

APPENDIX B – INTERVIEW QUESTIONS

Table B.1 *Full List of Interview Questions and Themes*

Question	Theme
1. What is your primary occupation? a) Do you have a secondary occupation? If so what?	Alternative Livelihood and Job Security
2. How is the marine reserve hurtful/harmful to you? How is it helpful/beneficial to you? a) Has your catch increased, decreased, or stayed the same in the last 3 years?	Perception of Marine Reserve and Catch
3. Are the rules generally followed? If so, why do you think that is? If not, why do you think that is? a) Do you know where the boundaries of the marine reserve are? How do you know? Do you think others know where the boundaries are? b) Are the rules about how to behave in the marine reserve enforced? If so, how? By whom? If not, why do you think that is? c) Is there conflict amongst fishers inside your community? If so, what? d) What about with fishers from outside your community? e) Have you ever seen someone fish in the marine reserve? If so, how often? f) If someone were to fish in the marine reserve, do you think there would be repercussions?	Perception of Compliance, Rules, Enforcement
4. Are you involved in making decisions about fishing management or the marine reserve? If so, how? a) How would you improve the management of fish in your community?	Community Participation

APPENDIX C – IRB APPROVAL LETTER

Office *of*
Research Integrity
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NOTICE OF INSTITUTIONAL REVIEW BOARD ACTION

The project below has been reviewed by The University of Southern Mississippi Institutional Review Board in accordance with Federal Drug Administration regulations (21 CFR 26, 111), Department of Health and Human Services regulations (45 CFR Part 46), and University Policy to ensure:

- The risks to subjects are minimized and reasonable in relation to the anticipated benefits.
- The selection of subjects is equitable.
- Informed consent is adequate and appropriately documented.
- Where appropriate, the research plan makes adequate provisions for monitoring the data collected to ensure the safety of the subjects.
- Where appropriate, there are adequate provisions to protect the privacy of subjects and to maintain the confidentiality of all data.
- Appropriate additional safeguards have been included to protect vulnerable subjects.
- Any unanticipated, serious, or continuing problems encountered involving risks to subjects must be reported immediately. Problems should be reported to ORI via the Incident submission on InfoEd IRB.
- The period of approval is twelve months. An application for renewal must be submitted for projects exceeding twelve months.

PROTOCOL NUMBER:	22-277
PROJECT TITLE:	Community factors of community-based managed marine reserves in the Philippines
SCHOOL/PROGRAM	Coastal Sciences
RESEARCHERS:	PI: Sara Marriott Investigators: Marriott, Sara~de Mutsert, Kim~
IRB COMMITTEE ACTION:	Approved
CATEGORY:	Exempt Category
APPROVAL STARTING:	07-Mar-2022

Donald Sacco Jr.

Donald Sacco, Ph.D.
Institutional Review Board Chairperson

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