Bottom-Up Engagement Increases Marine Protected Area Effectiveness

By

Andrea Mast

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List of Abbreviations

CaMPAM – Caribbean Marine Protected Areas Management Network and Forum

CRCP – Coral Reef Conservation Program

FAO – Food and Agriculture Organization

GDP – Gross Domestic Product

HDI – Human Development Index

IUCN – International Union for the Conservation of Nature

MPA – Marine Protected Area

METT – Management Effectiveness Tracking Tool

NGO – Non-Governmental Organization

UNEP-WCMC – United Nations Environment Program World Conservation Monitoring Centre

WDPA – World Database on Protected Areas

WGI – World Governance Indicators

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Abstract

Marine Protected Areas (MPAs) have been shown to provide benefits for biodiversity conservation within marine habitats, by reducing direct human impacts and restoring fish populations that provide critical ecosystem functions. Protected areas can be established and governed in different ways, primarily through bottom-up arrangements that involve local people and multiple stakeholders, or top-down decisions imposed by government agencies. Yet little is known about how these two governance strategies compare in terms of the protection and benefits they provide to MPAs globally. Using an extensive data set of MPA conditions, a set of Bayesian hierarchical models were developed to understand the role of top-down versus bottom up governance on the net reef fish biomass differences between MPA and adjacent non MPA areas from 218 global MPAs. The results suggest that collaborative governance, or co-management, provides larger positive effects on reef fish biomass differences between MPAs and adjacent open areas than top-down, or federal arrangements. Additionally, while total gross domestic product is positively related to net biomass, there is a negative relationship with the human development index. The results illustrate the importance of stakeholder participation for improving ecological outcomes, with the policy recommendation that existing MPAs transition to collaborative management where possible.

Key words: marine protected areas, management, top-down management, bottom-up management, co-management, reef fish biomass difference

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Chapter 1: Introduction

1.1 Marine Protected Areas

The International Union on the Conservation of Nature (IUCN) defines a Marine Protected Area (MPA) as "a clearly delineated geographical space, recognized, dedicated and managed, through legal or other effective means, to achieve the long-term conservation of nature with associated ecosystem services and cultural values" (Day et al., 2012). MPAs can be established for multiple purposes and can allow and prohibit a number of different activities. From a conservation perspective, they are often regarded as the most important tool in the marine managers toolbox and are associated with multiple ecosystem benefits (O'leary et al., 2018). These benefits include increased habitat heterogeneity, increased abundance of threatened species, increased dispersal of larvae, spillover to adjacent areas, safeguarding of biodiversity, and preservation of cultural values (Day et al., 2012; O'leary et al., 2018). MPAs can also be used as reference sites to properly assess anthropogenic impacts and are useful areas for scientific data collection.

However, MPAs that contain fisheries closures can at times be detrimental towards human society by displacing fishing effort and reducing fisheries catches (Charles & Wilson, 2008). For many communities the presence of an MPA with fishing restrictions can impact their livelihood, calling for a need to balance both social and ecological goals (Ban et al., 2011), an area where MPAs can often fall short (Gill, Mascia, Ahmadia, Glew, Lester, Barnes, Craigie, Darling, Free, Geldmann, et al., 2017). Concerns include political motivations when establishing MPAs and inadequate stakeholder consultation (De Santo, Jones, & Miller, 2011). It is therefore important to consider people along with nature when establishing MPAs to promote equity and justice, as well as improve compliance and increase management effectiveness (Agardy, Claudet, & Day, 2016; Di Franco et al., 2016; O'leary et al., 2018).

Another stressor affecting MPAs is climate change. MPAs have been shown to increase the resilience of ecosystems such as coral reefs, allowing them to adapt to changing environmental conditions (O'leary et al., 2018). This can occur through increased grazing by herbivorous fish, which generates substantial reductions in macroalgal cover on coral reefs (Mumby et al., 2006), and can also occur through trophic cascades in which there is increased predation on coral predators (Mellin, MacNeil, Cheal, Emslie, & Caley, 2016). Furthermore, MPAs can reduce cumulative stressors on the environment and enable for faster recovery from climate change impacts (Selig, Casey, & Bruno, 2012), as well as promote larger and more resilient populations of organisms (Roberts et al., 2017).

The Convention on Biological Diversity Aichi Target 11 and the United Nations Sustainable Development Goal 14.5 both commit signatory governments to protecting 10% or more of their marine environments by the year 2020 (CBD, 2010; United Nations., 2016). The need to meet this target is driving the creation of new MPAs and the expansion of existing MPAs, while also creating challenges of improper management and enforcement, and leading to an overall lack of community involvement in the process (Agardy et al., 2016). This target calls for the increased establishment of MPAs but also the continued effectiveness of MPAs.

1.2 Effective Management of MPAs

The success of MPAs largely depends on the capacity and effectiveness of managers to enforce regulations (Bergseth, Gurney, Barnes, Arias, & Cinner, 2018; Clifton, 2003). Effective management is necessary to ensure the adequate protection of these habitats, (Cvitanovic et al., 2013) unfortunately many MPAs lack proper management and enforcement, leading to a failure to provide positive social and ecological outcomes (Gill, Mascia, Ahmadia, Glew, Lester, Barnes, Craigie, Darling, Free, Geldmann, et al., 2017; Mora et al., 2006).

Management of MPAs is commonly through top-down or bottom-up forces, where in top-down arrangements the MPA is managed entirely by the government of a given country. These federally or sub-nationally managed MPAs can fall into the 'paper-park' category due to a lack of enforcement and monitoring, and overall lack of community involvement and stake in the process (Ayers & Kittinger, 2014). On the other hand, bottom-up, or collaborative governance, has gained recent attention for coastal resource management due to its involvement with the local community, that often relies on the resources the environment provides (Ban et al., 2011; Joshua E Cinner et al., 2012; Wamukota, Cinner, & McClanahan, 2012). Through collaborative governance local community members can help monitor and enforce the MPA, and in this way gain a better understanding of the benefits coastal environments provide, and a better appreciation of their roles in the ocean environment (Ayers & Kittinger, 2014; Granek & Brown, 2005).

1.3 Co-management of Marine Protected Areas

Co-management involves shared management between users and communities at the local level and government agencies (Ayers & Kittinger, 2014). Thus, collaborative management has become a popular resource for the protection of coastal marine habitats due to its potential ability to meet both social and ecological goals, something government agencies alone can easily fail to achieve (Ayers & Kittinger, 2014; Clifton, 2003; Indab & Suarez-Aspilla, 2004; Pollnac, Crawford, & Gorospe, 2001). The recent upsurge in popularity of co-management arose from a perceived failure of more traditional, top-down management institutions (Wamukota et al., 2012). Co-management is often already used by governments to deliver better outcomes for people and ecosystems (Cinner et al., 2012), for it is thought to create better incentives for local communities to comply with the rules and regulations of the protected area (Wamukota et al., 2012). Because this management regime is designed to meet the needs of a specific community it can achieve greater compliance (McClanahan, Marnane, Cinner, & Kiene, 2006). Cinner, Marnane, & Mcclanahan (2005), found that compliance with regulations is largely driven by perceived legitimacy of the process, its ability to provide benefits to the community, and its reflection of socioeconomic circumstances. Because co-management encourages management by communities and stakeholders that have a vested interest in the success of the MPA this kind of management is more likely to lead to increased compliance (Johannes, 2002). Awareness of the benefits increased biodiversity, coral cover, and spillover can provide may lead communities to contribute to the success of the protected area (Granek & Brown, 2005).

There are multiple other recorded benefits of co-management including increased collaboration among partners and community empowerment (Ayers & Kittinger, 2014). Local capacity is built and local knowledge is often incorporated into the MPA design, which can lead to a greater sense of community responsibility and environmental stewardship (Granek & Brown, 2005). Although co-management is not applicable or necessarily desired in every situation (Wamukota et al., 2012), the consideration of socioeconomic factors along with environmental protection is recommended moving forward with effective protected area management and the conservation of resources (Cinner et al., 2005).

1.4 Coral Reefs: Benefits and Threats

An example of a coastal marine habitat that is often protected through the establishment of MPAs is coral reefs. Coral reefs are highly productive biodiversity hotspots that support the livelihoods of millions of people worldwide (Hughes et al., 2003; Wamukota et al., 2012). These important habitats provide food, protection from coastal erosion, and employment in the form of fisheries and tourism (Gomez, 1997; Spalding, Ravilious, & Green, 2001). Yet despite their importance, coral reefs remain vulnerable to natural and anthropogenic disturbances such as over-fishing, pollution, disease, coral bleaching, and decreased calcification (Cvitanovic et al., 2013; Donner & Potere, 2007; Gomez, 1997; Wamukota et al., 2012). The decline of these habitats will not only affect the reefs themselves but the well-being and livelihood of those who depend on them (Cvitanovic et al., 2013; Spalding et al., 2001). Furthermore, the majority of coral reef habitats are located in developing nations whose citizens have a high dependence on reef resources for subsistence (Ban et al., 2011; Gomez, 1997). These developing nations are only responsible for a small fraction of the world's greenhouse gas emissions, however are suffering the greatest consequences (Donner & Potere, 2007). With future projections of decreased calcification and increased bleaching events, coral cover will continue to decline, impacting the livelihoods of many communities (Donner & Potere, 2007). Increased future natural and anthropogenic disturbances call for the reassessment of current management practices and the establishment of more effective governance of coral reef habitats (Ban et al., 2011; Bellwood, Hughes, Folke, & Nyström, 2004).

1.5 MPAs as a Management Tool for Coral Reefs

MPAs are widely used as a means to protect and manage coastal resources, including coral reefs (Ban et al., 2011; Cvitanovic et al., 2013; Pollnac et al., 2001; Selig et al., 2012). MPAs have the ability to protect species and ecosystems within their boundaries, while also increasing fish biomass in adjacent unprotected areas, known as spillover (Cvitanovic et al., 2013). This increase in fish biomass can help species recover and help control algal growth on reefs, while also restoring food webs (Keller et al., 2009; Magdaong et al., n.d.; Selig & Bruno, 2010). In this way MPAs have been shown to increase resilience of coral reefs to natural disturbances as well (Mellin et al., 2016; Mora et al., 2006). MPAs can also help prevent destructive fishing practices, decrease anchor damage, and decrease terrestrial run-off of excess nutrients and pollution (Selig & Bruno, 2010).

1.6 Research Questions

Using an extensive dataset of MPA conditions for 218 MPAs around the world, the relative effects of top-down and bottom-up governance arrangements on net reef fish biomass benefits were estimated. This was done by creating a series of Bayesian hierarchical models with covariates at the MPA and country level. The main research question being answered in this project is bellow, followed by two sub-questions

Are there substantial differences in reef fish biomass between top-down and bottom-up management of MPAs?

> *What other factors, either at a local or global scale, affect the reef fish biomass differences within MPAs?*

> *What relevant policy information can be learned from analyzing multiple MPA management plans?*

Chapter 2: Methods

2.1 Scale of the data

The data was organized in two spatial scales, MPA (n=218) and country (n=38). The MPAs were clustered based on their respective country.

2.2 Reef fish biomass difference

Reef fish biomass difference values were obtained from Gill et al. (2017) and used as the response variable for the model. To produce these values, ecological data was collected on marine fish populations from seven independent global and regional datasets, carefully standardized so as to be comparable. Biomass in this case represents the total biomass of all recorded fish species, averaged across all transects at each site. Biomass was calculated using individual body lengths and allometric length-weight data obtained from the data provider or FishBase. MPA causal effects were identified by matching MPA survey sites to comparable non-MPA sites (outside MPA boundaries and/or before establishment) and calculating LnRR values, or the natural logarithm of the ratio of mean fish biomass per unit area inside an MPA site, relative to mean fish biomass in a statistically matched control site. The control sites were either pre-MPA establishment or outside the MPA. Statistical matching was used to account for selection biases in MPA placement, spatiotemporal dynamics of fish response to protection, and other biological, social, and physical factors that can affect fish populations.

2.3 Model Covariates

2.3.1 MPA Level Covariates

The distance from shore of each MPA was obtained from Gill et al. (2017). The governance was recorded based on information available on The World Database on Protected Areas (WDPA). The WDPA uses governance terms based on the IUCN Governance of Protected Areas Guidelines. In this document the IUCN defines governance as the decision-making structure of the protected area where the decision-making power of delegating management authority rests (Day et al., 2012). Four broad protected area governance types are outlined in the Governance of Protected Area guidelines: governance by government, shared governance, private governance, and governance by indigenous peoples and local communities. The MPAs used for this study only featured governance by government and shared governance. Governance by government can be further broken down into federal, sub-national, or joint, and shared governance is considered collaborative or co-management (Table 1). Governance information not present in the WDPA was supplemented using MPAtlas, CaMPAM, and MPA-specific management documents. The WDPA was also used to recover information on the IUCN category of each MPA as well as the age and size of the MPA. The IUCN categories classify protected areas based on their management objectives and are the standard for defining and recording protected areas (Table 2, 3 & 4). An additional MPA level covariate used was whether the MPA was located in a tropical or temperate latitude. This information was obtained from Gill et al. (2017) and was used to account for the fact that not all the MPAs were located in the same latitude.

2.3.1.1 Governance

As mentioned above the IUCN has determined four broad management categories for MPAs (Dudley, 2008). The first is governance by government, in which a government body holds all authority and responsibility for establishing and managing the protected area. This can also occur under the management of a sub-national managing body, such as regional or municipal government agencies. Shared governance can also occur, in which management authority is shared between governmental and non-governmental actors. This form of governance can also be referred to as "collaborative" management, or co-management, where the authority may rest with one agency however other stakeholders must be informed and consulted in the process. Lastly in joint management multiple governing bodies have decision making power and responsibility. This can be applied to transboundary protected areas or protected areas in territories of larger countries.

Name	Description
Federal or national ministry or agency	Federal or national ministry or agency in charge
Sub-national ministry or agency	Sub-national ministry or agency is in charge (regional, provincial, municipal level)
Collaborative	Collaborative governance (through various ways) in which diverse actors and institutions work together
Joint governance	Pluralist board or other multi-party governing body

Table 1. Governance categories and descriptions as outlined in the IUCN Governance of Protected Areas Guidelines

2.3.1.2 IUCN Categories

The IUCN has developed a set of guidelines to define a protected area through seven management types, known as MPA categories (Dudley, 2008). These categories are assigned based on the primary management objective of the MPA, and they range from Ia to VI.

Category	Name	Description
Ia	Strict Nature Reserve	Strictly protected areas set aside to protect biodiversity and also possibly ecological/geomorphological features, where human visitation, use and impacts are strictly controlled and limited to ensure protection of the conservation values.
Ib	Wilderness Area	Usually large unmodified areas retaining their natural character and influence without permanent or significant human habitation, which are protected and managed so as to preserve their natural condition.
II	National Park	Large natural or near natural areas set aside to protect large-scale ecological processes, along with the complement of species and ecosystems characteristics of the area, which also provide a foundation for environmentally and culturally compatible, spiritual, scientific, educational, recreational, and visitor opportunities.
III	Natural Monument or Feature	Generally small areas set aside to protect a specific natural monument, which can be a landform, seamount, submarine canyon, geological feature such as a cave or even a living feature such as an ancient grove.
IV	Habitat/Species Management Area	Protects particular species or habitats and management reflects this priority. Often need regular active interventions to address the requirements of particular species or to maintain habitats.

Category	Name	Description
V	Protected Landscape/Seascape	Protected area where the interaction of people and nature over time has produced an area of distinct character with significant, ecological, biological, cultural, and scientific value, and where safeguarding the integrity of this interaction is vital to protecting and sustaining the area and its associated nature conservation.
VI	Protected area with sustainable use of natural resources	Conserve ecosystems and habitats together with associated cultural values and traditional natural resource management systems. One of the aims of the area is the low-level use of non-industrial use of natural resources compatible with nature conservation

Table 2. IUCN MPA Categories descriptions (Day et al., 2012)

Table 3. Matrix of marine activities that may be appropriate for each IUCN management category (Day et al., 2012)

Activity	Ia	II	III	IV	V	VI
Research: non-extractive	Y*	Y	Y	Y	Y	Y
Non-extractive traditional use	Y*	Y	Y	Y	Y	Y
Restoration/enhancement for conservation	Y*	Y	Y	Y	Y	Y
Traditional fishing/collection	N	Y	Y	Y	Y	Y
Non-extractive recreation	N	Y	Y	Y	Y	Y
Large scale low intensity tourism	N	Y	Y	Y	Y	Y
Shipping	N	Y*	Y*	Y*	Y	Y
Problem wildlife management	N	Y*	Y*	Y*	Y*	Y
Research: extractive	N*	N*	N*	Y	Y	Y
Renewable energy generation	N	N	N	Y	Y	Y
Restoration/enhancement for other reasons	N	N*	N*	Y	Y	Y
Fishing/collection: recreational	N	N	N		Y	Y
Fishing collection	N	N	N		Y	Y
Aquaculture	N	N	N		Y	Y
Works (ex. dredging)	N	N	N		Y	Y
Untreated water discharge	N	N	N	N	Y	Y
Mining	N	N	N	N	Y*	Y*
Habitation	N	N*	N*	N*	Y	N*

Key

No	N
Generally no, unless special circumstances apply	N*
Yes	Y
Yes, because no alternatives exist, but special approval essential	Y*
Variable, depends on whether this activity can be managed in such a way that is compatible with the MPAs objectives	

Table 4. Compatibility of fishing/collecting activities in different management categories (Day et al., 2012)

IUCN category	Long term and sustainable local fishing/collecting practices	Recreational fishing/collecting	Traditional fishing/collecting	Collection for research
Ia	No	No	No	No*
II	No	No	Yes**	Yes
III	No	No	Yes**	Yes
IV	Variable #	Variable #	Yes	Yes
V	Yes #	Yes	Yes	Yes
VI	Yes #	Yes	Yes	Yes

Key

*	Any extractive use of Category Ia MPAs should be prohibited with possible exceptions for scientific research which cannot be done anywhere else
**	In category II and III MPAs traditional fishing/collecting should be limited to an agreed sustainable quota for traditional, ceremonial or subsistence purposes, but not for purposes of commercial sale of trade
#	Whether fishing or collecting is or is not permitted will depend on the specific objectives of the MPA

2.3.2 Country level covariates

Three indicators of broad dimensions of national governance were used as country-level covariates: voice and accountability, rule of law, and control and corruption. These World Governance Indicators (WGI) are a dataset by the World Bank summarizing the views on the quality of governance provided by a large number of enterprises, citizen and expert survey respondents in industrial and developing nations (The World Bank, 2017). The data was collected through a number of surveys, think tanks, NGOs, and private sector firms and are represented as numbers ranging from -2.5 (weak) to 2.5 (strong). Voice and accountability reflects perceptions of the extent to which a country's citizens are able to participate in selecting their government, freedom of expression, freedom of association, and a free media. Rule of law reflects the perceptions of the extent to which agents have confidence in and abide by the rules of society, and in particular the quality of contract, property rights, the police and the courts, as well as the likelihood of crime and violence. Lastly, control and corruption reflects the perceptions of the extent to which public power is exercised for private gain, including both petty and grand forms of corruption, as well as capture of the state by elites and private interests.

Other country-level covariates included in the model are gross domestic product (GDP), and human development index (HDI). GDP was gathered from the World Bank 2016 estimates. The following countries did not have 2016 data, so the most recent available data was used: Cayman Islands, Cuba, New Caledonia, Puerto Rico, US Virgin Islands, Curaçao, Saba, and Turks and Caicos. HDI values from 2015 were gathered from the United Nations Development Program Human Development Reports. The following countries did not have 2015 data, so the most recent available data was used: Cayman Islands, Guam, Puerto Rico, Turks and Caicos and US Virgin Islands. No value was found for Saba, so the value for Curaçao was used, as they are both islands in the Netherland Antilles.

The final country level covariate is the fish landings per capita per reef area. The fish landings were obtained from the Food and Agriculture Organization (FAO), and are reported in tons, and correspond to the total catches in 2014. The population of each country was obtained through the World Population Review, and reef area was obtained through the Coral Reef Atlas, which is prepared by the United Nations Environment Program World Conservation Monitoring Centre (UNEP-WCMC).

2.3.2.1 Human Development Index

The Human Development Index was developed because economic growth alone was being used to assess the development of a country (United Nations Development Programme, 2018) (Figure 1). HDI is a summary measure of average achievement in key dimensions of human development: a long and healthy life, being knowledgeable and having a decent standard of living (United Nations Development Programme, 2018). The HDI itself is the geometric mean of normalized indices of each of these three dimensions. Health dimensions are assessed by life expectancy at birth, the education dimension is measured by mean of years of schooling for adults over 25 years of age and expected years of schooling for children entering school. The standard of living dimension is measured by gross national income per capita. However, it is important to keep in mind that HDI simplifies and captures only a small part of what development actually entails. It does not account for inequality, poverty, human security, among others.

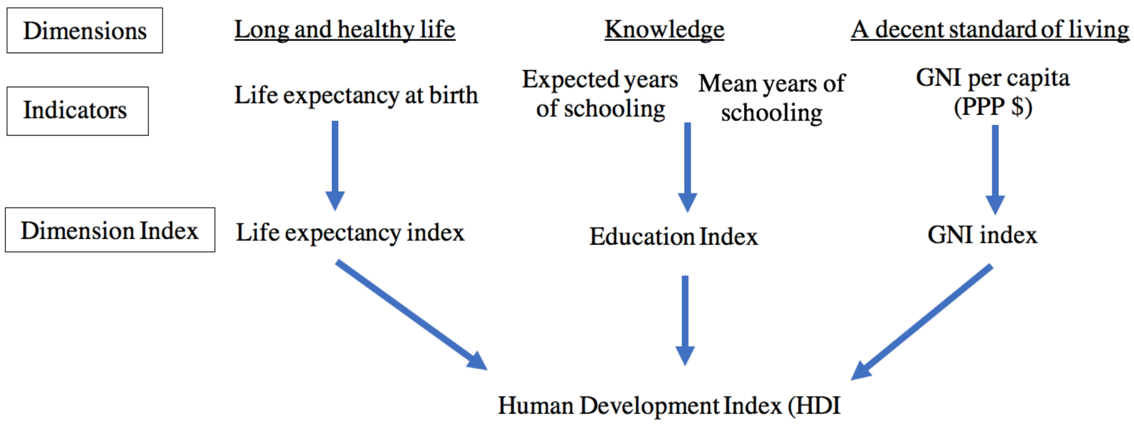

Figure 1. Dimensions and indicators that lead to the determination of the Human Development Index of a given country

2.3.2.2 Gross Domestic Product

The Gross Domestic Product can be defined as the total unduplicated value of the goods and services produced in the economic territory of a country or region in a given period (Government of Canada, 2017). It is considered the best way to measure a country's economy. There are four main components that go into calculating the GDP of a country: personal consumption expenditures, business investment, government spending, and the difference between exports and imports (Amadeo, 2018). GDP is a good measure for comparing economies and seeing how they change over time.

2.4 Statistical Analysis

To quantify the multi-scale factors affecting reef fish biomass a set of Bayesian hierarchical models were adopted that recognized the two spatial scales: MPA and country. Two models were developed, a null model consisting of only the hierarchical units of observation and a full model with the covariates present. The null model was used as a baseline to ensure the covariate model improved on simply accounting for the inherent hierarchical structure of the data alone. Covariates were entered into the model at their appropriate level, with lower level (MPA) covariates nested within higher level (country) model intercepts. The full model assumed the observed MPA level observations of LnRR (Y) were normally distributed as:

$$Y_{ij} \sim N(\eta_{ij}, \sigma_\beta)$$

$$\eta_{ij} = \beta_{0i} + \beta_1 * Z_{1ij} \ldots + \beta_n * Z_{nij}$$

$$\beta_{0i} \sim N\left(\mu_i, \sigma_\gamma\right)$$

$$\mu_i = \gamma_0 + \gamma_1 * X_{1i} \ldots + \gamma_n * X_{ni}$$

$$\gamma_{0 \ldots n}, \beta_{1 \ldots n} \sim N(0,100)$$

$$\sigma_\gamma \sigma_\beta \sim U(0,100)$$

Where X are the country level covariates and Z are the MPA level covariates.

The relationship between fish biomass difference and MPA and country level covariates was carried out using the PyMC3 package (Salvatier, Wiecki, & Fonnesbeck, 2016) for the Python programming language. Posterior predictive checks were conducted for goodness of fit by examining posterior predictive distributions for the observations, examining Geweke scores from multiple chains for each parameter, and observed fits of the model and data (Gelman et al., 2013).

2.4.1 Sub-set model analysis

A sub-set model was created in order to incorporate additional data provided by Gill et al. (2017). The model structure is the same as above, however an additional covariate was added at the MPA scale, staff capacity. Only 63 MPAs had both staff capacity values and LnRR values, therefore a sub-set model was necessary. The staff capacity value was sourced from the Management Effectiveness Tracking Tool (METT), the World Bank MPA Score Card, and the NOAA Coral Reef Conservation Program (CRCP) MPA Management Assessment Checklist. The binary thresholds were defined for the indicator based on the description of the scoring level and social theory.

Two additional subset models were also created, one with governance as the only covariate and one with the IUCN category as the only covariate. These models were created to ensure the effects of governance and IUCN category remained constant without the influence of other covariates.

Chapter 3: Results

3.1 Full Model Results

The response variable, reef fish biomass difference, ranged from -3.76 to 3.70 with a mean of -0.466 and standard deviation of 0.960 (Figure 2). A total of 218 MPAs were analyzed for this study, 74 of which were classified as federal, 23 as joint, 66 as sub-national, and 28 as collaborative. A total of 27 MPAs did not have a reported management and were therefore classified as an additional 'not reported' category. MPAs were distributed worldwide, with a number of governance types present in each country. All governance types had a positive effect on reef fish biomass difference over federally managed MPAs, however collaborative management, or co-management, had the greatest positive effect, followed by sub-national, and joint (Figure 4). There was a 96.8% chance that a collaborative MPA would provide greater positive benefits than a federally managed MPA, a 92.6% chance a sub-nationally managed MPA would provide greater benefits and a 52.5% chance a jointly managed MPA would provide greater benefits to reef fish biomass difference than a federally managed MPA. On average, the benefits provided by co-managed MPAs were 21 times greater than joint and 1.4 times greater than sub-national, on a log scale.

In total there were 20 IUCN Ia MPAs, 48 category II, 2 category III, 37 category IV, 28 category V, 23 category VI, and 60 that did not have assigned categories (Figure 3). All IUCN categories also had a positive relationship with the response variable, and all categories provided greater benefits than the baseline category, which was category Ia (Figure 4). Based on the strictness and levels of human contact one would expect category Ia to provide the most positive benefits, however that was not the case. There was an 86%, 52.7%, 67%, 87.6%, and 73.5% chance a category II, III, IV, V, and VI MPA would provide greater positive benefits than a category Ia MPA, respectively.

Although many of the remaining covariates did not have an appreciable effect on reef fish biomass difference, the strongest positive relationship between the response variable and a covariate was with Gross Domestic Product (GDP; Figure 5; Figure 12, appendix). A positive relationship also existed between the response variable and the distance from shore and age of the MPA. On the other hand, there was a negative relationship between the response variable and the Human Development Index (HDI; Figure 5; Figure 11, appendix), as well as with the size of the MPA.

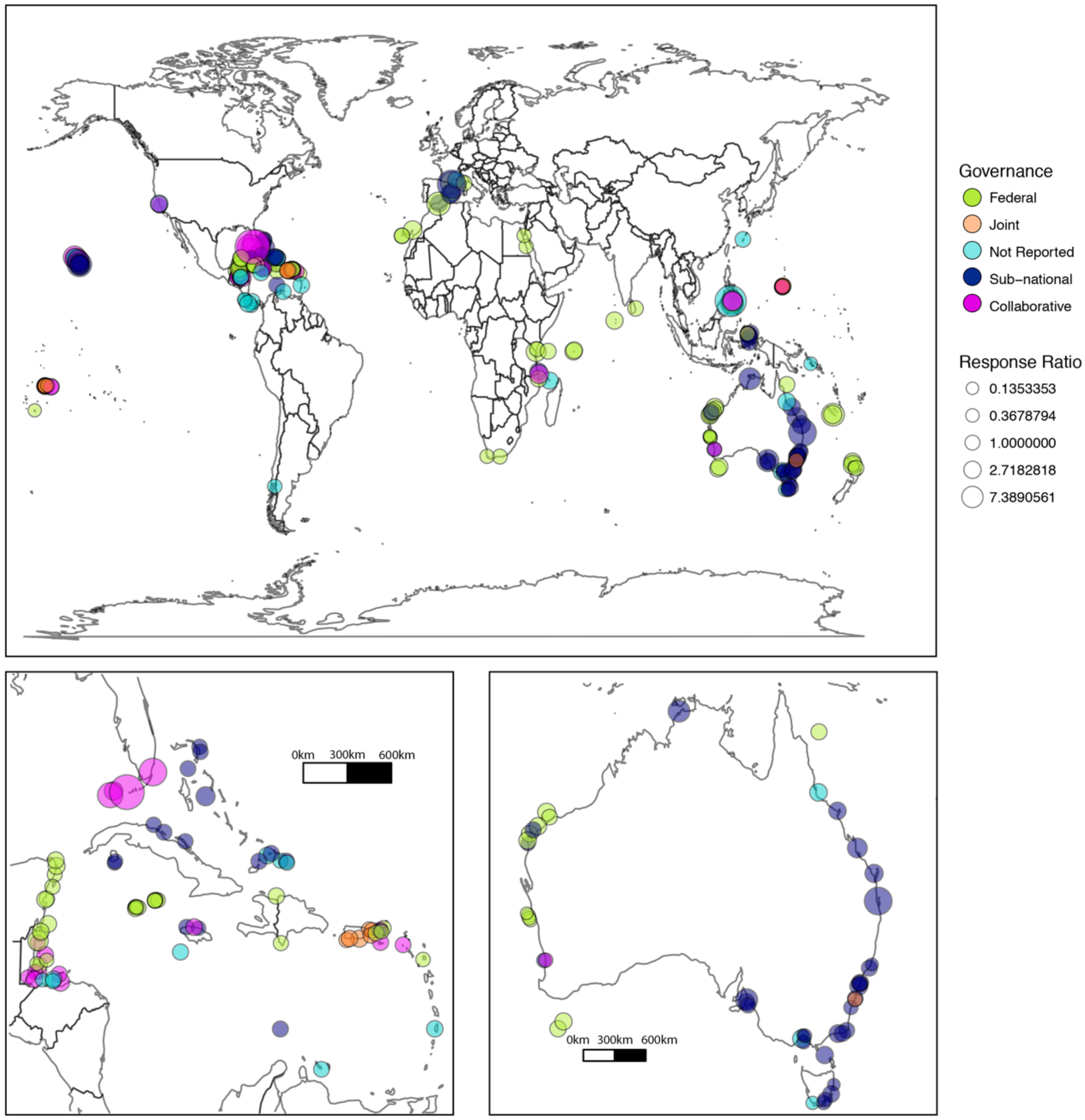

Figure 2. World map depicting the 218 MPAs used in this study. The color of the circle represents the governance of the MPA and the size of the circle represents the corresponding response variable, or reef fish biomass difference, for each MPA.

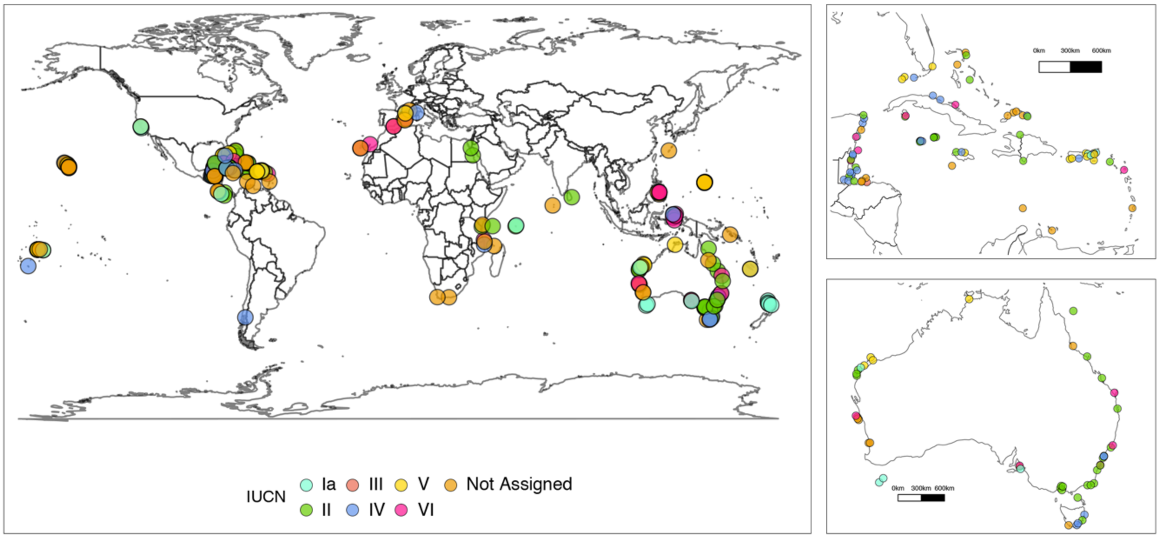

Figure 3. World map depicting the 218 MPAs used in this study. The color of the circle represents the IUCN category of the MPA. Two sub-set maps on the right represent a clos-up of the Caribbean and Australia

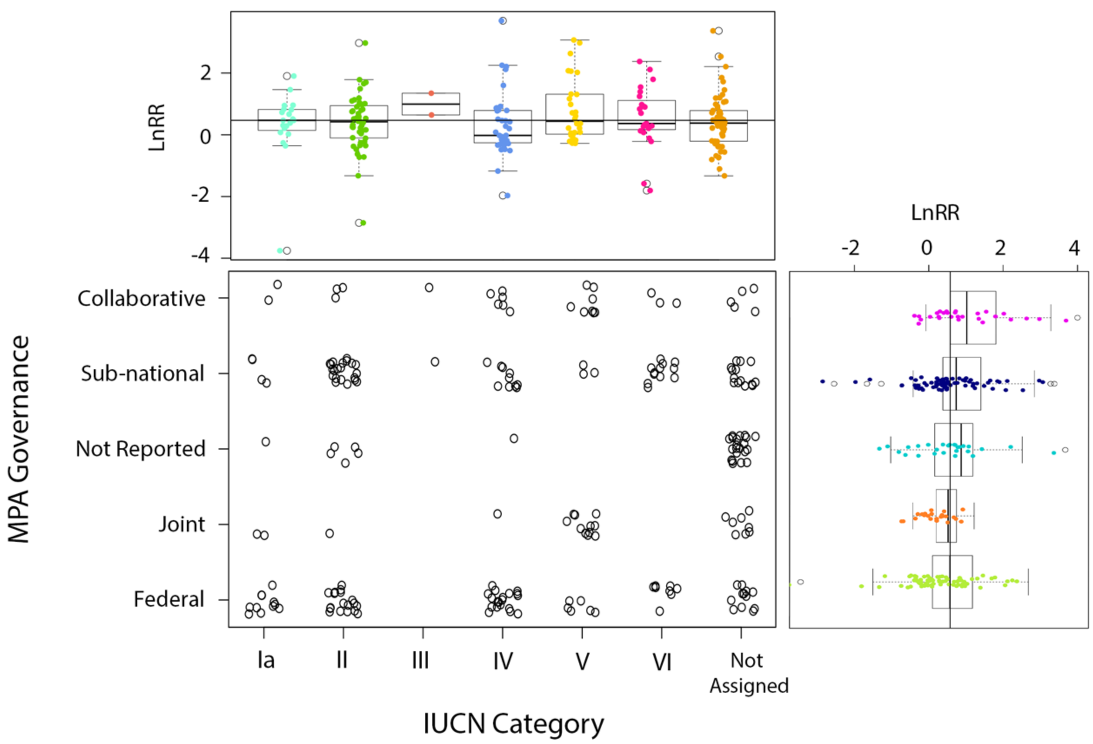

Figure 4. Relationship between IUCN category and the MPA governance for each MPA in the dataset. The two boxplots represent the biomass values for each IUCN category (top) and each governance category (right). The vertical and horizontal lines represent the baseline category, IUCN Ia and Federal.

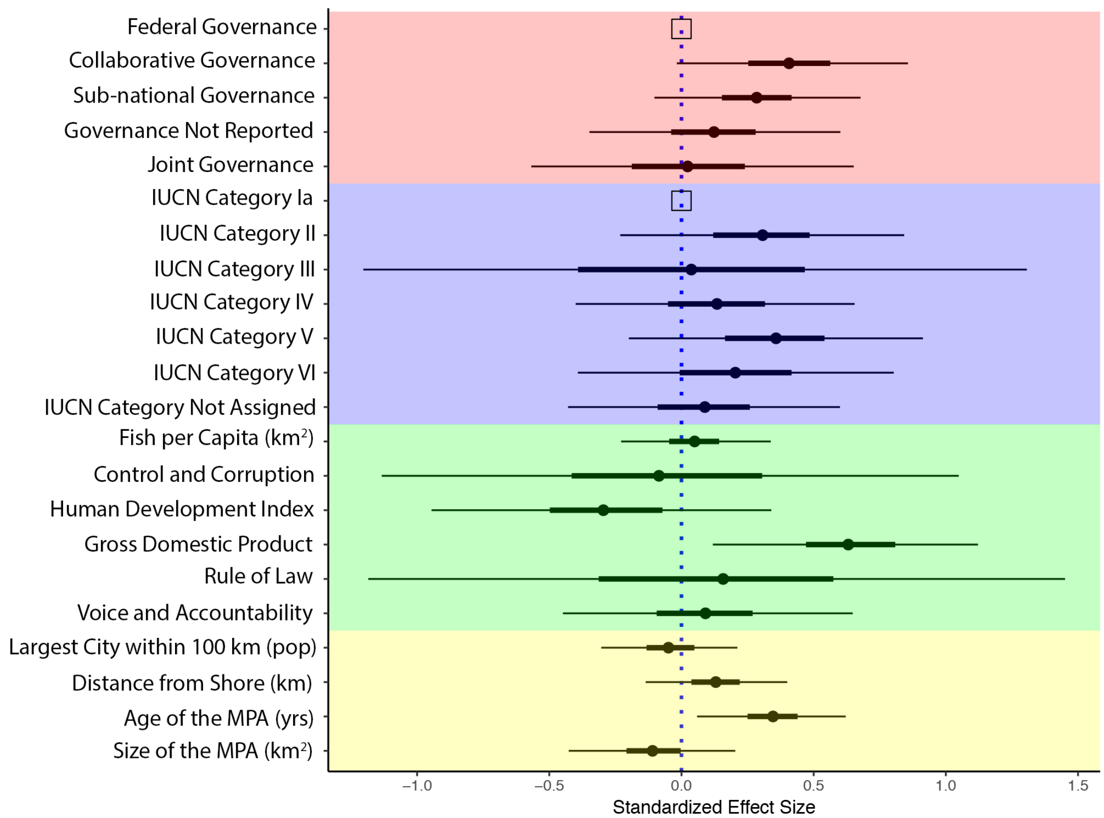

Figure 5. Standardized effects sizes of local MPA (yellow) and country level covariates (green), as well as the effects sizes of MPA governance (red), and IUCN Categories (blue). Represents the Bayesian posterior mean values with 95% uncertainty intervals (thin lines) and 50% uncertainty intervals (thick lines). The two squares represent the baseline categories, federal governance and IUCN category Ia.

3.1.1 Model Fit

There was no evidence of poor model fit, with posterior predictive distributions consistent with the observed data (Figure 6 & 7).

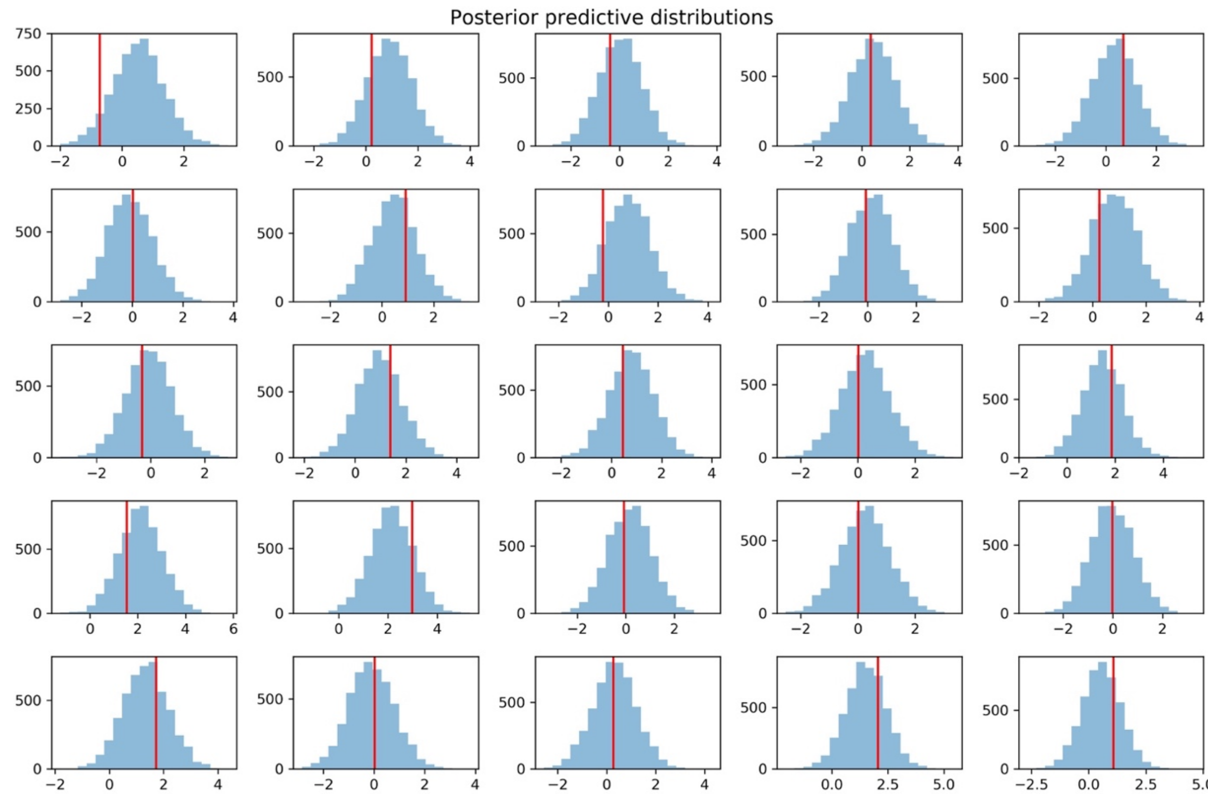

Figure 6. Posterior predictive distributions for the model, demonstrates that there is no evidence for poor model fit.

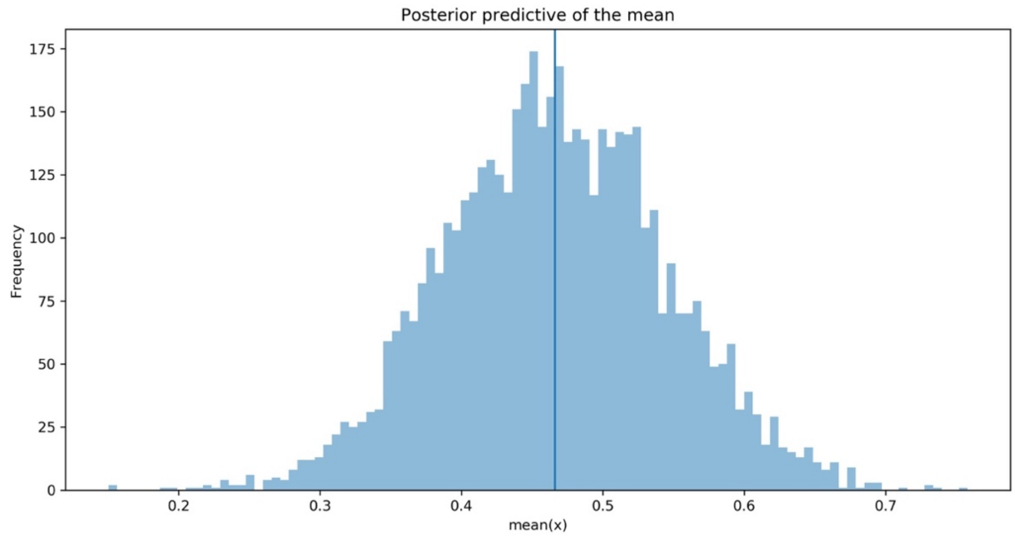

Figure 7. Posterior predictive distribution for the mean, also shows no evidence of poor model fit

3.1.2 Correlation Matrices

Correlation matrices were also made for the raw data and posterior distributions (Figures 8 & 9). There were strong positive correlations between the WGI covariates, voice and accountability, rule of law, and control and corruption. There was also a strong positive correlation between the Human Development Index and the three WGI covariates. Less strong positive correlations existed between the latitude of the MPA and many country level covariates including Gross Domestic Product, the largest city within 100km, control and corruption, rule of law, voice and accountability, and HDI. Similarly, GDP had a positive correlation with all the other country level covariates. Another important positive correlation occurred between the size of the MPA and the distance from shore. There were a few negative correlations, namely between the size and distance from shore of the MPA and several country level covariates, however these were not very strong.

In terms of the correlations between the posterior distributions of the covariates there were positive correlations between the different IUCN categories, as well as some between the different governance categories. There were negative correlations between rule of law and many covariates, including HDI, voice and accountability, GDP, and control and corruption. There were additional correlations that were not strong enough to report.

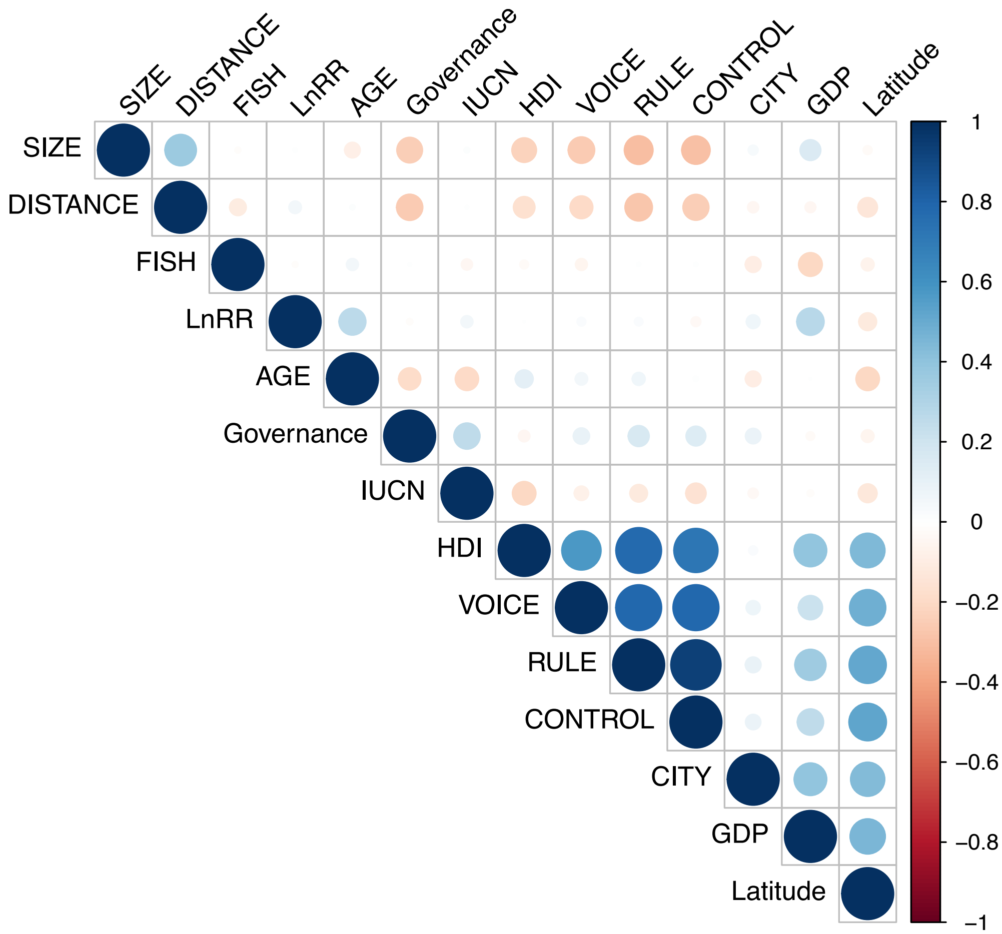

Figure 8. Correlation matrix for all covariates using the raw data. The size of the dot represents the level of correlation, with bigger dots being stronger correlations and smaller dots weaker correlations. The color of the dots represents whether the correlation is positive or negative, with blue being positive and red being negative.

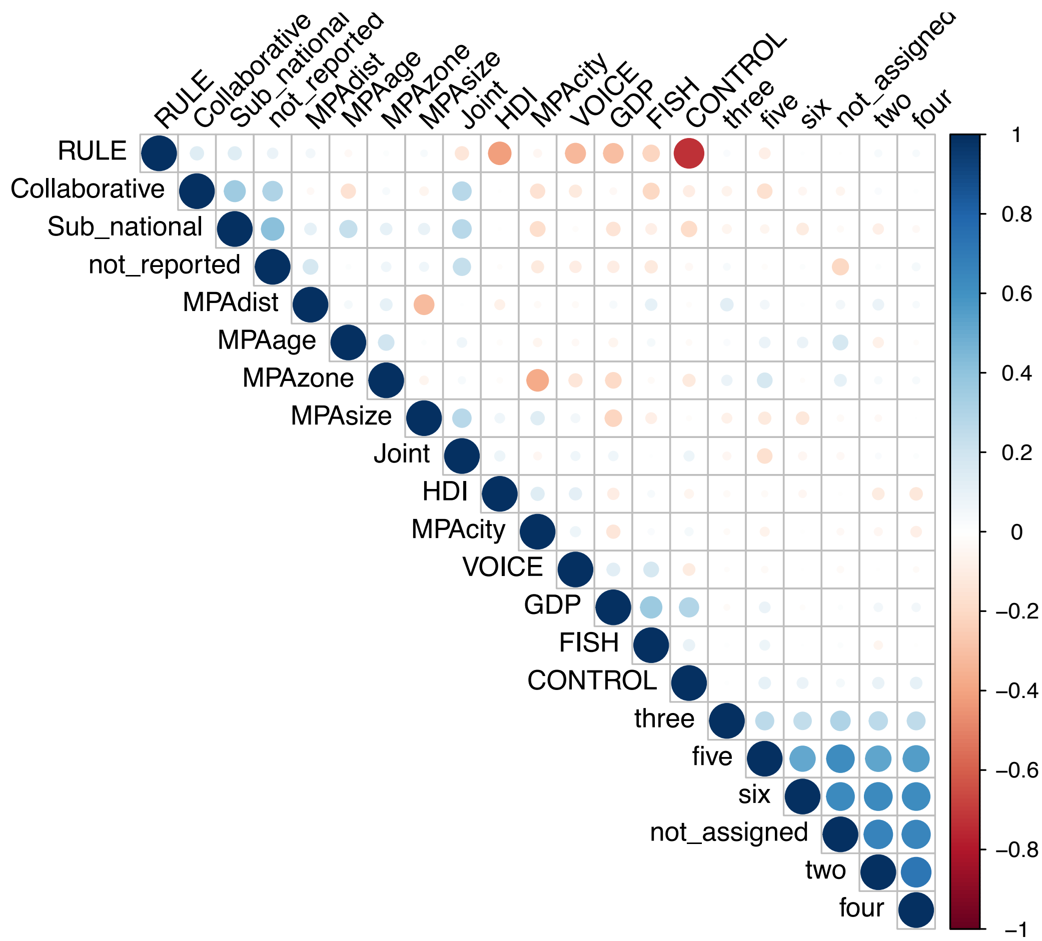

Figure 9. Correlation matric between all the posterior distributions of the covariates used in the model. The size of the dot represents the level of correlation, with bigger dots being stronger correlations and smaller dots weaker correlations. The color of the dots represents whether the correlation is positive or negative, with blue being positive and red being negative.

3.2 Subset Model Results

The results of the subset model were consistent with the full model with the exception of staff capacity which was not previously included. Staff capacity had the strongest positive effect on reef fish biomass difference in this model (Figure 10). Distance from shore, the age of the MPA, and GDP had a positive effect on the response variable while MPA size and HDI had a negative effect on the response variable. Voice and accountability, control and corruption, and rule of law all had no effect on the response variable. The rest of the covariates in the previous model were not included in this model due to the limited sample size.

The results of the two additional subset models agreed with the results of the full model. In the case of governance, co-management once again had the greatest positive effect on reef fish biomass difference, followed by sub-national, joint, and federal. Federal was once again used as the baseline category and it provided the least positive effects on the response variable, as in the full model. In terms of IUCN categories, the results were consistent with the first model, where all categories provided a positive effect on the response variable, and all provided a greater response than the baseline category, Ia.

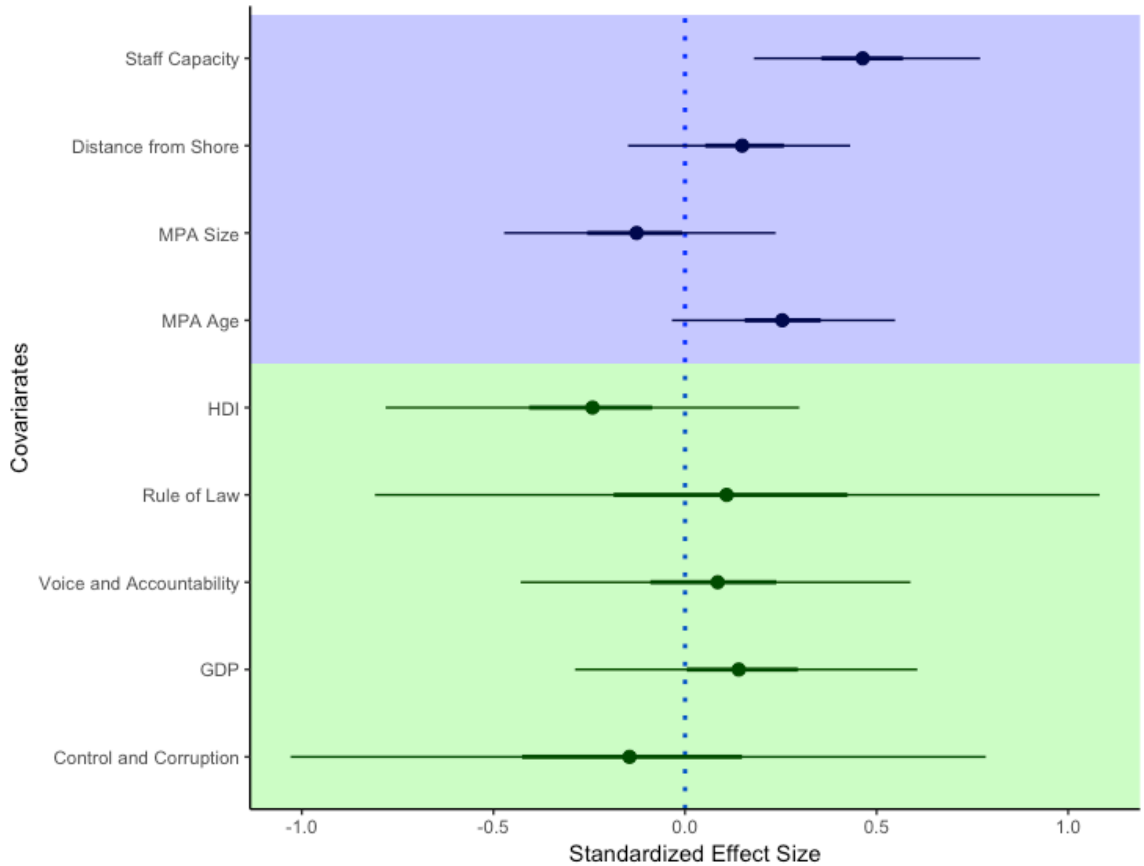

Figure 10. Standardized effects sizes of local MPA (blue) and country level covariates (green) for the model subset including staff capacity. Represents the Bayesian posterior mean values with 95% uncertainty intervals (thin lines) and 50% uncertainty intervals (thick lines)

Chapter 4: Discussion

The establishment of Marine Protected Areas is commonly promoted as a conservation measure to protect coastal resources. However once established, they are often not followed by effective governance (Ayers & Kittinger, 2014; Clifton, 2003; Gill, Mascia, Ahmadia, Glew, Lester, Barnes, Craigie, Darling, Free, & Geldmann, 2017; Mora et al., 2006). The results of this study show that collaborative management, also known as co-management, provided the greatest positive effect on reef fish biomass difference out of the governance categories included in the model, emphasizing the critical role that local engagement can play in ecological outcomes. The mechanisms by which this happens are abundant; co-management can be associated with increased collaboration among partners, higher compliance with regulations, and community empowerment (Ayers & Kittinger, 2014). Furthermore, co-management can develop local capacity and incorporate local knowledge in management and design of the MPA, while instilling a sense of community responsibility (Granek & Brown, 2005). These aspects of co-management can go a long way towards ensuring proper protection of coastal resources that are used by local communities on a daily basis. Co-management can also consider local socioeconomic factors when setting regulations, which is essential for the conservation of resources while also providing a livelihood for local community members (McClanahan et al., 2006). In contrast, federal MPAs, where there may be a disconnect between local communities and those making the decisions, had the lowest reef fish biomass difference, further signaling the need to move towards co-management of coastal MPAs where possible.

The International Union for the Conservation of Nature (IUCN) has established a series of categories to classify protected areas based on their management objectives (Dudley, 2008). These categories are recognized as the global standard for defining and recording protected areas by the United Nations and many national governments. However, this classification system has been criticized due to the activities allowed in some of these categories, namely category VI, which allows for fishing, mining, and waste water discharge (Locke & Dearden, 2005) (Table 3). IUCN category Ia has the most restrictions on paper and should therefore have the highest reef fish biomass difference due to increased regulations and decreased human contact. This however is not the case in this study, for there was no clear pattern between the different IUCN categories and reef fish biomass difference. This begs the question as to whether the IUCN should ensure managers are assigning the correct categories to MPAs or whether collaborative governance is actually more impactful for MPA success than the perceived level of impact, determined through its assigned IUCN category. Finding the answers to these questions is important to make the most of the IUCN categorizing system and ensure its continued use as a global standard for MPA regulations. It is important to note that the differences between the reef fish biomass between categories may be due to other processes, such as poaching, that may undermine the regulations of the MPA (Bergseth et al., 2018).

At the local level, MPAs that were farther from shore had higher reef fish biomass differences, reflecting that MPAs farther away from shore have fewer human disturbances and tend to experience less fishing pressure (Cinner et al., 2016). Local fishers may not have the capacity to fish reefs farther away from shore due to factors such as travel time, choosing instead to fish more accessible reefs (Maire et al., 2016). The age of the MPA also had a positive relationship with the response variable, meaning that older MPAs have higher reef fish biomass differences. Older MPAs are more established, and managers have had more time to set proper boundaries and review the management plan, hopefully leading to better compliance over time (Claudet et al., 2008; Edgar et al., 2014). Older MPAs may also have accrued greater biomass inside their boundaries (Edgar et al., 2014; Vandeperre et al., 2011). Lastly, there was a negative relationship between the size of the MPA and the biomass response ratio. This could be because small MPAs are easier to enforce and monitor, helping to prevent illegal fishing more effectively than in larger MPAs (McLeod, Salm, Green, & Almany, 2009). Smaller MPAs may also have smaller fishing zones than larger MPAs, deterring fishing altogether in that area.

At the country level, the strongest positive relationship in the model was between GDP and the biomass response ratio; countries with higher GDP therefore had higher reef fish biomass. These countries with higher GDP may have higher funding for environmental regulations, which allows the government to allocate more funds towards marine conservation, subsequently leading to greater opportunities for MPA management and enforcement (McCarthy et al., 2012). The Human Development Index had a negative relationship with the biomass response ratio, therefore countries with lower HDI had higher reef fish biomass differences. Higher HDI may be associated with higher exploitation, while countries with lower HDI may not have the adequate resources to exploit at such high levels. Countries with low development indices may have technological constraints and social institutions that may limit the exploitation of their marine resources (Cinner et al., 2009). The remaining country level covariates used in the model had no discernible effect on the reef fish biomass difference. Although these relationships are important for understanding the different factors that contribute to MPA effectiveness, they function at the country level, making them difficult to control and are therefore out of the MPA managers jurisdiction.

This research shows the importance of governance participation in achieving ecological outcomes. Governance is a condition that can in most cases be controlled by MPA managers and the government departments in charge of establishing protected areas. Managers can make a conscious choice to include the local community and form partnerships with local organizations to better protect their coastal environments through co-management. It is important to note that co-management will not be applicable in all situations, and it will not work the same way in all MPAs (Cinner et al., 2005; Wamukota et al., 2012). Furthermore, those who participate in co-management arrangements may also be more likely to designate proper sites for protection as opposed to those forced to comply. The results of this study demonstrate that a move towards co-management of MPAs, through the inclusion of local community members and organizations, can lead to better protection of coastal environments and resources in the future by increasing the reef fish biomass within protected areas. With coastal zones bearing the brunt of climate change impacts (Dolan & Walker, 2006) local communities are increasingly threatened with the loss of valuable sources of income and subsistence. New management plans that include local communities and organizations must be developed to protect coastal habitats, for by implementing co-management awareness and responsibility can be increased while at the same time making MPAs more effective and successful.

4.1 A Closer Look at Management Plans

MPAs often have a management plan that outlines their goals and objectives, threats, zones, among others that is drawn up when an MPA is being established. Many of these are found online and provide important information regarding the management of the MPA that cannot be obtained from the World Database on Protected Areas. For this section of the project information from multiple MPA management plans was compiled into tables outlining what managers identified as the greatest threats to their MPA, the main goals and objectives of establishing their MPA, the zones established to accomplish these goals, and whether or not there was any mention of collaboration or cultural significance within the management plan.

4.1.2 Management Tables

Table 5. Bacalar Chico – Belize

Reef Fish Biomass Difference	• -0.1912681
IUCN Category	• IV
Governance	• Federal
Threats	• Illegal extraction, land ownership and development, transboundary development and pollution risk
Zones	• General use zone • Conservation zone 1 • Conservation zone 2 • Preservation zone
Management Objectives Management Objectives	• Provide protection to the physical and biological resources of north Ambergris Caye • Provide an area for education and research • Preserve the value of the area for fisheries and other important genetic resources • Develop recreational and tourism services that will enhance the economic and social benefits of the area without causing environmental damage
Co-management	• The promotion of the Bacalar region as an ideal place for an MPA was a collaborative effort • The endorsement came from fishing communities, and a number of local and international environmental organizations
Cultural significance	• Subsistence fishing

The general use zone allows for the sustainable management of existing and traditional uses and this zone is accessible to fishers who use the area for commercial harvesting (*The Revised Bacalar Chico National Park Marine Reserve Management Plan*, 2004). The first conservation zone is designed for the non-extractive use of resources for monitoring, research, education and is also open to limited recreational use. The key objectives of this area are to conserve a representative sample of important habitats and provide an area for the recruitment of species to adjacent areas open to fishing. The second conservation zone is a controlled extraction zone to accommodate subsistence fishing, recreation and tourism. Lastly, the preservation zone is closed to all human contact.

This MPA is assigned an IUCN Category IV, which has a main goal of protecting particular species or habitats. However, there are zones in this MPA that allow for the extraction of resources, namely the second conservation zone which allows for subsistence fishing. This could be due to the fact that the IUCN category is assigned based on the activities within 75% of the MPA, however one would only associate the extraction of resources with a category VI MPA. There is a mention of collaborative management in their plan, however most of this was in the implementation stages of the MPA and there is no mention as to whether community members are still involved in the management and monitoring of the MPA. Furthermore, there is no mention of any cultural significance in the area other than the presence of subsistence fishing, which may or may not be due to cultural reasons.

Table 6. Florida Keys Marine Sanctuary – USA

Reef Fish Biomass Difference	• 2.632745984
IUCN Category	• V
Governance	• Collaborative
Threats	• Direct human impacts such as vessel groundings, anchor damage and destructive fishing gear
Zones	• Sanctuary preservation area • Ecological reserves • Special use area • Wildlife management areas
Management Objectives	• Protect the marine resources of the Florida Keys • Prevent and minimize vessel grounding impacts • Reduce stress of human activities
Co-management	• Good community relations essential to management
Cultural Significance	• Maritime heritage resources action plan

The sanctuary preservation area is used to protect shallow and heavily used reefs, where consumptive activities are limited (*Florida Keys National Marine Sanctuary Revised Management Plan*, 2007). The ecological reserve zone protects biodiversity and all consumptive activities are prohibited with minimal human disturbance. The special use area is set aside for research and education, or for the recovery of degraded resources. Lastly, the wildlife management area seeks to minimize disturbance by including buffer zones, no-motor zones, and closed zones. This MPA has been assigned as a category V, where the interaction of people and the environment has created an area of distinct character and value.

This MPA is classified as collaborative on the World Database of Protected Areas however the only mention of collaboration is that including members of the community is essential to management, and there is no further mention of how they plan to include community members.

Furthermore, the Maritime Heritage Resources Action Plan consists of a partnership between the state, NOAA and the Advisory Council on Historic Preservation. They define Maritime Heritage Resources as underwater items and sites that have historical, cultural, archeological, or paleontological significance. The importance of these historical resources brings a responsibility to protect them, and they are therefore protected for the public benefit and enjoyment while also preserving their cultural heritage into the future.

Table 7. South Water Caye – Belize

Reef Fish Biomass Difference	• -0.484523703
IUCN Category	• IV
Governance	• Federal
Threats	• Development, fishing pressure, climate change, poor fishing practices, agricultural runoff, oil spills, visitor impacts, and oil exploration and drilling
Zones	• General use zone • Conservation zone • Preservation zone
Management Objectives	• The overarching goal is to provide for the protection, wise use, and enjoyment of the natural resources of South Water Key in perpetuity
Co-management	• "Collaborate effectively with local NGOs in coastal fishing communities to engage fishing stakeholders" • "Liaise and collaborate with local NGOs for joint educational outreach to schools in stakeholder communities"
Cultural Significance	• No mention

The general use zone permits fishing however has several gear restrictions on gillnets, long lines, and spear fishing (*Management Plan South Water Caye Marine Reserve World Heritage Site*, 2010). Furthermore, residents of the marine reserve can fish for subsistence in this area. The conservation zone does not allow for fishing but does allow for non-extractive activities while the preservation zone does not allow fishing, diving, or any other activity that could impact the environment. This MPA is designated as a category IV MPA, which are established to protect particular species and habitats. There is an active effort to collaborate with stakeholders such as NGOs and local communities and partner with them for education purposes however there is no mention of cultural significance within the protected area.

Table 8. Gladden Spit and Silk Cayes Marine Reserve – Belize

Reef Fish Biomass Difference	• 0.504210076
IUCN Category	• IV
Governance	• Collaborative
Threats	• Climate change, unsustainable fishing practices, inappropriate visitor use, poor boating practices, inappropriate development, oil exploration, sewage pollution, insufficient enforcement
Zones	• General use zone • Conservation zone 1 • Conservation zone 2
Management Objectives	• The main goal is to afford special protection to the aquatic flora and fauna and to protect and preserve the natural breeding grounds and habitats of aquatic life
Co-management	• The first co-management agreement was signed in 2001 with Friends of Nature, now known as the Southern Environmental Association (SEA)
Cultural Significance	• No mention

The general use zone allows for commercial fishing with appropriate fishing licenses however long lines, trawlers and gill nets are prohibited (Wildtracks Belize, 2011). Furthermore, it is prohibited to drop anchor and fishing lobster and conch is allowed, however they must clean and fillet them on shore and not in the reserve. Conservation zone 1 does not allow for commercial, sport, or recreational fishing or dropping anchor other than on a designated mooring. Lastly, no fishing is allowed in conservation zone 2. There is also an additional spawning area within conservation zone 2 that contains additional rules, mostly pertaining to diving and boating. In terms of co-management the Southern Environmental Association (SEA), a local NGO, is in charge of the daily management of the reserve, including activities such as patrols and fee collection. They have also been working with the Fisheries Department to improve management and scientific monitoring.

It is further mentioned in the management document, which was written for the period of 2011-2016 that the zones must be reassessed and redone, however there is no updated management document currently available online. The MPA managers express concern that the conservation zones are not large enough, and therefore will not provide adequate environmental protection and decrease the effectiveness of the MPA.

Table 9. Batemans Marine Park – Australia

Reef Fish Biomass Difference	• -0.35177049
IUCN Category	• II
Governance	• Sub-national
Threats	• Resource use, land-based pollution, marine based pollution, invasive species, climate change
Zones	• Sanctuary zones • Habitat protection zones • General use zone • Special purpose zones
Management Objectives	• Conserve marine biodiversity, marine habitats and maintain ecological processes on the marine park • Provide for ecologically sustainable uses • Provide opportunities for public appreciation, understanding and enjoyment
Co-management	• No mention
Cultural Significance	• No mention

The sanctuary zone has the highest level of protection, and only activities that will not harm wildlife are permitted (Wales & Authority, 2010). The habitat protection zones allow for recreational and commercial fishing but prohibit some gear types from being used. The general use zones allow fishing but no trawling and is established for the sustainable management of habitat and animals. The special purpose zones are established for specialized management. This MPA is identified as a category II MPA, which is a National Park set aside to protect large scale ecological processes while balancing cultural, spiritual, scientific, educational, and recreational opportunities. In this case, two zones allow for fishing, one even commercial fishing, which would fit in better with a category VI MPA, which is the only IUCN category that allows for the sustainable use of resources.

Table 10. Maria Island – Tasmania

Reef Fish Biomass Difference	• 0.772412119
IUCN Category	• II
Governance	• Sub-national
Threats	• Wildfires, erosive agents, invasive species, development
Zones	• Darlington Zone • Point Leseur • Recreation zone • Natural Zone • Marine Zone
Management Objectives	• Conserve and maintain marine and terrestrial processes and biodiversity • Conserve the features of the park • Protect culturally significant elements • Protect and preserve recreational and tourism character of the park
Co-management	• No mention
Cultural Significance	• Aboriginal importance in the area that is mentioned throughout the management plan

The Darlington zone is established to protect and conserve environmental and heritage features and values (*Maria Island National Park*, 1998). Point Leseur it to preserve the recreational and tourism atmosphere, by providing a range of recreational and tourism opportunities. The recreation zone is to provide low-impact, low density, non-intrusive recreational use and enjoyment of the area while the natural zone is to preserve the area in an undisturbed condition. Lastly, the marine zone is to preserve species and marine ecosystems. There is no mention of collaborative management or co-management in the document, however there is a strong mention of the past and present Aboriginal culture surrounding this area.

Table 11. Cottlesloe Reef – Australia

Reef Fish Biomass Difference	• -0.384898227
IUCN Category	• Not assigned
Governance	• Collaborative
Threats	• Recreational fishing, collecting, near shore marine water quality, foreshore erosion
Zones	• No information
Management Objectives	• Conserve and protect fish, fish breeding areas, and other aquatic ecosystems • Manage fish and activities relating to the appreciation and observation of fish
Co-management	• Strong community involvement through the Volunteer Community Reef watchers training program
Cultural Significance	• The Cottesloe Reef is of great value to Aboriginal people in the area

There is no mention of specific zones within the management document (Department of Fisheries, 2001). The Reef Watchers training program highlights the value of the reef and promotes public education. The campaign has been successful in raising levels of awareness of the reef system and developing a sense of environmental stewardship in the area. Furthermore, the Cottesloe Reef is important to Aboriginal people in the area and this fact is evident within the management plan.

4.1.3 Analysis

Every management plan is different, presents a different amount of information, and focuses on different aspects of the MPA. Because most MPAs use the IUCN categorizing system and possibly the IUCN guidebook for evaluating MPA management effectiveness (Pomeroy, Parks, & Watson, 2004) it may be useful for the IUCN to create a general template of an MPA management plan to be used globally. With the Convention on Biological Diversity (CBD) and United Nations Sustainable Development (UN) targets of protecting 10% of the ocean by 2020 (CBD, 2010; Nations., 2016) a universal management plan would be beneficial moving forward, for it would allow for a global process of establishing, monitoring, and categorizing MPAs. This would allow for more effective monitoring of global progress towards these conservation goals.

MPAs themselves often have multiple goals, all of which are determined to reach an overall objective relating to the MPA and the reason for its establishment. These goals are also considered when establishing the zones of an MPA, which in turn help determine the IUCN Category. If using the IUCN categorizing system, the overall category is determined by the activities allowed in 75% of the total area of the MPA (Day et al., 2012). The zones of an MPA are important, especially if each zone has different management objectives and different users of the space. However, after analyzing the different zones of the above MPAs one can see how it can be difficult for managers to assign IUCN categories accurately. Each zone in itself could be a different IUCN category, however the MPA as a whole gets assigned just one category (Day et al., 2012). For example, in Maria Island the

Natural Zone is set up to preserve the area in an undisturbed condition, which would likely severely limit human contact, more in line with a category Ia MPA (*Maria Island National Park*, n.d.). On the other hand, the Recreation Zone's main purpose is to provide low impact recreational use and enjoyment of the area, more in line with a different IUCN category. Overall, this MPA has been assigned as category II, despite some of its activities fitting better into other categories. This can provide a challenge for MPA managers but also for the public's understanding of the use of IUCN categories.

Some MPAs include a zone open to the extraction of natural resources, which is not a concept typically associated with MPAs. Most citizens would associate MPAs with areas completely closed to fishing and with very limited human contact, however from these management plans it is clear this is not always the case. Of the seven management plans investigated, three allowed for some kind of resource extraction within its boundaries. This further leads to the possible difficulty of correctly assigning an IUCN category to the MPA and could be one of the reasons this dataset did not provide the expected results with regards to IUCN categories. Only category V and VI allow for commercial and recreational fishing, however because these zones comprise less than 75% of the overall MPA area, the MPAs are not classified as allowing for resource extraction. This may lead to the publics misunderstanding that MPAs are often synonymous with fisheries closures, and may lead some to automatically associate MPA placement with an impact on their livelihood (Agardy, Di Sciara, & Christie, 2011).

One important thing to note is that not all management plans are available online, and not every MPA has a management plan. Many of the management plans analyzed for this project were written when the MPA was first established and are therefore outdated. The plans outline their monitoring and evaluation strategy however there is no follow up regarding whether their goals and objectives were met. This information may exist but not be available to the public, however this prevents people from learning whether the MPA has been successful. Management objectives may have been met along the way and new ones created, and increased community involvement may have already been initiated but not reported. Management documents can provide important information about the internal workings of an MPA, however they are often not updated frequently enough to be a good source of comparison among different MPAs.

Overall, MPA management plans can provide useful information regarding the goals and objectives of a protected area, as well as the zones within its boundaries. However, due to the lack of a universal template for these management plans they can be difficult to compare and difficult for the general public to access. Furthermore, it is difficult to assess the progress of an MPA if only the original management plan is available, as is often the case. A proper management plan should include all relevant information relating to the establishment, management, and monitoring of a protected area and should be written in a more concise way if released to the public. Important elements include the goals and objectives, a timeline for accomplishing them, zones, a clear map of the area, management, monitoring and evaluation plans, and a timeline for reassessment and the drafting of a new document. The plans should also be updated in a timely manner as their goals and objectives are met to ensure the public that the area is actually being protected and contributing to the CBD and UN targets in an effective way. It is important especially for new MPAs established to reach these targets to be properly documented through management plans, ensuring they won't fall, or appear to fall into the "paper park" category.

Chapter 5. Conclusions and Recommendations

5.1 Conclusion

The results of this study demonstrate that collaborative management, also known as co-management had the most positive effect on reef fish biomass difference out of the four governance arrangements in this study. Furthermore, federal management had the least positive effect on reef fish biomass difference, suggesting managers should transition from federal management to co-management where possible. In terms of IUCN categories, all had a similar relationship to reef fish biomass difference despite varying levels of strictness and human contact. Covariates that had a positive effect on reef fish biomass difference include the age of the MPA and gross domestic product of the country while covariates that had a negative effect include the size of the MPA and the human development index of the country. Multiple covariates had no discernible effect on the reef fish biomass difference.

5.2 Recommendations

Four main recommendations arise from this study. The first is that marine protected area management should transition towards collaborative management where possible and appropriate. As seen above collaborative management provided the most positive effect on reef fish biomass difference out of the five management styles investigated. Implementing co-management in an MPA can increase compliance and make communities more aware of the impact they are having on the marine environment. It may not be feasible for all MPAs to be managed collaboratively due to various factors such as size, distance from shore, among others. However, the results of this study suggest that transitioning towards co-management can deliver positive outcomes to local communities and to the success of MPAs. It is important to note that a transition to co-management may not always be possible and/or appropriate. This transition may bring about unintended consequences that may change the distribution of power among authorities and benefit some groups while excluding others (Nadasdy, 2005).

A second recommendation includes MPA managers assigning the IUCN categories more effectively. Because each category allows a varying set of activities and prohibits others there should be a clear distinction between the reef fish biomass differences among the categories. Category Ia, the strictest, does not allow any human interaction with the protected area, which should ensure that the environment remains more pristine than an area in which human activities continue to occur. However, as seen in the results of the model there was not much variation between the reef fish biomass differences among categories, calling for MPA managers to ensure they are correctly assigning a category to their MPA based on allowed activities, and properly monitoring activities within the MPA. This will ensure that the IUCN categories remain a valid way to categorize MPAs globally.

A third recommendation involves the covariates at the country level. Although many of them did not have an appreciable effect on the reef fish biomass difference, MPA managers should ensure they understand these country level covariates and the effects they could be having on the success of their MPA. Understanding the effects of these covariates can help managers make better decisions and have a greater understanding of what factors are contributing to the success and effectiveness of their MPA.

Lastly, MPA managers should ensure they are keeping their management plans up to date and publishing them online. These documents are a great way to outline the zones, goals, objectives, and monitoring plans for MPAs however in order for them to be of value they need to be updated in a timely manner. The presence of these plans is a great way to ensure that the goals and objectives of the MPA are being accomplished over time and they are also a good way to keep the public informed on the progress of an MPA. This may be difficult to managers to accomplish alone, making a global database of MPA management documents a possible next step in this process. This global database would allow for a more streamlined process for managers to draft and update their respective management plans.

5.3 Future Directions

Given the results of this project and the recommendation that MPAs transition, where possible, to collaborative or co-management, future studies can look into the factors that contribute to this successful transition. Furthermore, future studies can look into what factors lead to the continued success of MPAs once this transition has occurred. Lastly, reef fish biomass difference is just one of many measures for the success of an MPA. Other environmental and social measures can be used as response variables for similar models with covariates like the ones used in this project. This will further solidify the recommendation that MPAs transition towards co-management, if it is demonstrated that co-management continues to provide the most positive effect on various different response variables.

Glossary of Terms

Bayesian model: a Bayesian model uses probability to represent all uncertainty within the model (for both inputs and outputs). The inference is based on Bayes theorem to obtain a posterior distribution for quantities of interest, based on a prior distribution for the unknown parameters and the likelihood from the model (Spiegelhalter & Rice, 2009).

Correlation: statistical measure that indicates the extent to which two or more variables fluctuate together. A positive correlation indicates the extent to which those variables increase or decrease in parallel while a negative correlation indicates the extent to which one variable increases as the other decreases (Rouse & Wigmore, 2016).

Control and corruption: reflects the perceptions of the extent to which public power is exercised for private gain, including both petty and grand forms of corruption, as well as capture of the state by elites and private interests (The World Bank, 2017).

Goodness of fit: The goodness of fit of a statistical model describes how well the model fits into a set of observations. Goodness of fit indices summarize the discrepancy between the observed values and the values expected under a statistical model (Maydeu-Olivares & García-Forero, 2010)

Gross Domestic Product (GDP): the total unduplicated value of the goods and services produced in the economic territory of a country or region in a given period (Government of Canada, 2017).

Human Development Index (HDI): a summary measure of average achievement in key dimensions of human development: a long and healthy life, being knowledgeable and have a decent standard of living (United Nations Development Programme, 2018).

IUCN (International Union for the Conservation of Nature): The International Union for the Conservation of Nature provides public, private and non-governmental organizations with the knowledge and tools that enable human progress, economic development and nature conservation to take place together (IUCN, 2017).

Marine Protected Area (MPA): a clearly defined geographical space, recognized, dedicated and managed, through legal or other effective means, to achieve the long-term conservation of nature with associated ecosystem services and cultural values (Day et al., 2012).

Posterior predictive distribution: in Bayesian statistics it is the distribution of possible unobserved values conditional on the observed values (Barbieri, 2014).

Reef fish biomass: the amount of living matter in a given area (Definition of Biomass by Merriam-Webster," n.d.). In this case reef fish biomass as used, so the amount of fish in a certain area studied.

Rule of law: reflects the perceptions of the extent to which agents have confidence in and abide by the rules of society, and in particular the quality of contract, property rights, the police and the courts, as well as the likelihood of crime and violence (The World Bank, 2017).

Standardized effects sizes: effect sizes provide information on the magnitude and direction of the difference between two groups or the relationship between two variables (Durlak, 2009). Standardized effects sizes remove the units of the variables (Martin, n.d.).

Voice and accountability: reflects perceptions of the extent to which a country's citizens are able to participate in selecting their government, freedom of expression, freedom of association, and a free media (The World Bank, 2017).

Literature Cited

Agardy, T., Claudet, J., & Day, J. C. (2016). 'Dangerous Targets' revisited: Old dangers in new contexts plague marine protected areas. *Aquatic Conservation: Marine and Freshwater Ecosystems*, *26*, 7–23.

Agardy, T., Di Sciara, G. N., & Christie, P. (2011). Mind the gap: addressing the shortcomings of marine protected areas through large scale marine spatial planning. *Marine Policy*, *35*(2), 226–232.

Amadeo, K. (2018). GDP: Definition, Formula, Types, How It Affects You. Retrieved October 17, 2018, from https://www.thebalance.com/what-is-gdp-definition-of-gross-domestic-product-3306038

Ayers, A. L., & Kittinger, J. N. (2014). Emergence of co-management governance for Hawai 'i coral reef fisheries. *Global Environmental Change*, *28*, 251–262.

Ban, N. C., Adams, V. M., Almany, G. R., Ban, S., Cinner, J. E., McCook, L. J., … White, A. (2011). Designing, implementing and managing marine protected areas: Emerging trends and opportunities for coral reef nations. *Journal of Experimental Marine Biology and Ecology*. https://doi.org/10.1016/j.jembe.2011.07.023

Barbieri, M. M. (2014). Posterior Predictive Distribution. *Wiley StatsRef: Statistics Reference Online*, 1–6.

Bellwood, D. R., Hughes, T. P., Folke, C., & Nyström, M. (2004). Confronting the coral reef crisis. *Nature*, *429*(6994), 827.

Bergseth, B. J., Gurney, G. G., Barnes, M. L., Arias, A., & Cinner, J. E. (2018). Addressing poaching in marine protected areas through voluntary surveillance and enforcement. *Nature Sustainability*, *1*(8), 421.

Biomass | Definition of Biomass by Merriam-Webster. (n.d.). Retrieved October 17, 2018, from https://www.merriam-webster.com/dictionary/biomass

CBD, U. (2010). Strategic plan for biodiversity 2011–2020 and the Aichi targets. In *Report of the Tenth Meeting of the Conference of the Parties to the Convention on Biological Diversity*.

Charles, A., & Wilson, L. (2008). Human dimensions of marine protected areas. *ICES Journal of Marine Science*, *66*(1), 6–15.

Cinner, J. E., Huchery, C., MacNeil, M. A., Graham, N. A. J., McClanahan, T. R., Maina, J., … Mora, C. (2016). Bright spots among the world's coral reefs. *Nature*, *535*(7612), 416.

Cinner, J. E., Marnane, M. J., & Mcclanahan, T. R. (2005). Society for Conservation Biology Conservation and Community Benefits from Traditional Coral Reef Management at Ahus Island, Papua New Guinea. *Source: Conservation Biology*, *19*(6), 1714–1723. Retrieved from http://www.jstor.org/stable/3591193

Cinner, J. E., McClanahan, T. R., Daw, T. M., Graham, N. A. J., Maina, J., Wilson, S. K., & Hughes, T. P. (2009). Linking Social and Ecological Systems to Sustain Coral Reef Fisheries. *Current Biology*. https://doi.org/10.1016/j.cub.2008.11.055

Cinner, J. E., McClanahan, T. R., MacNeil, M. A., Graham, N. A. J., Daw, T. M., Mukminin, A., … Jiddawi, N. (2012). Comanagement of coral reef social-ecological systems. *Proceedings of the National Academy of Sciences*, *109*(14), 5219–5222.

Cinner, J. E., McClanahan, T. R., MacNeil, M. A., Graham, N. A. J., Daw, T. M., Mukminin, A., … Kuange, J. (2012). Comanagement of coral reef social-ecological systems. *Proceedings of the National Academy of Sciences*. https://doi.org/10.1073/pnas.1121215109

Claudet, J., Osenberg, C. W., Benedetti-Cecchi, L., Domenici, P., García-Charton, J., Pérez-Ruzafa, Á., … Bulleri, F. (2008). Marine reserves: size and age do matter. *Ecology Letters*, *11*(5), 481–489.

Clifton, J. (2003). Prospects for co-management in Indonesia's marine protected areas. *Marine Policy*, *27*(5), 389–395.

Cvitanovic, C., Wilson, S. K., Fulton, C. J., Almany, G. R., Anderson, P., Babcock, R. C., … Cinner, J. (2013). Critical research needs for managing coral reef marine protected areas: Perspectives of academics and managers. *Journal of Environmental Management*, *114*, 84–91.

Day, J., Dudley, N., Hockings, M., Holmes, G., Laffoley, D. d'A, Stolton, S., & Wells, S. M. (2012). *Guidelines for applying the IUCN protected area management categories to marine protected areas*. IUCN.

De Santo, E. M., Jones, P. J. S., & Miller, A. M. M. (2011). Fortress conservation at sea: a commentary on the Chagos marine protected area. *Marine Policy*, *35*(2), 258–260.

Di Franco, A., Thiriet, P., Di Carlo, G., Dimitriadis, C., Francour, P., Gutiérrez, N. L., … del Mar Otero, M. (2016). Five key attributes can increase marine protected areas performance for small-scale fisheries management. *Scientific Reports*, *6*, 38135.

Dolan, A. H., & Walker, I. J. (2006). Understanding vulnerability of coastal communities to climate change related risks. *Journal of Coastal Research*, 1316–1323.

Donner, S. D., & Potere, D. (2007). The inequity of the global threat to coral reefs. *Bioscience*, *57*(3), 214–215.

Dudley, N. (2008). *Guidelines for applying protected area management categories*. Iucn.

Durlak, J. A. (n.d.). How to Select, Calculate, and Interpret Effect Sizes. https://doi.org/10.1093/jpepsy/jsp004

Edgar, G. J., Stuart-Smith, R. D., Willis, T. J., Kininmonth, S., Baker, S. C., Banks, S., … Berkhout, J. (2014). Global conservation outcomes depend on marine protected areas with five key features. *Nature*, *506*(7487), 216.

Florida Keys National Marine Sanctuary Revised Management Plan. (2007). Retrieved from https://nmsfloridakeys.blob.core.windows.net/floridakeys-prod/media/archive/mgmtplans/2007_man_plan.pdf

Gelman, A., Carlin, J. B., Stern, H. S., Dunson, D. B., Vehtari, A., & Rubin, D. B. (2013). *Bayesian data analysis*. CRC press.

Gill, D. A., Mascia, M. B., Ahmadia, G. N., Glew, L., Lester, S. E., Barnes, M., … Fox, H. E. (2017). Capacity shortfalls hinder the performance of marine protected areas globally. *Nature*. https://doi.org/10.1038/nature21708

Gill, D. A., Mascia, M. B., Ahmadia, G. N., Glew, L., Lester, S. E., Barnes, M., … Geldmann, J. (2017). Capacity shortfalls hinder the performance of marine protected areas globally. *Nature*, *543*(7647), 665.

Gomez, E. D. (1997). Reef management in developing countries: a case study in the Philippines. *Coral Reefs*, *16*(1), S3–S8.

Government of Canada. (2017). Gross domestic product (GDP). Retrieved October 17, 2018, from https://www.statcan.gc.ca/eng/nea/list/gdp

Granek, E. F., & Brown, M. A. (2005). Co-Management Approach to Marine Conservation in Mohéli, Comoros Islands. *Conservation Biology*, *19*(6), 1724–1732.

Hughes, T. P., Baird, A. H., Bellwood, D. R., Card, M., Connolly, S. R., Folke, C., … Kleypas, J. (2003). Climate change, human impacts, and the resilience of coral reefs. *Science*, *301*(5635), 929–933.

Indab, J. D., & Suarez-Aspilla, P. B. (2004). Community-based marine protected areas in the Bohol (Mindanao) Sea, Philippines. *NAGA, WorldFish Center Quarterly*, *27*(1–2), 4–8.

IUCN. (2017). About | IUCN. Retrieved October 17, 2018, from https://www.iucn.org/about

Johannes, R. E. (2002). The renaissance of community-based marine resource management in Oceania. *Annual Review of Ecology and Systematics*, *33*(1), 317–340.

Keller, B. D., Gleason, D. F., McLeod, E., Woodley, C. M., Airamé, S., Causey, B. D., … Miller, S. L. (2009). Climate change, coral reef ecosystems, and management options for marine protected areas. *Environmental Management*, *44*(6), 1069–1088.

Locke, H., & Dearden, P. (2005). Rethinking protected area categories and the new paradigm. *Environmental Conservation*, *32*(1), 1–10.

Magdaong, E. T., Fujii, M., Yamano, H., Wilfredo, @bullet, Licuanan, Y., Maypa, A., … Martinez, R. (n.d.). Long-term change in coral cover and the effectiveness of marine protected areas in the Philippines: a meta-analysis.

Maire, E., Cinner, J., Velez, L., Huchery, C., Mora, C., Dagata, S., … Mouillot, D. (2016). How accessible are coral reefs to people? A global assessment based on travel time. *Ecology Letters*, *19*(4), 351–360.

Management Plan South Water Caye Marine Reserve World Heritage Site. (2010). Retrieved from http://fisheries.gov.bz/wp-content/uploads/2016/01/South-Water-Caye-Management-Plan_Final.pdf

Maria Island National Park. (n.d.). Retrieved from https://www.parks.tas.gov.au/file.aspx?id=6731

Martin, K. (n.d.). Two Types of Effect Size Statistic: Standardized and Unstandardized. Retrieved October 17, 2018, from https://www.theanalysisfactor.com/two-types-effect-size-statistic/

Maydeu-Olivares, A., & García-Forero, C. (n.d.). *Goodness-of-Fit Testing*. Retrieved from http://www.ub.edu/gdne/amaydeusp_archivos/encyclopedia_of_education10.pdf

McCarthy, D. P., Donald, P. F., Scharlemann, J. P. W., Buchanan, G. M., Balmford, A., Green, J. M. H., … Garnett, S. T. (2012). Financial costs of meeting global biodiversity conservation targets: current spending and unmet needs. *Science*, 1229803.

McClanahan, T. R., Marnane, M. J., Cinner, J. E., & Kiene, W. E. (2006). A Comparison of Marine Protected Areas and Alternative Approaches to Coral-Reef Management. *Current Biology*. https://doi.org/10.1016/j.cub.2006.05.062

McLeod, E., Salm, R., Green, A., & Almany, J. (2009). Designing marine protected area networks to address the impacts of climate change. *Frontiers in Ecology and the Environment*, *7*(7), 362–370.

Mellin, C., Aaron Macneil, M., Cheal, A. J., Emslie, M. J., & Julian Caley, M. (2016). Marine protected areas increase resilience among coral reef communities. *Ecology Letters*. https://doi.org/10.1111/ele.12598

Mora, C., Andréfouët, S., Costello, M. J., Kranenburg, C., Rollo, A., Veron, J., … Myers, R. A. (2006). Coral reefs and the global network of marine protected areas. *SCIENCE-NEW YORK THEN WASHINGTON-*, *2006*, 1750.

Mumby, P. J., Dahlgren, C. P., Harborne, A. R., Kappel, C. V, Micheli, F., Brumbaugh, D. R., … Sanchirico, J. N. (2006). Fishing, trophic cascades, and the process of grazing on coral reefs. *Science*, *311*(5757), 98–101.

Nadasdy, P. (2005). The anti-politics of TEK: the institutionalization of co-management discourse and practice. *Anthropologica*, 215–232.

Nations., U. (2016). *Sustainable Development Goals Report 2016*. UN.

O'leary, B. C., Ban, N. C., Fernandez, M., Friedlander, A. M., García-Borboroglu, P., Golbuu, Y., … Langlois, T. (2018). Addressing criticisms of large-scale marine protected areas. *BioScience*, *68*(5), 359–370.

of Fisheries, D. (2001). Final Plan of Management for the Cottesloe Reef Proposed Fish Habitat Protection Area. Retrieved from http://www.fish.wa.gov.au/Documents/management_papers/fmp155.pdf

Pollnac, R. B., Crawford, B. R., & Gorospe, M. L. G. (2001). Discovering factors that influence the success of community-based marine protected areas in the Visayas, Philippines. *Ocean & Coastal Management*, *44*(11–12), 683–710.

Pomeroy, R. S., Parks, J. E., & Watson, L. M. (2004). *How is your MPA doing?: a guidebook of natural and social indicators for evaluating marine protected area management effectiveness*. IUCN.

Roberts, C. M., O'Leary, B. C., McCauley, D. J., Cury, P. M., Duarte, C. M., Lubchenco, J., … Wilson, R. W. (2017). Marine reserves can mitigate and promote adaptation to climate change. *Proceedings of the National Academy of Sciences*, 201701262.

Rouse, M., & Wigmore, I. (n.d.). What is correlation? - Definition from WhatIs.com. Retrieved October 17, 2018, from https://whatis.techtarget.com/definition/correlation

Salvatier, J., Wiecki, T. V, & Fonnesbeck, C. (2016). Probabilistic programming in Python using PyMC3. *PeerJ Computer Science*, *2*, e55.

Selig, E. R., & Bruno, J. F. (2010). A Global Analysis of the Effectiveness of Marine Protected Areas in Preventing Coral Loss. *PLoS ONE*, *5*(2). https://doi.org/10.1371/

Selig, E. R., Casey, K. S., & Bruno, J. F. (2012). Temperature-driven coral decline: The role of marine protected areas. *Global Change Biology*. https://doi.org/10.1111/j.1365-2486.2012.02658.x

Spalding, M., Ravilious, C., & Green, E. P. (2001). *World atlas of coral reefs*. Univ of California Press.

Spiegelhalter, D., & Rice, K. (2009). Bayesian statistics. *Scholarpedia*, *4*(8), 5230.

The Revised Bacalar Chico National Park & Marine Reserve Management Plan. (2004). Retrieved from http://fisheries.gov.bz/wp-content/uploads/2016/01/BCNPMR-Management-Plan-Report.pdf

The World Bank. (2017). Worldwide Governance Indicators (WGI) | Data Catalog. Retrieved October 17, 2018, from https://datacatalog.worldbank.org/dataset/worldwide-governance-indicators

United Nations Development Programme. (2018). Human Development Index (HDI) | Human Development Reports. Retrieved October 17, 2018, from http://hdr.undp.org/en/content/human-development-index-hdi

Vandeperre, F., Higgins, R. M., Sánchez-Meca, J., Maynou, F., Goni, R., Martín-Sosa, P., … Crec'hriou, R. (2011). Effects of no-take area size and age of marine protected areas on fisheries yields: a meta-analytical approach. *Fish and Fisheries*, *12*(4), 412–426.

Wales, S., & Authority, M. P. (2010). *Department of Environment, Climate Change and Water (DECCW) on behalf of the New*. Retrieved from www.mpa.nsw.gov.au

Wamukota, A. W., Cinner, J. E., & McClanahan, T. R. (2012). Co-management of coral reef fisheries: a critical evaluation of the literature. *Marine Policy*, *36*(2), 481–488.

Wildtracks Belize. (2011). Gladden Split and Silk Marine Reserve Management Plan. Retrieved from ftp://ftp.library.noaa.gov/noaa_documents.lib/CoRIS/Gladden-Spit-and-Silk-Cayes-Mgmt-Plan_2011-16.pdf

Appendix

Table 12. Category Ia – Strict Nature Reserve

Description	Strictly protected areas set aside to protect biodiversity and also ecological features, where human visitation, use and impacts are strictly controlled and limited to ensure protection of the conservation values. Such protected areas can serve as indispensable reference areas for scientific research and monitoring
Primary Objective	To conserve regionally, nationally or globally outstanding ecosystems, species and/or geodiversity features; these attributes will have been formed mostly or entirely by non-human forces and will be degraded or destroyed when subjected to all but very light human impact
Secondary Objectives	- To preserve ecosystems, species, and geodiversity features in a state as undisturbed by recent human activity as possible - To secure examples of the natural environment for scientific studies, environmental monitoring and education - To minimize disturbance through careful planning and implementation of research and other approved activities - To conserve cultural and spiritual values associated with nature
Additional Information	- Surrounding areas should also be protected and managed - Removal of species, collection of resources, dredging, mining and drilling are incompatible

Table 13. Category II – National Park

Description	Large natural or near natural areas set aside to protect large-scale ecological processes, along with the complement of species and ecosystems characteristics of the area, which also provide a foundation for environmentally and culturally compatible spiritual, scientific, educational, recreational and visitor opportunities
Primary Objective	To protect natural biodiversity along with its underlying ecological structure and supporting environmental processes, and to promote education and recreation
Secondary Objectives	- To manage the area in order to perpetuate, in as natural a state as possible, representative examples of physiographic regions, biotic communities, genetic resources and unimpaired natural processes - To maintain viable and ecologically functional populations and assemblages of native species to conserve ecosystem integrity and resilience in the long term - To contribute to conservation of wide-ranging species, regional ecological processes and migration routes - To manage visitor use for inspirational, educational, cultural and recreational purposes at a level which will not cause significant biological or ecological degradation to the natural resources - To consider the needs of indigenous people and local communities - To contribute to local economies through tourism
Additional Information	- Should provide for visitation and research - Extractive use not consistent with objectives

Table 14. Category III – Natural Monument of feature

Description	Set aside to protect a specific natural monument, which can be a landform, sea munt, submarine cavern, geological feature such as a cave or even a living component such as a specific coralline feature. They are generally quite small protected areas and often have high visitor use
Primary Objective	To protect specific outstanding natural features and their associated biodiversity and habitats
Secondary Objectives	- To provide biodiversity protection in landscapes or seascapes that have otherwise undergone major changes - To protect specific natural sties with spiritual and/or cultural values where these also have biodiversity values - To conserve traditional spiritual and cultural values of the site
Additional Information	- Extractive use not considered consistent with the objectives

Table 15. Category IV – Habitat/species management areas

Description	Aim to protect particular species or habitats and management reflects this priority. Many category IV protected areas will need regular, active interventions to address the requirements of particular species or to maintain habitats, but this is not a requirement for the category
Primary Objective	To maintain, conserve, and restore species and habitats
Secondary Objectives	- To protect biological features through traditional management approaches - To develop public education and appreciation of the species and/or habitats concerned - To provide a means by which the urban residents may obtain regular contact with nature
Additional Information	- Aimed at protecting particular stated species or habitats

Table 16. Category V – Protected landscape of seascape

Description	Areas where the interaction of people and nature over time has produced an area of distinct character with significant ecological, biological, cultural and scenic value: and where safeguarding the integrity of this interaction if vital to protecting and sustaining the area and its associated nature conservation and other values
Primary Objective	To protect and sustain important landscape/seascapes and the associated nature conservation and other values created by interactions with humans through traditional management practices
Secondary Objectives	- To maintain a balanced interaction of nature and culture - To contribute to broad scale conservation by maintaining species associated with cultural landscapes and/or by providing conservation opportunities in heavily used landscapes - To provide opportunities for enjoyment, well-being and socioeconomic activity through recreation and tourism - To provide natural products and environmental services - To provide a framework to underpin active involvement by the community in the management of values landscapes or seascapes and the natural and cultural heritage they contain - To encourage the conservation of aquatic biodiversity - To act as models for sustainability so that lessons can be learnt for wider application
Additional Information	- Applies to areas where local communities live within and sustainably use the seascape

Table 17. Category VI – Protected areas with sustainable use of natural resources

Description	Areas that conserve ecosystems and habitats, together with associated cultural and traditional resource management systems. They are generally large, with most of the area in a natural condition, where a proportion is under low-level non-industrial sustainable natural resource management and where such use of natural resources compatible with nature conservation is seen as the main aims of the area
Primary Objective	To protect natural ecosystems and use natural resources sustainably, when conservation and sustainable use can be mutually beneficial
Secondary Objectives	- To promote low-level sustainable use of natural resources - To promote social and economic benefits to local communities where relevant - To facilitate inter-generational security for local communities' livelihoods – therefore ensuring that such livelihoods are sustainable
Additional Information	- Allows sustainable collection of some species - Careful consideration needs to be given as to whether activities such as seabed mining and some commercial fishing practices should be permitted

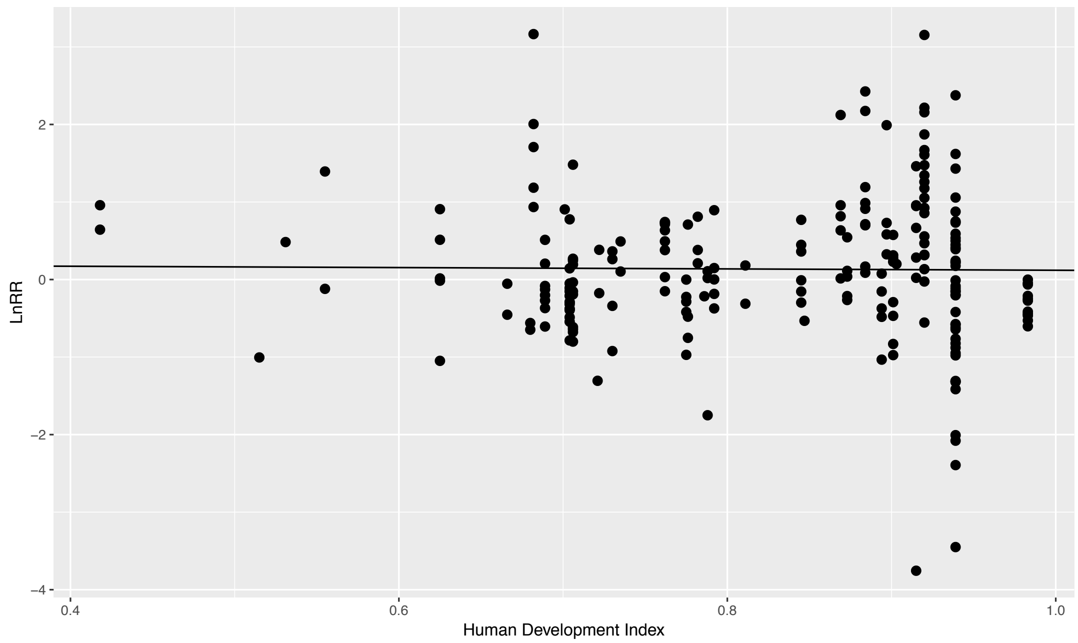

Figure 11. Negative relationship between the Human Development Index and the reef fish biomass difference values for all 218 MPAs. Data points represent the LnRR values after considering the effects of all other covariates in the model.

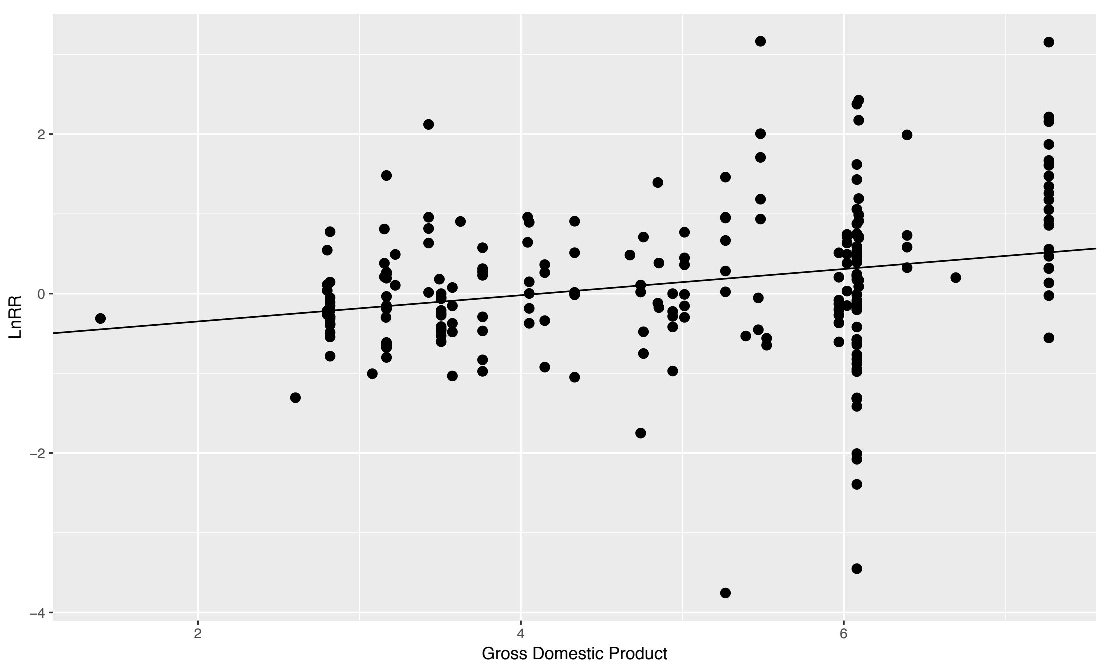

Figure 12. Positive relationship between the Gross Domestic Product and the reef fish biomass difference values for all 218 MPAs. Data points represent the LnRR values after considering the effects of all other covariates in the model.