Social-Ecological Resilience to Climate Change: A case Study of the Sandy Island Oyster Bed Marine Protected Area

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ABSTRACT

Climate change is likely to alter the physical and chemical properties of the ocean within the next century, having long-term and perhaps irreversible effects on the marine ecosystems upon which coastal communities are reliant for sustenance and livelihood. Extensive reef development within the Sandy Island Oyster Bed Marine Protected Area (SIOBMPA) off the coast of Carriacou, Grenada, provides neighboring communities with important ecosystem goods and services which are threatened by warming sea surface temperatures, ocean acidification and sea level rise. Building the capacity to cope, adapt and transform in response to climate change is thus imperative to the long-term welfare of the SIOBMPA and associated stakeholder community. This study provides an assessment of the current resilience of the SIOBMPA to climate change from the social-ecological system (SES) perspective. Through the understanding of the resilience of each individual subsystem (i.e. ecological and social), the interactions that exist between the two and the current and future impacts that will influence these interactions, this study identifies system components that may contribute to building or diminishing the resilience of the SIOBMPA SES. Findings suggest that functional group diversity and low anthropogenic influence in ecological systems enhance coping capacity when faced with long-term climate driven impacts, while the social system's ability to build institutions that foster communication, trust, social learning and effectively use available capital promote adaptation and transformation. Based on the results yielded from this analysis, recommendations for marine management measures that promote SES resilience are provided.

CHAPTER 1 – INTRODUCTION

It is believed that small island developing states (SIDS) will be the first to feel the impacts of a changing climate (Nurse et al., 2014). Irrespective of their geographical and cultural diversity, SIDS worldwide share similarities that increase their vulnerability to climate change. Remoteness and lack of geographic and economic scale incur high communication, transportation, administration and infrastructure cost, and make SIDS heavily reliant on the international market for commodities and services (Nurse et al., 2014). These shared characteristics, combined with rapidly growing populations, limit their ability for sustainable development. Furthermore, SIDS are susceptible to natural disasters and weather patterns influenced by large ocean-atmosphere interactions such as trade winds and El Niño (Nurse et al., 2014). With human settlements, agricultural lands and important infrastructure often concentrated in low-lying coastal areas, SIDS are vulnerable to the impacts of sea level rise and intense hurricanes including storm surge, erosion, saltwater intrusion and inundation (Nurse et al., 2014). This combination of climate features, physical attributes and socio-political traits renders SIDS highly exposed and sensitive to environmental change and limits their capacity for adaptation.

Caribbean SIDS are strongly reliant on the marine ecosystem for sustenance and livelihood; fishing and coastal tourism being an important source of economic capital (Chakalall et al., 2007). Warming sea surface temperatures, ocean acidification and sea level rise will likely drive drastic and irreversible changes in the marine environment, threatening the ecological and biological function of all marine ecosystems (UNFCCC, 2015). Coral reef systems operate within a very narrow set of environmental conditions and are particularly sensitive to changes in temperature, water chemistry and depth (Kleypas et al., 1999). Climate change will likely drive coral bleaching and mortality, erosion and smothering, the propagation of disease within reef systems and changes in the migration and reproductive timing of commercially and ecologically important fish species (Hoegh-Guldberg et al., 2010). In the face of a changing climate, well managed marine protected areas can be effective adaptation strategies to climate change, offering multiple benefits on various geographical and economic scales (Roberts et al., 2017).

The Sandy Island Oyster Bed Marine Protected Area (SIOBMPA), located off the coast of the Carriacou, Grenada, is 659 hectares of protected marine space comprising mangroves, seagrass beds and extensive reef development (MCPMA, 2015). Also known as the "isles of reefs", Carriacou's bountiful coral reef ecosystems have long provided residents with an important source of food, economic capital, recreation and cultural identity. The communities lying adjacent to the SIOBMPA as well as local fisherfolk and tourism operators benefit from the marine protected area (MPA) on daily basis through numerous extractive and non-extractive uses (MCPMA, 2015). Furthermore, multiples agencies, both governmental and non-governmental, are directly and in-directly involved in the management and monitoring of the MPA (MCPMA, 2015). Due to the tightly bound dynamics existing between the community and the marine environment, the SIOBMPA represents a complex Social-Ecological System (SES), whereby stakeholder behaviours and actions have a prominent influence on the health of the coral reef system, and in turn the health of the coral reef determines the availability and quality of the ecosystem goods and services provided to stakeholders (Berkes and Folke, 1998; Ostrom, 2009).

Impending detrimental impacts highlight the need to build SES resilience as a first response to climate change. The SIOBMPA management team have identified climate change as a key threat to coral reefs within the MPA, and anticipatory ecological response measures have been identified accordingly (MCPMA, 2015). However, knowledge gaps and uncertainties can arise due to the complexity of the interactions existing within coral reef systems, especially while undergoing change (Folk et al., 2002; Gunderson & Holling, 2002). Attempting to directly manage the ecosystem for resilience under changing environmental conditions through the use of existing knowledge streams and rigid control mechanisms is therefore likely to be ineffective (Folke et al., 2002). Managing for SES resilience to climate change will thus be based on shaping human actions that will both increase the capacity of the internal social system to cope, adapt and transform as well as promote coral reef resistance and recovery. In order to understand the social system components that contribute to shaping the SIOBMPA SES resilience, this study will seek to answer the following question, and sub-questions:

What components of the social system are improving and/or diminishing the resilience of the social-ecological system to climate change?

How are current ecological monitoring efforts contributing to the understanding of the SIOBMPA reef's resilience to climate change?

What exogenous threats and opportunities exist that may diminish or facilitate resilience building in the SES, respectively?

What MPA management strategies can be implemented to improve the resilience of the SES to climate change?

In order to set the context, a description of the subsystems that comprise the SIOBMPA SES will first be provided, including an overview of the marine park, the coral reef system, the governance system in place and the stakeholder community. Both the local anthropogenic impacts that affect the reef and the relevant regional climate change projections and impacts for the South-East Caribbean will be discussed. Background theory regarding SES resilience and the resilience of each subsystem (i.e. the social and ecological system) will also be described and used as the foundation for the study methodology used to address the above questions. Results will be revealed and interpreted using a SWOT analysis (strength, Weaknesses, Opportunities, Threats), which will expose the SES' internal strengths and weaknesses that enhance or diminish resilience, as well as the opportunities and threats provided by the external system. Information drawn from this analysis will then be used to draft a list of recommendations for effective MPA management within the context of a changing climate.

CHAPTER 2 - SETTING THE CONTEXT

As a complex SES, the SIOBMPA is composed of separate human and environment subsystems that interact to generate outcomes at the SES level, which in turn feed back into system to affect subsystem level interactions (Ostrom, 2009). The following chapter will draw on the SES assessment framework developed by Elinor Ostrom (2009) to describe the multiple subsystems that compose the SIOBMPA SES as seen in Figure 1, starting with a description of the marine park and more specifically the SIOBMPA coral reef system. The social system, including the SIOBMPA governance system as well as the primary and secondary stakeholders and their use of the marine environment, will be described, followed by an overview of the direct anthropogenic impacts affecting the reef system. Finally, regional climate change projections relevant to coral reef ecosystem health will be discussed as well as the impacts that they will incur.

Figure 1. The SIOBMPA depicted as a complex Social-Ecological System with four dominant subsystems: the marine park, the reef system, the governance system and the stakeholders.

2.1 – THE ECOLOGICAL SYSTEM

THE MARINE PARK

Carriacou is the largest of the Grenadines Islands in Grenada located in the south-east Caribbean Sea. The island is characterized by a tropical climate with an average daily temperature of 25-27°C and alternating wet and dry seasons (MCPMA, 2015). The SIOBMPA, at the south-east point of Carriacou, is an area of approximately 659 hectares of protected space comprising mangroves, seagrass beds and extensive reef development (Figure 2) (MCPMA, 2015). The park is bordered by three communities: Lauriston, L'esterre and Harvey Vale/ Tyrell Bay. Mangroves within the area serve as a habitat for oysters and nursing grounds for various fish species. Local boaters and visiting yachters also use the Tyrell bay mangrove system for its protection from high wave action during tropical storms (MCPMA, 2015). Three small offshore islands exist within the area: Sandy Island, Mabouya Island and Sister rocks – all of which are bordered by coral reefs (MCPMA, 2015). Seagrass beds within the MPA serve as feeding grounds for several species of marine fauna, including stingrays and turtles (MCPMA, 2015). As the largest and most biologically diverse MPA in Grenada, the SIOBMPA is of great ecological, social, political and economical importance (MCPMA,2015).

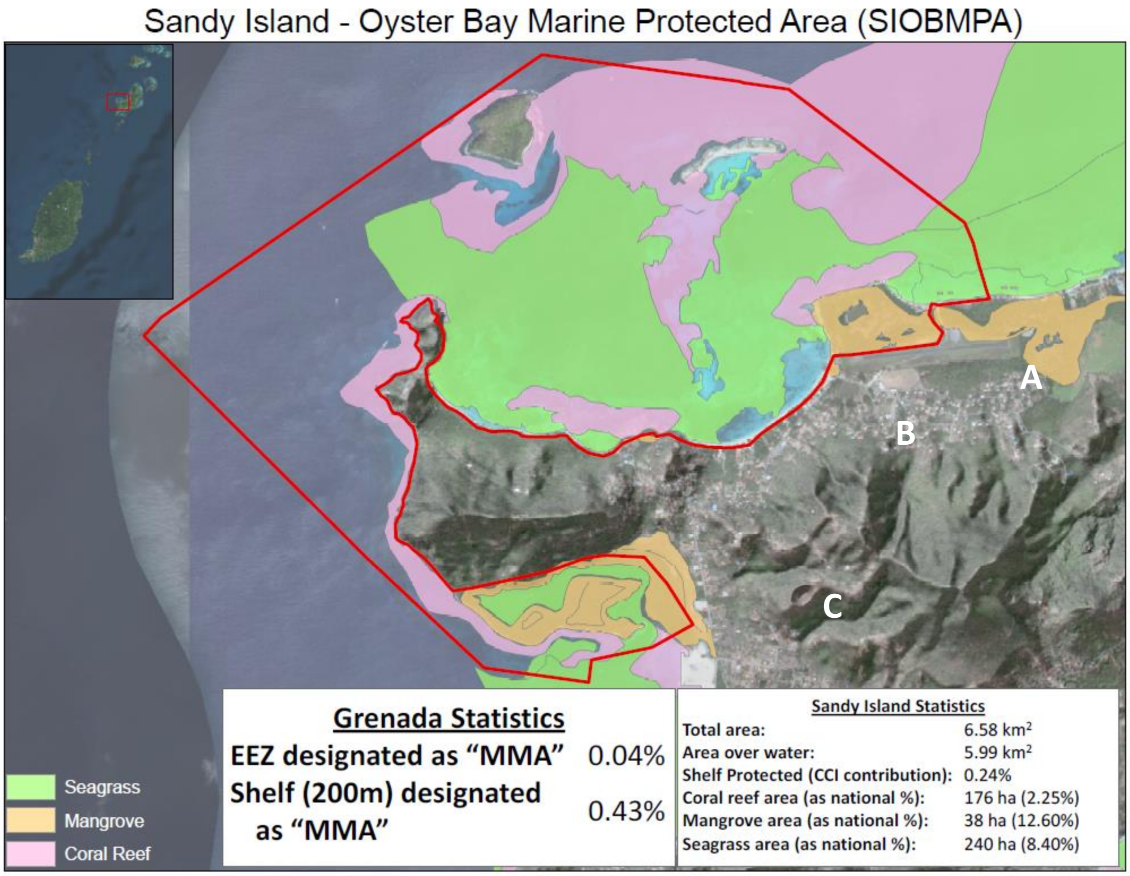

Figure 2. An aerial photograph and schematic representation of the SIOBMPA, where the park borders are outlined in red, marine ecosystems are differentiated by colour, and communities lying adjacent to the park are: A. Lauriston, B L'Esterre, and C. Tyrell Bay/Harvey Vale. The SIOBMOA is a marine managed area (MMA) that comprises 0.24% of the Grenadian protected shelf area. Source: TNC, n. d.

THE CORAL REEF

Several fringing reef systems border the offshore islands in addition to patch reef systems existing within the western and northern areas of the park. The coral reef systems are diverse and complex, and include species of mollusks, crustacean, echinoderms, fish and elasmobranchs among others (MCPMA, 2015).

Reef health monitoring efforts have been underway by local and international non-governmental organizations (NGOs) in partnership with the SIOBMPA management authority and the Ministry of Carriacou and Petite Martinique Affairs (MCPMA). Since MPA implementation in 2007, Atlantic and Gulf Rapid Reef Assessment (AGGRA) data has been collected to monitor the health of the reef, which has been used in the formulation of *the 2016 Eastern Caribbean Coral Reef Report Card*, an assessment of the Climate-Resilient Eastern Caribbean Marine Managed Areas Network (ECMMAN), which includes the SIOBMPA. This project, which is part of the International Climate Initiative (IKI), is lead by The Nature Conservancy (TNC), funded by the German Federal Ministry for the Environment, Nature Conservation, Building and Nuclear Safety (BMUB), and supported by the local NGO Sustainable Grenadines Inc. (SusGren), The Grenada National Marine Protected Area (GNMPA) agency and the Gulf of Caribbean Fisheries Institute (GCFI). Coral reef health for ECMMAN sites is deduced using a set of four indicators which are averaged to determine the sites Coral Reef Health Index (RHI) developed by the Healthy Reefs Initiative (Figure 3). The RHI indicators, namely coral cover, fleshy macroalgae, herbivorous fish and commercial fish, are assessed and attributed a score from 0-5, ranging from Critical to Very Good condition respectively.

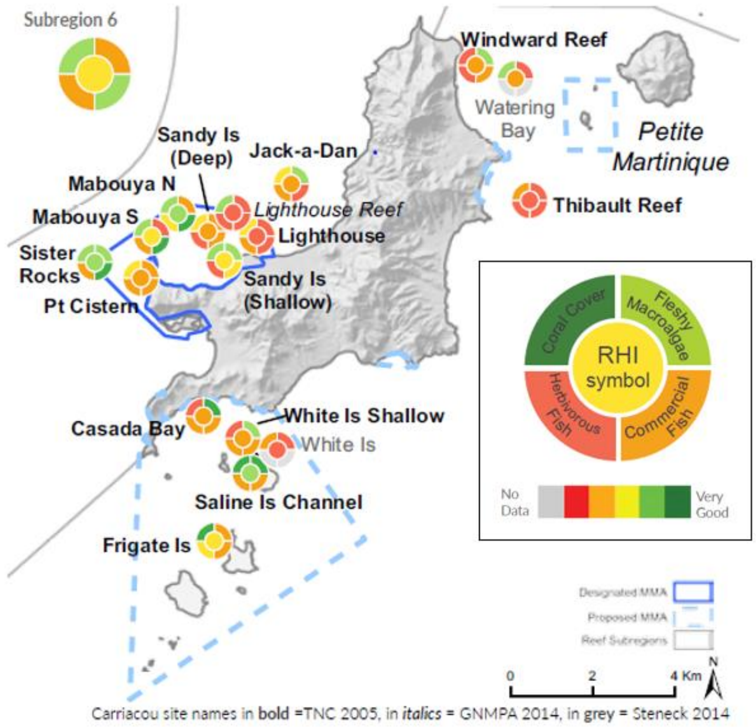

Figure 3. Reef Health Index results from the 2016 Report Card on coral reef health in Carriacou, Grenada, where the SIOBMPA is identified as Subregion 6. RHI was determined using data collected by TNC and GNMPA between 2005 and 2014. Source: TNC, 2016.

The health of the SIOBMPA coral reef under the RHI is in fair condition (TNC, 2016). Live coral cover in the SIOBMPA is between 20-39.9%, and commercial fish density, including large predatory fish such as groupers and barracuda, is 1260-1679 g/100m^2, which are considered good under the RHI (TNC, 2016). High live coral coverage is indicative of a reef that provides the structural complexity required for biodiversity to be sustained (Hoegh-Guldberg et al., 2007). Furthermore, predatory fish contribute to maintaining the dynamics and ecological feedback systems necessary to the health of the coral-reefs. Conversely, macroalgae cover is 12.1-25%, and herbivorous fish density is 960-1919 g/100m^2, which is considered poor under the RHI (TNC, 2016). Herbivory plays a predominant role in maintaining a healthy balance in coral to macroalgae coverage (Mumby et al., 2007), therefore low populations of herbivorous fish can directly be associated with the high coverage of fleshy macroalgae on the SIOBMPA reef. Macroalgae proliferation (specifically turf macroalgae) heavily reduces coral larval recruitment and settlement through various processes, including covering space and accumulating sediment as well as changing the chemical and microbial balance of the system, which reduces the availability of suitable settlement space and conditions for coral recruits (Nystrom et al., 2008). The health of the SIOBMPA directly influences the goods and services offered to the community. While high coral coverage and the abundance of commercially important fish in the reef will be beneficial to fishermen in the surrounding area (due to the "spill over" of fish into neighboring waters) as well as the local tourism industry, the presence of high macroalgae coverage may represent a significant threat to the future health of the marine park.

2.2 – THE SOCIAL SYSTEM

THE SIOBMPA GOVERNANCE

The SIOBMPA was officially established as a marine protected area by the Prime Minister in 2010 under the Fisheries Act Cap 108 (MCPMA, 2015). Due to the MPA's distance from mainland Grenada, a local co-management Board was established with representatives from Government Ministries, NGOs, community organizations and private sector associations, and powers were delegated to the Ministry of Carriacou and Petite Martinique Affairs (MCPMA, 2015). There have been challenges in defining the governance structure of the MPA, particularly the relationships between the National MPA board, site level management boards and the MPA manager, which has lead to significant constraints in addressing and achieving the MPA management goals (MCPMA, 2015). Table 1 summarizes the various governance roles and their intended responsibilities in supporting and implementing the SIOBMPA co-management objectives, as outlined in the 2015-25 management plan (MCPMA, 2015), as well as the current efforts that are underway, the latter established through personal communication with members of the MPA governance authority and partner organizations in August 2017.

Table 1. SIOBMPA governance roles by category as of August 2017. Information concerning position responsibilities in the second column are drawn from the 2015-25 management plan (MCPMA, 2015) and current efforts underway in the third column are drawn from publications and personal communication with members of the MPA governance authority and partner organizations in August 2017.

Category	**Role in SIOBMPA management**	**Current efforts underway**
MPA board	- Secure funding for community research - Develop revolving line of credit for fishers - Engage police prosecutor to support enforcement - Build relations with marina developer/operator solid waste management authority - Communicate with ferry company about designated route - Seek role in development approval processes	- The board is non-operational
Partner organizations	- Lionfish control - Baseline assessment of oyster bed and land-	- Local dive shops (and their respective affiliated NGOs) currently take part in coral

	based sources of pollution, - assist with coral bleaching response and coral nursery - Organize learning exchange on mooring maintenance - Private sector allies assist in communications- with ferry company	reef monitoring (predominantly through reef check training and data collection), lionfish control and have assisted the United Nations Development Program with the coral nursery in place - SusGren in partnership with the MCPMA and the local community are developing a Local Early Adaptation plan to climate change with the support of external consultants and NGOs, including GCFI and the National Oceanic and Atmospheric Administration (NOAA). - Independent research conducted by student interns
Communications Officer	- Develop outreach campaign to fishers and youth - With fisheries extension officer raise awareness of fishing regulations - With fisheries extension officer and KIDO raise awareness about sea turtle protections - Additional target outreach: dumping, illegal sand mining, yacht moorings, etiquette for MPA visitors & speed restrictions	- The communications officer was hired in August 2017 – The officer is undergoing training to fulfill these duties
Wardens	- Patrol to: enforce fishing regulations, proper use of moorings, prevent dumping in mangroves	- There is one fully trained MPA warden currently in position and two trainees. MPA patrolling is taking place, but enforcement has

	and beaches, prevent tying up in mangroves during non-emergencies, prevent cutting of vegetation and sand mining, enforce speed restrictions and collect MPA - Joining patrol with police and forestry department - Inspect and maintain mooring - Participate in coral reef monitoring and beach profiling - Help organize beach clean-ups	been deemed weak by local communities (Harvey, 2013) particularly in: interacting with fisheries to enforce fishing regulations as well as manage illegal anchoring and mooring sites.
Managers	- Oversee strategic enforcement - Fisher consultation about MPA zoning - Address encroachment into Lauriston mangrove - Establish buffer zones for oyster bed - Implement 24-hour duty phone - Encourage best practices by developers - Seek funding for removal of derelict vessels - Encourage partner efforts on lionfish - Establish junior rangers and community research - Oversee coral reef monitions and adaptive management	- There is currently no official MPA manager - a senior government official is acting as stand-in supervisor while this position is filled

The lack of a functional board, a permanent MPA manager and communications officer (until recently) may impede effective communication along the chain of command, and lead to weak regulation enforcement and a slowed progression in achieving MPA goals. Efforts are currently in place to fill empty positions to increase the capacity of the SIOBMPA management team and stakeholder community (Personal communication with senior government representative and partner organizations, August 2017).

THE MANAGEMENT PLAN

The development of the original Sandy Island Oyster Bed MPA Management Plan in 2007 was undertaken as "a partnership between TNC, the Government of Grenada Ministry of Agriculture, Lands, Forestry and Fisheries, the Carriacou Environmental Committee (CEC), The Caribbean Regional Environmental Program (CREP) and supported by grants from the Parks in Peril program of the United States Agency for International Development (USAID)" (TNC and GFD 2007). In the plan, 18 conservation objectives were designated to protect a suite of priority resources, including coral reef communities, mangroves, sea grass beds, sea turtles, sandy beaches, offshore islands and livelihood security. As stated in the in the SIOBMPA 2015-2025 management plan, "Between development of the 2007 draft management plan and the 2015 update process, it became clear that the management goals, objectives and activities were disjointed, and they were not adequately articulated so as to be actionable or realistic "(MCPMA, 2015, p.29). Since, GCFI and NOAA have provided technical assistance to the SIOBMPA management team in addressing these issues and in developing the new management goals, objective and activities stated in the 2015-2025 management plan (MCPMA, 2015).

The management objectives are as follows:

1. Conserve the coastal and marine resources of the SIOBMPA for current and future generations
2. Increase awareness and knowledge about SIOBMPA and engage stakeholders/communities in the sustainable use, development and management of coastal and marine resources

3. Provide opportunities for socio-economic benefits to the community of Carriacou and the wider Caribbean while preserving the cultural value of the SIOBMPA
4. Efficiently and effectively coordinate and administer the management of SIOBMPA
5. Ensure that SIOBMPA is an integral part of a marine protected areas network in the Grenadines, the Caribbean and more broadly, the world.

Coral reef communities have been identified as a priority resource threatened by overfishing/illegal fishing, habitat damage by fishing seine nets, invasive species, pollution (especially land-based sources), dredging, inappropriate boat use and climate change. In order to respond to the impacts of climate change, the management team identified a list of 3 key activities that should take place within the first 5 years of the plan's implementation (MCPMA, 2015):

1. Develop a coral bleaching response plan
2. Check coral reef watch alerts and work with partners to monitor for coral bleaching
3. Outplant from coral nursery to strategic areas with increased surveillance

STAKEHOLDER IDENTIFICATION

Most of Carriacou's 8000 residents are subsistence agriculturists and fishermen, with many also involved in the tourism sector (MCPMA, 2015). The ecological diversity of the SIOBMPA provides coastal communities with various sources of livelihood and food, and represents an important space for community recreation and socialization. In 2013, the Centre for Resource Management and Environment Studies (CERMES) from the University of the West Indies assessed the Socio-Economic trends of adjacent communities of the SIOBMPA to identify the uses of the MPA as well as determine impacts, attitudes and perception trends among MPA stakeholders. Information drawn from this assessment was used to generate the following list of stakeholders:

Table 2. The list of local SIOBMPA stakeholder groups by category. Only local Carriacou or neighboring island stakeholder groups were included in this analysis.

Stakeholder category	Groups	Activity practiced in the SIOBMPA	Use (extractive or

			non-extractive)
Tourism	Water Taxi, tour operators and dive shops	- Tour guiding - Water taxi - Dive operating - Ecological monitoring programs (Dive shops)	Non-extractive
Fisheries	Hillsborough, Tyrell Bay and L'Esterre bay	- Pot fishing - Spear fishing - Seine fishing	Extractive
Government	MPA management team (manager, wardens and communications officer), MPA board and Senior government representatives	- MPA management - Decision making	Non-extractive
Community	L'esterre, Lauriston and Harvey Vale/Tyrell Bay	- Swimming - Diving - Picnicking - Sunbathing - Snorkelling - Recreational fishing	Non-extractive and Extractive
Non-Governmental Organization (NGO)	Local NGO –SusGren	- Support government with ecological monitoring	Non-extractive

While MPAs offer ecosystem services at various geographical, economic, social and political scales (Roberts et al., 2017), the scope of this study will be limited to primary and secondary stakeholders living in direct proximity to the MPA and which play a role in the management of the marine space or rely on the SIOBMPA for sustenance, livelihood and/or wellbeing. Various key stakeholders that are indirectly affiliated with the SIOBMPA through past and present initiatives, such as national and international governmental representatives and international NGOs, lie beyond the scope of this study. Therefore, organizations such as Gulf and Caribbean Fisheries Institute (GCFI), the Nature Conservancy (TNC) and the US National Ocean and Atmospheric Administration (NOAA), which took part in the development of the SIOBMPA management plan but aren't directly affected by the plan or in charge of decision making, will not be considered.

Furthermore, the scope of this analysis is also temporally limited to current primary stakeholder groups (assessed from year 2015-current). Thus, groups that may have been historically considered stakeholders or have been involved in MPA capacity building projects in the past will not be included in this analysis. The scope of this study is bound to the local level in order to limit the number and breath of the dynamics and interactions examined in the analysis.

2.3 – LOCAL ANTHROPOGENIC IMPACTS

Ecological monitoring initiatives lead by Dive Shops (and their affiliated internal NGOs) in the SIOBMPA supply valuable information regarding ecosystem health and local anthropogenic impacts affecting the reef. Reef Check is a citizen science ecological reef monitoring program (www. Reefcheck.org) used by Caribbean Reef Buddies (affiliated to Deefer Diver) to collect data concerning the state of the SIOBMPA reef. According to data collected during their August 2017 Reef check survey from three different sites within the SIOBMPA (Mabouya Garden, Sandy Island Garden and Whirlpool), the most prominent extractive anthropogenic impacts are attributed to the harvest of invertebrates and fish for commercial sale and personal consumption (Table 3). These results are consistent with statements from the 2015-2015 SIOBMPA management plan, which states that "Unregulated fishing has resulted in a serious decline in [commercial] species, which has affected the overall health of the marine ecosystem, and the well-being of fishermen who find it increasingly difficult to make a living from the industry" (MCPMA, 2015). The highest non-extractive impacts include the presence of yachts, divers and snorkelers, with very low impacts generated from siltation, industrial and sewage pollution (table 3). Overall, direct anthropogenic impacts are low in all three sites.

Table 3. A list of estimated local anthropogenic impacts affecting three coral reef sites within the SIOBMPA according to Reef Check data collected in August 2017 by Caribbean Reef Buddies. The frequency of the impact is a rated on a descriptive (non-numerical) scale.

Impact	**Sandy Island Garden**	**Mabouya Garden**	**Whirlpool**
Siltation	Occasionally	Occasionally	Occasionally

Harvest of invertebrates for food	Medium	Medium	Medium
Tourist diving/snorkeling	Medium	Low	Low
Sewage pollution (outfall or boat)	Low	Low	Low
Industrial pollution	Low	Low	Low
Commercial fishing (caught to sell for food)	Medium	Medium	Medium
Artisanal/recreational fishing for personal consumption	Low	Low	Low
Yachts typically present within 1km of site	Many (>5)	Medium (3-5)	None
Overall anthropogenic impact (estimate)	**Low**	**Low**	**Low**

The anthropogenic impacts outlined in table 2 illustrate how the human system presently interacts with the coral reef ecosystem. These interactions play a prominent role in defining the current SES resilience (Ostrom, 2009), and can be a detrimental or positive force in building resilience to the impacts of climate change.

2.4 - REGIONAL CLIMATE CHANGE PROJECTIONS AND IMPACTS

RISING SEA SURFACE TEMPERATURE AND OCEAN ACIDIFICATION

Rising ocean temperatures and ocean acidification represent predominant threats to the health and survival of coral reefs (Hughes et al., 2003 & 2007; Hoegh-Guldberg, 1999). As slow drivers of change, rising Sea Surface Temperatures (SST) and ocean acidification gradually alter the long-term physical and chemical properties of the ocean (Hughes et al., 2003).

According to the fifth Assessment Report on climate change (AR5) submitted in 2014-15 by the Intergovernmental Panel on Climate Change (IPCC), global mean sea surface temperatures (SST) are expected to rise between 1.8°C and 3.7°C by year 2081-2100, according to intermediate-low and high future GHG emissions scenarios (referred to as representative concentration pathways (RCPs) 4.5 and 8.5, respectively) (IPCC, 2014a). The impacts of warming sea surface temperatures on marine ecosystems are vast; long-term changes in temperature can change the fundamental properties of marine ecosystems, influencing the behaviour, migration patterns and reproductive timing of marine fauna, and prompting coral bleaching and mortality (Hoegh-Guldberg et al., 2010). Coral bleaching is often a result of warming sea surface temperatures disrupting the mutualistic relationship that exists between stony corals and the algal symbionts (Zooxanthellae) that live within their tissue (Hoegh-Guldberg et al., 2010). Coral polyps under heat stress expel the zooxanthellae, losing their primary source of energy and pigmentation, becoming completely white in the process (Hoegh-Guldberg et al., 2010). While short periods of bleaching are not lethal to corals, eight weeks of temperatures exceeding normal levels by 1-2°C (also known as degree heating weeks or DHW) within a three-month period are known to cause severe bleaching and mortality in coral colonies (Donner et al., 2005; Eakin et al., 2010; Frieler et al., 2012). Yearly conditions consisting of 8 or more DHW is referred to in this study (as in Van Hooidonk et al., 2015 & Van Hooidonk et al., 2016) as annual severe bleaching (ASB). We are now undergoing the longest coral bleaching event on record due to prolonged ocean warming since 2014 (Hughes et al., 2017); fortunately, conditions have not sufficiently altered in the SIOBMPA to cause wide-spread coral bleaching. Van Hooidonk et al (2015) used downscaled projections of expected SST rise under RCP 4.5 and 8.5, to assess the resulting annual number of DHW in the Caribbean Sea over the next century. According to this study, the eastern Caribbean will be subject to consistent ASB starting sometime between years 2040-2050.

Current levels of carbon dioxide in earth's atmosphere exceed 380 parts per million (ppm) (surpassing historical levels by at least 80 ppm) which has caused SST to rise by 0.74°C and seawater acidity to decrease by 0.1 pH units since pre-industrial times (Hoegh-Guldberg et al., 2007). The ocean acts as a major carbon sink, absorbing 25% of the carbon dioxide emissions released into the atmosphere (IPCC, 2014). When carbon dioxide chemically reacts with seawater, it reduces the availability of carbonate ions in the water necessary for stony corals and other marine species to build calcium carbonate skeletons and shells (McField, 2017). Global climate models for all emissions scenarios indicate an increase in ocean acidification and a slow recovery rate after 2050 (IPCC, 2014). Ocean pH will decrease by 0.14-0.15 and 0.3-0.32 pH units, under low-intermediate and high emissions pathways, respectively (IPCC, 2014).

Coral reefs generally have slow growth rates and are constantly eroding due to natural chemical and biophysical processes, which results in low net growth (McField, 2017). Because ocean acidification decreases carbonate and aragonite saturation in the water column, it becomes increasingly challenging for coral reefs to grow and rebuild following perturbations (McField, 2017). Furthermore, very small changes in ocean pH can shift reefs from net accreting to net eroding. In a study by Perry et al (2013), 37% of Caribbean reefs were already net eroding, while 26% were accreting but with low net calcification rates.

SEA LEVEL RISE

In a low-intermediate RCP scenario (RCP 4.5), sea level rise will be between 0.5-0.6m in the Caribbean between years 2081-2100 – a highly conservative results compared to higher RCP projections and current observations in the rate of ice melt (Rignot et la., 2014 & Morlighem et al., 2014). In a 2010 report on "SLR in the Caribbean" prepared by CARIBSAVE and the United Nations Development Program (UNDP) for the Caribbean community (CARICOM member states), several studies including the fourth IPCC report assessment were reviewed. Central estimates for SLR by year 2100 averaged from 0.9 to 1.2 m with higher range values exceeding 2 meters among the reviewed literature (Simpson et al., 2010). Sea levels will continue to rise even if global temperatures stabilize post-2100, which highlights the importance of not considering *if* the Caribbean will face SLR of more than 1m but *when* (Simpson et al., 2010). Deeper waters generate higher wave action, especially on near shore fringing reefs such as the ones in the SIOBMPA (Storlazzi et al., 2011). Larger waves generate stronger coastal erosion and increase the quantity and size of sediment transport around the reef. Sediment circulation and mixing in the water column decreases light availability for coral photosynthesis and increase sediment-induced stress (Storlazzi et al., 2011). The impacts of SLR will be exacerbated by the impacts of sea surge especially during storm events (IPCC, 2014 & Simpson et al., 2010).

Slow or non-existent coral growth rates due to ocean acidity, rising SST prompting ASB and SLR eroding and smothering the reef in sediment, create a triple threat to coral reef systems and highlights the need for resilient reefs and communities. The following chapter will explore the meaning of resilience as it pertains to SESs under the impacts of climate change.

CHAPTER 3 – BACKGROUND THEORY

The SES approach recognizes that the internal resilience of each system will shape the human-environment interactions that take place within the MPA, and ultimately define the resilience of the system as a whole (figure 1). The theory behind SES resilience, and the resilience of both the ecological and social component will thus be discussed. Although ecological resilience is not the focal component of this study, current findings in this field of study will be discussed to identify how current ecological monitoring efforts are contributing to the understanding of the SIOBMPA reef's resilience to climate change. The theoretical basis of social resilience, as well as the components of the social system that enable resilience to emerge, will be discussed and used as the basis for the study's methodology.

3.1 - SOCIAL-ECOLOGICAL SYSTEM RESILIENCE

All SESs are continuously challenged by natural and anthropogenic disturbances that move the system away from the state in which it tends to remain, also known as the "basin of attraction" (Walker et al., 2004). Multiple stable states can exist for any given system, all of which are defined by different combinations of variables or characteristics, such as the abundance of coral, herbivores and predators in a coral reef system. Simply put, resilience is defined as the capacity to remain within a favourable basin of attraction when subject to disturbance. Walker et al. (2004) define resilience as the "the capacity of a system to absorb disturbance and reorganize while undergoing change so as to still retain essentially the same function, structure, identity, and feedbacks". According to their review of resilience literature, Walker and his colleagues identify four fundamental aspects of resilience: latitude, resistance, precariousness and panarchy. As illustrated in figure 4, latitude (L) is the amount a system can be changed before crossing into an alternative basin of attraction, resistance (R) is the ability of the system to resist change and precariousness (Pr) is the proximity at which the system finds itself in relation to a threshold. Panarchy relates to the dynamic interplay that exists between the focal system and other external subsystems, such as the cross-scale interactions that exist between global SLR and beach erosion along the beaches of an island.

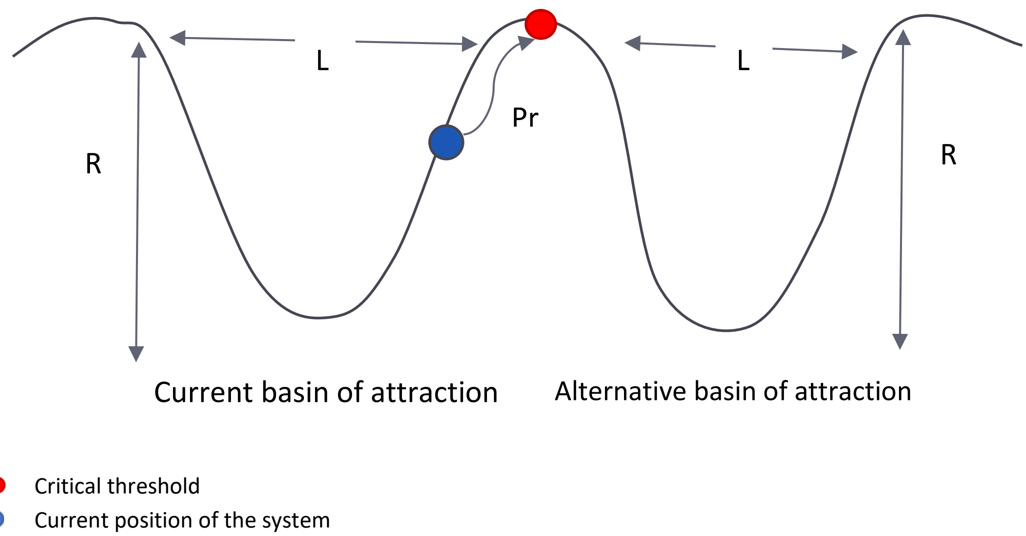

Figure 4. A schematic representation of a portion of the stability landscape (i.e. the many basins of attractions a system can occupy) for a given SES. Latitude (L) is the amount a system can be changed before crossing into an alternative basin of attraction, resistance (R) is the ability of the system to resist change and precariousness (Pr) is the proximity at which the system finds itself in relation to a threshold.

Three distinct capacities determine the trajectory of the SES when undergoing disturbance: persistability (also known as coping capacity), adaptability and transformability (Keck & Sakdapolrak,2013 & Walker et al., 2004):

1. ***Persistability (or Coping capacity):*** defined by the characteristics that enable a system to persist during times of instability and disturbance (Holling, 1996). Persistability can also be referred to as a system's coping capacity, as it represents the ability to restore levels of health and wellbeing directly following disturbance (Keck & Sakdapolrak,2013).

2. ***Adaptability:*** is defined by the collective ability of a system re-organize following a perturbation and learn from past experiences to ensure future well-being (Berkes, Colding & Folke, 2003; Holling, 2001). As per Walker et al. (2004), adaptation "is the capacity of actors in a [social-ecological]

system to influence resilience”, and therefore is predominantly defined by the capacity of humans to effectively manage resilience within the SES (Walker et el., 2002). Adaptive capacity is dependant on a system’s ability to communicate, collaborate and exchange knowledge and information in order to implement proactive and preventative measures that will enable the system to successfully deal with uncertainty and future change (Berkes, Colding & Folke, 2003).

3. ***Transformability:*** The ability to transform into a new and previously unknown stable state when ecological, economic, or social conditions make the existing system unattainable or unfavourable (Keck & Sakdapolrak,2013; Walker et al., 2004). In contrast to adaptability, transformability is geared towards a radical shift from one stable state to another, which enhances the systems wellbeing in the face of present and future threats (Keck & Sakdapolrak, 2013).

The following two sections will provide an overview of the theory behind the resilience of each focal subsystem, starting with the ecological resilience of coral reef systems, followed by social system resilience.

3.2 - ECOLOGICAL CORAL REEF RESILIENCE

As previously discussed, transformation is an important capacity in resilience building. However, a radical shift in coral reef ecosystems would result in the decline of current ecosystem services upon which coastal communities rely. Maintaining the ecological structure, processes and feedback systems in coral reef systems, and thus ensuring the system stays within the current basin of attraction, is thus the basis upon which coral reef resilience research has emerged.

Long-term anthropogenic drivers of change, such as nutrient loading, overfishing and climate change, slowly erode a coral reef's capacity to withstand stressors and disturbance (Hughes et al., 2010). This slow degradation of key processes can often be "cryptic" or "invisible" to stakeholders as the ecosystem slowly approaches a threshold (such as the one identified in figure 4), which when surpassed, shifts the system from a healthy coral-dominated state to a macroalgae-dominated state (Hughes et al., 2010; Nystrom et al., 2008). Coral reef resilience is thus a measure of the system's capacity to evade an irreversible phase shift to a macroalgae-dominated state (Hughes et al., 2010). Because the feedback systems that govern each state are different, the threshold or tipping point at which one stable state changes to the next are also different, a process known as hysteresis (Figure 5) (Hughes et al., 2010). While the tipping point away from coral-dominance requires considerable pressure from long-term drivers of change, once that tipping point has been crossed, it requires pressure levels to lower considerably more to reverse the switch. Many coral reefs have slowly been pushed across the tipping point and commonly fail to recover due to hysteresis (Hughes et al., 2010; Mumby et al., 2007). The ratio in coral, macroalgae and benthos cover in a healthy reef will vary temporally, spatially and geographically, thus there is no universal baseline coral cover that constitutes a healthy coral reef. Similarly, given the variation in hysteresis and feedback systems among coral

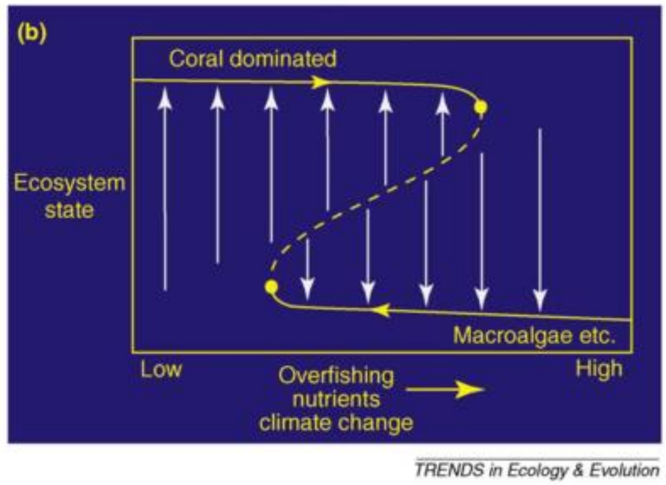

Figure 5. Hysteresis, as illustrated by Hughes et al (2010), The feedback systems that govern coral-dominated and macroalgae-dominated states are different, and therefore the threshold or tipping point (yellow dot on curved line) at which one stable state changes to the next are also different. Slow drivers of change must therefore be considerably reduced to revert the system back to its original coral-dominated state.

reefs, there is no defining tipping point or threshold that can be applied to all coral reef ecosystems. Phase shift trends are therefore highly context specific.

Because reef resilience encompasses a variety of complex and reinforcing feedback systems, hysteresis and non-linear threshold dynamics, it is very difficult to assess the resilience of a system without the availability of accurate historical data that would demonstrate the temporal and spatial characteristics of the mechanisms that govern the reef. Nonetheless, rapid global reef degradation and the anticipated impacts of climate change urge researchers to develop tangible and easily assessed indicators that are feasible within the means of coral reef researchers and managers. In recognition of this issue, McChlanan et al (2012) have designated a list of prioritized reef resilience indicators based on scientific evidence, expert opinions and on-site data collection feasibility. Indicators were divided based on their ability to promote recovery and resistance, the former enabling the reef to return to the ecosystem state following disruption and the latter allowing the reef to remain in the ecosystem state when influenced by drivers of change (McChlanahan et al., 2012). The TNC Reef Resilience Network, an online resource which provides guidance and resources to coral reef managers seeking to address the impacts of climate change, recommends the use of these prioritized indicators for resilience monitoring and assessment (Reef Resilience Network, November 2, 2017). A shortlisted version of the prioritized list are as follows (McChlanahan et al., 2012):

Resistance Factors

- Stress-resistant coral species
- Stress-resistant symbionts
- The presence of high annual temperature variability

Recovery Factors

- High levels of coral recruitment
- Suitable substrate for coral settlement/survival
- Low cover of macroalgae cover

An overview of all listed prioritized indicators shows that the most resilient coral reef systems are composed of high coral and fish diversity and are generally influenced by less direct human impacts (McClanahan et al., 2012). Monitoring the coral reef for resilience can provide marine managers with insight as to how the reef will persist through environmental change, and ensure that timely and appropriate measures are taken to enhance the system's internal resilience.

3.3 - SOCIAL RESILIENCE

Drawing from the definition of SES resilience, social resilience encompasses all aspects of the social system that directly improve a community's ability to withstand external shocks to their social, political and economic infrastructure, in the form of coping, adaptive and transformative capacities (lebel et al., 2006). Within the context of SESs undergoing long-term climate change stressors, the anticipatory capacities of the social system and their ability to learn from past events to prepare for the future, remain crucial attributes in both securing long-term survivability and finding opportunity for innovation (Bohle et al., 2009; Keck & Sakdapolrak, 2013; Orbrist et al., 2010). The system components that enable the social system to address change more competently can be grouped into three categories: (1) social network structure and content, (2) the capacity for learning and (3) access to capital (Adger, 2000 & 2003; Béné et al., 2012; Hodbod & Eakin, 2015; Keck & Sakdapolrak, 2013; Obrist et al., 2010; Pelling & High, 2005; Speranza, Wiesmann & Rist, 2014):

SOCIAL NETWORK STRUCTURE AND CONTENT

Social capital, the resources that enable social organization and collective action (Coleman, 1990), has largely been acknowledged as a predominant factor in determining the social resilience of a system (Adger 2000; Emery & Flora, 2009; Pelling & High, 2005; Putnam, 1995). Social capital is a feature of the social structure rather than of an individual actor and can be measured by indicators such as the presence of interpersonal relationships, bonds of trust, and networks of aid and support shared among individuals (Pelling & High, 2005). Networks of relationships among social groups (bonding capital), between social groups with a shared common interest but contrasting identities (bridging capital) and between groups of differing social class or interest (linking capital) give shape to a community's social capital (Pelling & High, 2005). The balance amongst them can provide valuable insight about the response a community will take when exposed to uncertainty, change and crisis (Pelling & High, 2005). Strong communication networks are defined by high communication frequency; daily conversation will provide more opportunities for meaningful relationships to form and for information to be quickly exchanged within a community (Keck & Sakdapolrak, 2013). Pelling and High (2005) suggest that informal relationships are also key to driving collective action within a community. While networks of trust, aid and support within a community can be directly attributed to bonding, bridging and linking capital, they can also be a function of shared norms and beliefs, such as common religious beliefs, behavioural codes, professional standards, etc. (Adger, 2000; Pelling & High, 2005). Positionality in the social system relating to expertise or credentials in a specific profession also influences trust for certain social groups (Pelling & High, 2005). Reciprocity among these networks represents a defining attribute of social capital as it enables the equal transfer of resources and information amongst a community, and thus prevents one social groups from being the sole beneficiary of a response (Adger, 2000; Keck & Sakdapolrak, 2013; Pelling & High, 2005).

CAPACITY FOR LEARNING

As social resilience largely encompasses ex-ante responses to risks, the system's capacity for learning significantly contributes to social resilience (Keck & Sakdapolrak, 2013; Speranza, Wiesmann & Rist, 2014). The community's knowledge or perception of the threats and opportunities will influence the efficacy of the response to change. While perceptions of risk and opportunities can be a directly conveyed to the community through the formal educational system (I.e. children learning about climate change in school), they can also be influenced by other factors such as culture, religion and past experiences (Keck & Sakdapolrak, 2013). The collective knowledge and visions shared by a community can direct a response towards higher or lower resilience. Additionally, the system's commitment to continuous learning and its capacity to identify external sources of information (out of the focal system), promotes resilience through the ongoing transfer and creation of skills and knowledge (Speranza, Wiesmann & Rist, 2014). Given the resilience of the SES as a whole is a function of the interaction between the coral reef system and the community, the ability of the social system to observe change in the reef and act accordingly is a dominant contributing factor in building resilience (Speranza, Wiesmann & Rist, 2014). Both formal initiatives to monitor coral reefs and the ability of stakeholder to observe change when using the marine space contribute to building functioning feedbacking systems. The level of response and the ability for stakeholders to transfer that knowledge and memory to other social actors within the social system will directly contribute to building the resilience of the SES.

ACCESS TO CAPITAL

Access to and ownership of other forms of capital, whether human, economic, physical or natural, not only determine the overall health and welfare of the social system, but also influence the breadth of responses available to the community, and their efficacy in raising the system's social resilience (Keck & Sakdapolrak, 2013; Speranza, Wiesmann & Rist, 2014). The capacity of the SIOBMPA stakeholder community to respond to climate change is thus influenced by the full range of assets, goods and services the community has access to (Speranza, Wiesmann & Rist, 2014). Much like social capital, natural capital generates many other sources of capital – natural resources and ecosystem services provide the necessary variables for livelihood, culture and wellbeing to emerge. Sources of human capital, such as health, skills and education, are basic human rights and are essential to the function of a society (Hodbod & Eakin, 2015). The amount of human capital owned and accessed by a community will undoubtedly influence the type of response taken when faced with change (Hodbod & Eakin, 2015). Likewise, access to economic capital such as income, savings and funding for community projects, as well as physical capital such as technology, machinery and tools used to accomplish goals, influence the variety of responses accessible to the community (Keck & Sakdapolrak, 2013; Speranza, Wiesmann & Rist, 2014).

The precariousness of coral reefs systems (biological function only operates within a 2-3°C range) (Kleypas et al., 1999), and the likelihood that long-term climate change impacts will push the system beyond the critical threshold into an algae-dominated state, emphasizes the importance of adaptation and transformation. Although the system as a whole can reorganize without human intent, the actions and management decisions taken by the human system can significantly influence the trajectory of the SES (Walker et al., 2004). Therefore, resilience building in the SIOBMPA will depend on human actions that can widen and deepen the current basin of attraction (as discussed in chapter 3.1) and increase resistance to movement towards a critical threshold. As thresholds will largely be defined by the ecological system (i.e. bleaching threshold), and adaptive capacity will be highly influenced by the social system, stakeholders and the MPA governance system will need to closely monitor the coral reef to observe change and respond accordingly. Social resilience theory thus forms the basis upon which the study methodology is shaped. The next chapter will explore how primary and secondary data was collected and analysed to gather an understanding of the social system characteristics that contribute to shaping the social resilience of the SIOBMPA stakeholder community.

CHAPTER 4 – METHODOLOGY

SCOPE & APPROACH

The scope of this research is bound spatially to the local context. As described in chapter 2.2, only primary and secondary stakeholders who currently live or work in Carriacou were included in this assessment. Furthermore, although the SIOBMPA comprises multiple marine ecosystems, only coral reefs located within the boundaries of the SIOBMPA will be studied. While abrupt disturbances such as hurricanes can be detrimental to coral reefs, the climate change impacts of interest in this study are slow-drivers of change, including SST rise, ocean acidification and sea level rise. As mentioned in chapter 3, resilience exists within a panarchy, whereby exogenous threats, weather they be social, political or environmental, are continuously impacting the focal system (Walker et al., 2004). However, in the interest of providing recommendations that are within the capacities of the local MPA governance system and stakeholder network, this analysis is limited to local system components.

In order to comprehensively address the study questions, both primary and secondary data were gathered and analysed. The social network's structure and content, the capacity of the community to learn and their access to capital was assessed through on-site interviews with key informants in the community, all of which had memberships in one of more of the stakeholder categories described in chapter 2.2. Secondary data in the form of ecological AGGRA data from a 2015 collection in the SIOBMPA was gathered directly from TNC and used to understand the contribution of current monitoring efforts to the understanding of coral reef resilience. Results from these analyses were then integrated in a SWOT analysis, which provided insight for management recommendations.

PRIMARY DATA COLLECTION AND ANALYSIS

Information used to understand the social resilience of the SIOBMPA stakeholder community was obtained through the collection of primary data through mixed-method semi-standardized interviews with key informants from all 5 stakeholder categories. Key informants were identified through a process of referral, starting with a list of recommendations from local government and environmental NGO representatives. Information was drawn from at least one key informant from each stakeholder group, aside from Hillsborough and Tyrell Bay fisheries, for which the principal investigator was unable to secure an interview with key informants due to time constraints. Many key representatives identified with more than one stakeholder group, and therefore data is not equally drawn from each stakeholder category. Nineteen interviews took place over the course of August 2017. Data concerning each component of social resilience, namely social network structure and content, capacity for learning and access the capital, was collected and analysed as follows (See Appendix 1 for the interview survey):

SOCIAL NETWORK STRUCTURE AND CONTENT

Collection:

A participatory mapping session was held to understand the structure and content of the stakeholder community network. Study participants were shown a map of all five stakeholder categories and groups, and asked to identify which groups they identified with. They were asked to discuss the number of members present in their respective stakeholder groups and the frequency and formality of conversation between group members (bonding capital). They were then asked to discuss the frequency and formality of communication (specifically concerning SIOBMPA related affairs) between their stakeholder group and other groups on the map (bridging and linking capital). The participant was asked to indicate which stakeholder group would be trusted with information about SIOBMPA related affairs (including details related to employment, as well as the use and health of the MPA), and which group would likely receive aid and support from members of their stakeholder group in times of need. Networks of communication, trust and aid/support were marked on the map using red, green and blue coloured pencils to help the informant visualize the networks. Informants were encouraged to comment and discuss aspects of the networks as wanted. Participants were also asked to answer short-answer questions to reveal the local institutions and management system that govern the behaviours taking place within the SIOBMPA. They were asked if members of their stakeholder group are part of any unions, associations or cooperatives, and whether the stakeholder group or any of the mentioned unions, associations or cooperatives are involved in decision-making or in the management of the SIOBMPA. Informant were inquired about the adaptive capacity and efficacy of the current management plans and what sorts of behaviours are completely unacceptable when using the MPA according to their stakeholder group.

Analysis:

Social network structure and content was assessed via social network analysis. A scale was designed to quantify the strength of the communication ties between groups by frequency and formality. High levels of frequency and lower levels of formality received the highest score. Since the frequency of the communication was deemed higher in importance than the level of formality in the context of building social resilience, higher values were attributed to daily communication than informal communication as seen in table 4. Using these scores, communication pathways between stakeholder groups were weighted and compiled into a matrix. The mean was used when multiple study participants weighted the strength of the communication differently. No weight was attributed to the networks of trust and aid/support, so a binary numeral system (1=connection, 0=no connection) was used to identify directional connections between stakeholder categories, which were subsequently incorporated into matrices. All three matrices (i.e. communications network, network of trust and network of aid/support) were digitized and used to generate visualisations and reports with ORA 2.3.2. (a network visualization and analysis software). Directionality was incorporated in the networks of trust and aid/support in order to visually depict reciprocity. In communication network visualisations, connection strength was depicted by line width, where thicker lines are representative of stronger network ties. The strength of each tie (also referred to as link or connection), was classified as strong, moderate or weak, according to scores of 6-11, 12-17 and 18-23 respectively. Hillsborough fisheries and Tyrell Bay Fisheries were omitted from the centrality analysis as to not skew results.

Table 4. Values used to quantify the strength of the communication networks between groups. Frequency of communications was attributed higher values than the degree of formality.

	Formal (1 point)	Neutral (2 points)	Informal (3 points)
Daily (20 points)	21	22	23
Weekly (15 points)	16	17	18
Monthly (10 points)	11	12	13

Yearly (5 points)	6	7	8

The communications network matrix and visualizations were analysed for trends to identify attributes such as strong and weak connections. Total-degree centrality, betweenness centrality and eigenvector centrality measures were used to identify which groups are in positions of power in the context of information exchange. Degree centrality simply showcases who has the most network connections. Betweenness centrality reveals which groups hold a central position amongst the communication network's shortest paths (groups that intercept the shortest communication pathways within the network hold power and responsibility in terms of relaying information amongst stakeholder groups). Eigenvector centrality reveals which stakeholder groups are the most central in terms of the overall structure of the network, which expands beyond the number of connections held by a stakeholder group to be proportional to the sum of its neighbor's centralities'. Thus, groups that share more ties with well-connected groups are considered to have more power than groups that share ties with less-connected groups. Reciprocity in trust and aid/support between stakeholder groups was assessed by comparing in-degree and out-degree centralities, which illustrates how much a stakeholder group is trusted and trusting compared to other groups in the network. Reciprocity between specific stakeholder groups was assessed through the analysis of the matrix and corresponding visualizations. A list of formal and informal institutions that govern the use of the MPA were listed and compiled into a table for discussion, and the analysis of the general commentary pertaining to the governance system was done to identify trends amongst responses.

CAPACITY FOR LEARNING AND ACCESS TO CAPITAL

Collection:

During interviews, study participants were asked to agree or disagree with 30 statements on a 5-point Likert scale to reveal information concerning the community's collective capacity for learning and access to different forms of capital. Informants were asked to provide answers that reflect the thoughts and opinions of their stakeholder group at the best of their abilities, and were given the option to skip any statement for which they could not answer with confidence.

Analysis:

The results yielded from the analysis of the data are perception-based, therefore the opinions expressed by study participants may not necessarily align with statistics or results obtained in prior studies. Perceptions are of value in this study, as they are key factors in determining how and whether adaptation takes place (Schwarz et al, 2011). Numerical data collected during interviews was transcribed onto a digital Microsoft Excel spreadsheet for analysis. To capture the average answer for each statement while also omitting outliers, the median across individuals was used for analysis. The medians were compared to mode values for each question (which could not be used due the possibility of two values most equally occurring within the data set) to ensure values reflected answers that were most often repeated. Data was projected into a web graph for visualization.

SECONDARY DATA COLLECTION AND ANALYSIS

MONITORING FOR RESILIENCE

Collection:

To understand if current monitoring efforts are allowing the MPA governance system to monitor the ecological resilience of the reef and implement management objectives accordingly (thus contributing to effective feedback systems), 2015 AGGRA data (used to generate the 2016 Eastern Caribbean Coral Reef Report Card) was reviewed.

Analysis:

The usefulness of current ecological monitoring data in providing information about the reef's resilience to climate change was critiqued based on ecological coral reef resilience theory and indicators defined in Chapter 2.3. Furthermore, additional data within the AGGRA collection (which could be used to monitor ecological resilience but was not used for the RHI) was assessed, including locally resilient genera of corals, the abundance of coral recruits and the availability of appropriate substrate for recruitment. The mean and standard deviation was calculated for each sampling site and then compared to values obtained for other sites in order to identify consistent trends occurring within the SIOBMPA.

SWOT ANALYSIS

A SWOT (strength, weaknesses, Opportunities and Threats) was used to amalgamate the results yielded from the study and effectively identify characteristics of the social system that are enabling and inhibiting SES resilience. Based on results as well as primary and grey literature, external opportunities and threats impacting the focal system where then discussed. This formed the basis upon which the management recommendations were drawn.

STUDY LIMITATIONS

The inability to acquire data from key informants of two fisheries stakeholder groups (Hillsborough and Tyrell Bay) has restricted their use in the analysis of directional networks. Because directionality in communication networks is unaccounted for, in-bound networks of communication by other stakeholder groups are used to assess strength and centrality measures. However, given the directional nature of the networks of trust and aid/support, data (i.e. scores of 0) from Hillsborough and Tyrell Bay fisheries were removed for analysis (still present in visualisations to illustrate in-bound links). The study process was the same for all key informants, aside from the key representative for the local NGO (SusGren), which was only invited to participate in the stakeholder community participatory mapping session and short answer questions. Although SusGren actively takes part in local initiatives in Carriacou, the office is based on a neighboring Grenadine island (Union Island) and thus questions concerning access and ownership to capital and capacity for learning at the community level were not deemed appropriate for this representative.

CHAPTER 5 – RESULTS

The results yielded from the analyses reveal components of the social system that are believed to raise or diminish the ability of the SIOBMPA stakeholder community to address the long-term impacts of climate change on coral reef systems. Resilience is a theoretical construct that can only be inferred (Obrist et la., 2010), and therefore although results expose components of the social system that may influence the capacity of the community to cope, adapt and transform, the real responses taken by the community as environmental conditions are progressively altered cannot be predicted. The following section will describe the results obtained through semi-standardized interviews conducted with community key informants.

5.1 – SOCIAL NETWORK STRUCTURE AND CONTENT

NETWORKS OF COMMUNICATION

BONDING CAPITAL

Bonding capital is highest in community stakeholder groups due to daily and informal interactions among community group members (Table 5). Similarly, L'esterre bay fisherfolk, many of which are also part of the l'Esterre bay community, communicate with each other informally on a frequent basis leading to strong bonds within the group. While senior government representatives and the MPA management team also hold strong group bonds, the MPA board, which is composed of members from various local disciplines and sectors, share a very low bonding capital score due to the infrequency in communication amongst all members. Bonding capital among tourism stakeholder groups is low due to infrequent communication among competing businesses. This is especially the case for competing dive shop operators on the island, which actively avoid seeking contact with members of opposing dive shops. Bonding capital within the SusGren team is moderate due to the formality of the relationships among members and the strong diversity in projects and responsibilities undertaken by members of the NGO leading to lower levels of communication amongst the team.

Table 5. Bonding capital for each stakeholder group by category. Group sizes are based on estimates by key informants and have been grouped into three classed based on membership: 1 (1-14 members), 2 (15-50 members), 3(>50 members).

Stakeholder Category	**Stakeholder group size class**	**Mean score (out of 23 points)**	**Bonding Capital Score**
Fisheries			
Tyrell Bay Fisheries	N/A	N/A	N/A
L'Esterre Bay Fisheries	2	19.6	0.85
Hillsborough Fisheries	N/A	N/A	N/A
Community			
Tyrell Bay / Harvey Vale	3	22.6	0.98
Lauriston	3	22.75	0.99
L'esterre	3	23	1.00
Government			
MPA Board	1	8.5	0.36
Senior Government Reps	1	23	1.00
MPA Management	1	22	0.95
Tourism			
Dive Shops	2	8	0.34
Water taxi & Tour Operators	2	14.6	0.63
NGO			
SusGren	2	12	0.52

Bonding capital is often a function of the size and geographical proximity of the members within the group. In this study, opinions expressed by key informants are relative to their perception of how people among the group generally communicate. For example, although communities have strong bonding capital, it is recognized that not all members of the community speak informally to each other on a daily basis - much like how bonding capital is low for dive shops even though some partnering shops communicate on a daily basis. Overall, it is assumed that given the size of the groups and the capacity for bonding capital to emerge, communities do in fact exhibit higher levels of capital than the dive shops in the area do.

BRIDGING AND LINKING CAPITAL

The number of social ties existing between stakeholder groups in the SIOBMPA stakeholder community is 78 out of 132 possible connections, which results in a network density of 0.59 (excluding internal group bonds). The relatively high number of links and bridges existing within the community is indicative of a close-knit community, especially as it pertains to the three communities lying adjacent to the MPA. As seen figures 6-8, the strongest communication ties exist within and between community, fisheries and water taxi & tour operator stakeholder categories. This is largely attributed to the fact that many members undertaking fishing or water taxi & tour operating as a livelihood, reside in a community adjacent to the MPA. Furthermore, many stakeholders have diversified incomes through livelihoods related to both fisheries and water taxi & tour operating. Therefore, due to strong overlap in members existing in all three stakeholder categories, communication between these groups is frequent and highly informal leading to strong bridging capital. Strong connections exist between Lauriston and L'Esterre communities, while both communities have weak ties with the Tyrell Bay/Harvey Vale communities. Moderate ties exist between both water taxi drivers & tour operators and dive shops. Taxi & tour operators do share strong links with fisheries while dive shops do not. Moderate ties exist between the MPA management team and senior government representatives, while weak ties exist between either group and the MPA board. Senior government representatives share weak ties with fisheries and tourism, and weak to moderate ties with communities. The MPA board shares no ties with nearly all stakeholder groups besides weak ties with other government groups, dive shops and NGOs, many of which are likely present on the basis that board members also identify with these stakeholder groups. Conversely, the MPA management group shares moderate ties with both fisheries and tourism, and moderate to strong ties with community groups. The MPA management group has stronger ties with all other stakeholder categories than does any other group within the government stakeholder category, indicating that the MPA management group serves an important bridge between the government and the rest of the stakeholder community. SusGren does not share strong ties with any of the stakeholder groups.

Water taxi & tour operators hold the highest number of connections in the network and thus hold the highest total-degree centrality, followed by the MPA management team and the Lauriston community (Figure 6). Conversely, the MPA board holds the lowest total-degree centrality, followed by the senior government representatives and SusGren

(Figure 6). SusGren, the MPA management team and senior government representatives are highest is centrality betweenness, which means they are most often present in the shortest network pathways between groups (Figure 7). However, note that line width in figure 7 is scaled to relationship strength and that groups considered high in centrality betweenness do not necessarily share strong ties with other groups amongst the network. While SusGren exhibits high centrality betweenness, the strength of the relationships shared with stakeholder groups within the network are low to moderate. Multiple stakeholder groups are not present in any of the shortest network pathways, namely the L'esterre community, L'esterre bay fisheries, the MPA board and Tyrell Bay/Harvey (Figure 7). Lastly, the water taxi association, the Lauriston community and the MPA management are highest in eigenvector centrality, which means they are well connected with many actors who are themselves connected with many other actors (Figure 8) – this implies that these groups play a role in influencing the type of information that is spread across the network and therefore contribute to forming shared perceptions and opinions. The MPA board, GCFI and SusGren have the lowest eigenvectors centrality score (Figure 8).

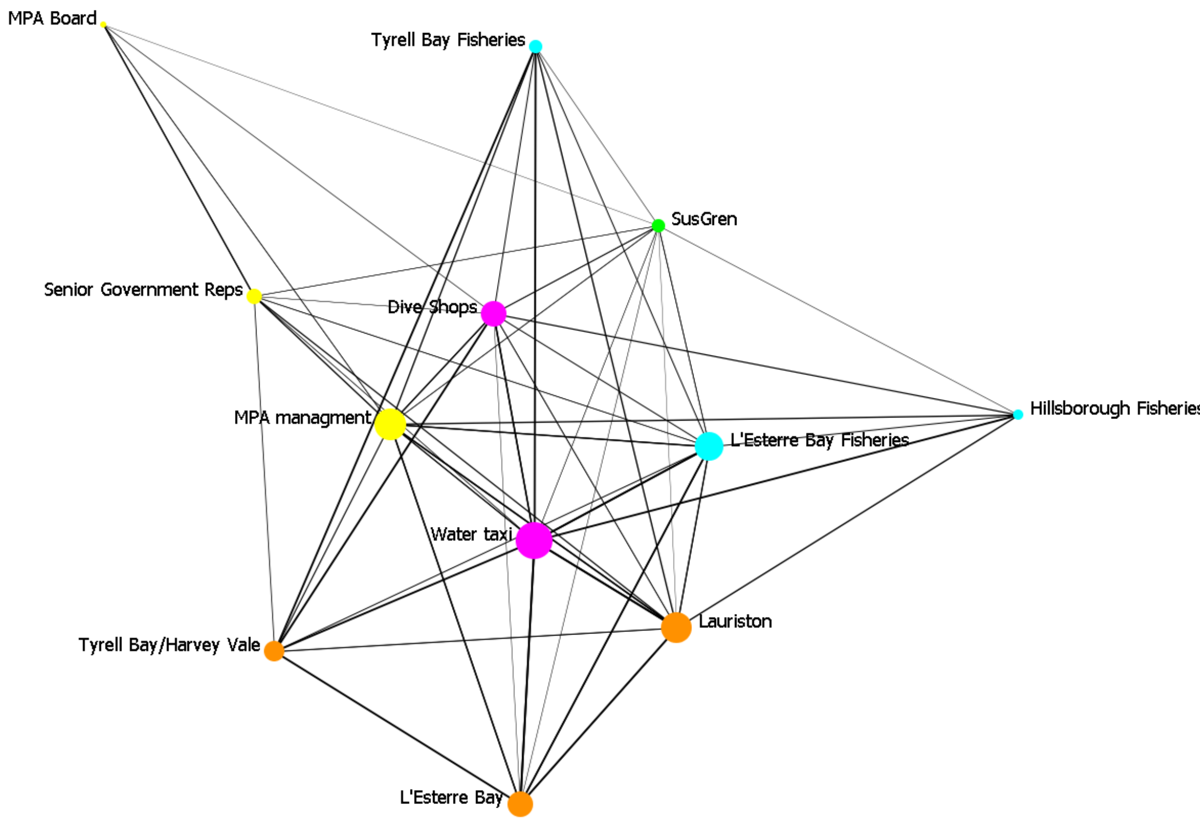

Figure 6. A visual representation of the communication network in the SIOBMPA stakeholder community. Node size is relative to total degree centrality, illustrating the most popular stakeholder groups that have the most ties in the network. The water taxi association holds the most connections (all possible connections aside from with the MPA board), followed by the MPA management team and the Lauriston community. Note that data was not collected from representatives from Hillsborough fisheries and Tyrell Bay fisheries, which means only in-degree centrality is illustrated through node size and that only connections towards these stakeholder groups are shown.

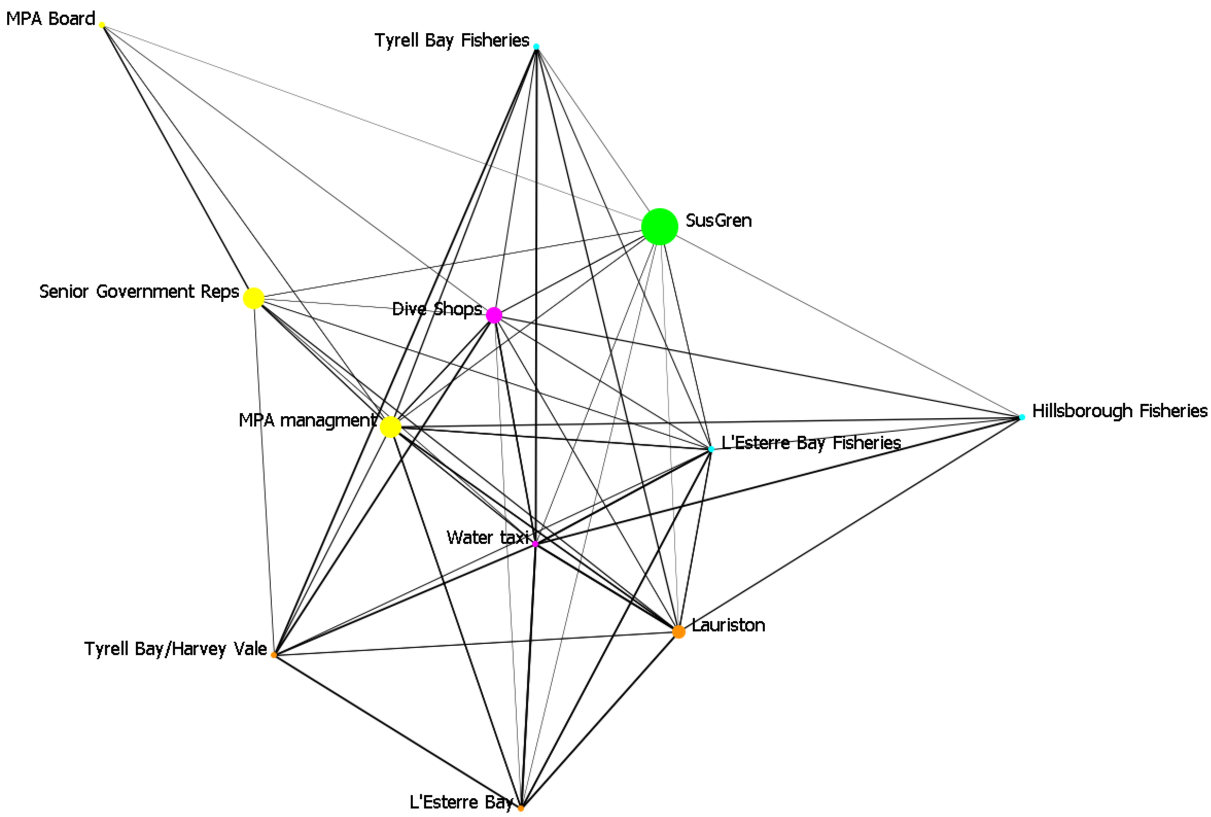

Figure 7. A visual representation of the communication network in the SIOBMPA stakeholder community. Node size is based on centrality betweenness, indicating that the groups represented by the large nodes are frequently present in the shortest path of communication through the network. These group thus hold a greater responsibility in sharing and spreading information across the network. Note that data was not collected from representatives from Hillsborough fisheries and Tyrell Bay fisheries; centrality betweenness could therefore not be calculated or illustrated through node size and that only connections towards these stakeholder groups are shown.

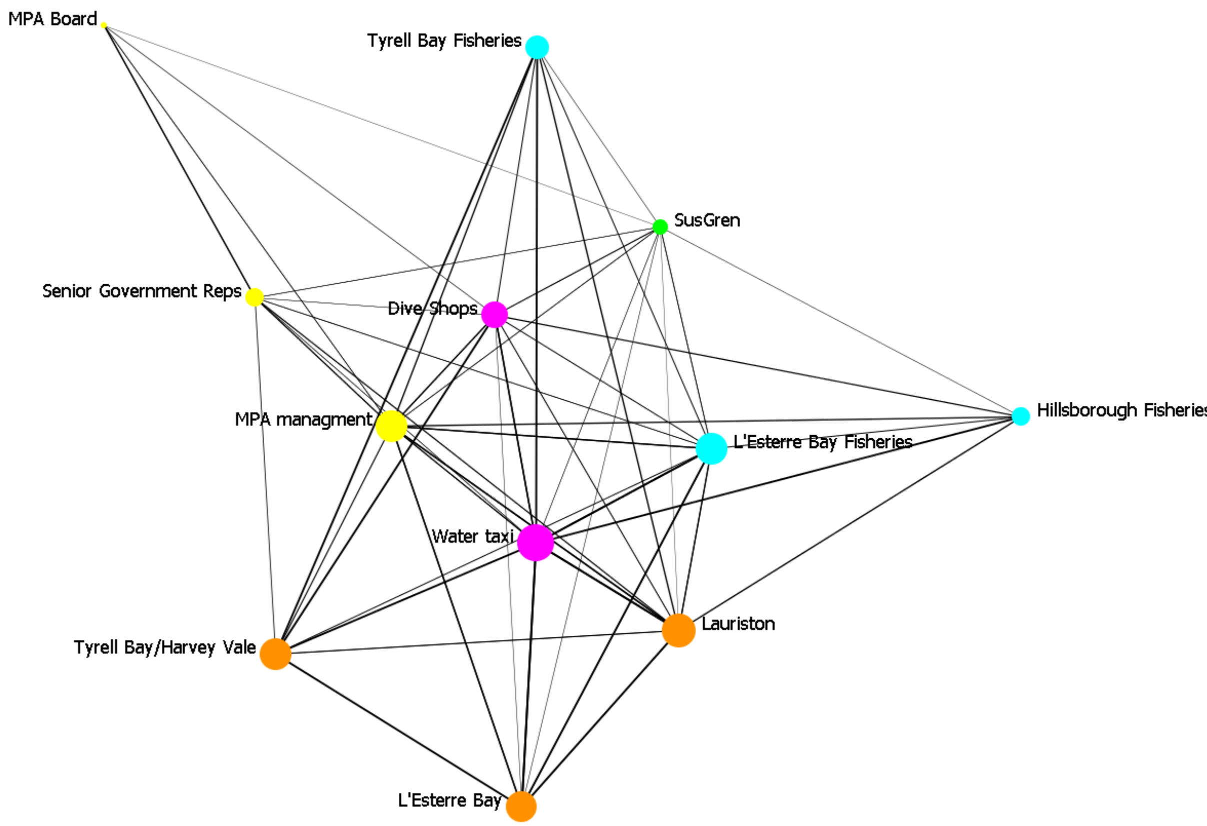

Figure 8. A visual representation of the communication network in the SIOBMPA stakeholder community. Node size is based on Eigenvector centrality, which demonstrates the centrality of a node to the extent that its neighbors (i.e. adjacent nodes) are central. The largest nodes are thus well connected with other groups that are themselves well connected. Note that data was not collected from representatives from Hillsborough fisheries and Tyrell Bay fisheries; Eigenvector centrality could therefore not be calculated or illustrated through node size and that only connections towards these stakeholder groups are shown.

NETWORKS OF TRUST AND AID & SUPPORT

In-degree centrality demonstrates the degree to which a stakeholder group is trusted by others, while out-degree centrality represents the degree to which a stakeholder group has trust in other groups within the network. The average in-degree centrality is 0.590±0.094 (5.9 in-bound trust bonds), where stakeholder groups are trusted by at least 4 to a maximum of 7 other stakeholder groups. Scaled in-degree values are highest for the MPA board, the water taxi & tour operators and the MPA management, and lowest for Lauriston, Tyrell Bay and Harvey Vale (Figure 9). The average out-degree centrality is

0.590±0.221 (5.9 out-bound trust bonds), where stakeholder groups are trusting of at least 3 to a maximum of 9 other stakeholder groups.

Figure 9. A visual representation of the networks of trust within the SIOBMPA stakeholder community. Node size is representative of in-degree centrality, where larger nodes are recipients of more trust than smaller nodes. Arrows are representative of the directionality of trust from one group to another.

Scaled out-degree centrality is highest for senior government representatives, SusGren and the water taxi & tour operator, and lowest for the MPA board, MPA management, the L'esterre Bay community and the Dive Shops (Figure 10). Three participants indicated that there was no trust between any of the stakeholder groups, which could not be represented in that data given the binary numeral system used for the assessments.

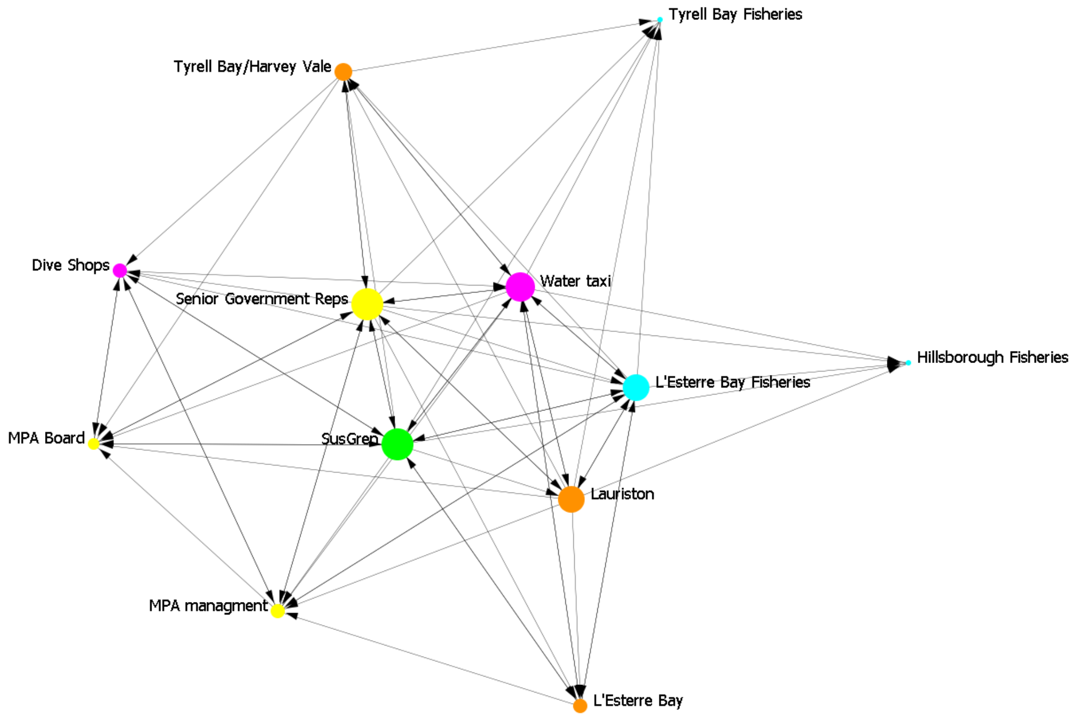

Figure 10. A visual representation of the networks of trust within the SIOBMPA stakeholder community. Node size is representative of out-degree centrality, where larger nodes represent groups that are trusting of other groups more so than smaller nodes. Arrows are representative of the directionality of trust from one group to another.

Aid and support is exchanged among stakeholder groups at a density of 0.85, with 77 connections taking place out of a possible 90, indicating a strong willingness to offer aid to other groups within the network. In-degree and out-degree centrality values for aid and support are synonymous to those in the network of trust, in that they are a scaled representation of incoming and outgoing networks of aid and support. The average scaled in-degree centrality value for aid and support is 0.770±0.064 S.D. (7.7 links of in-bound assistance), indicative that all stakeholder groups will receive aid from at least 7 other stakeholder groups in time of need. Scaled in-degree centrality values for aid and support networks are highest for MPA management, dive shops, L’esterre community, L’esterre Bay fisheries, the MPA board and the water Taxi & tour operators, and lowest for all other stakeholder groups (equal values) (Figure 11).

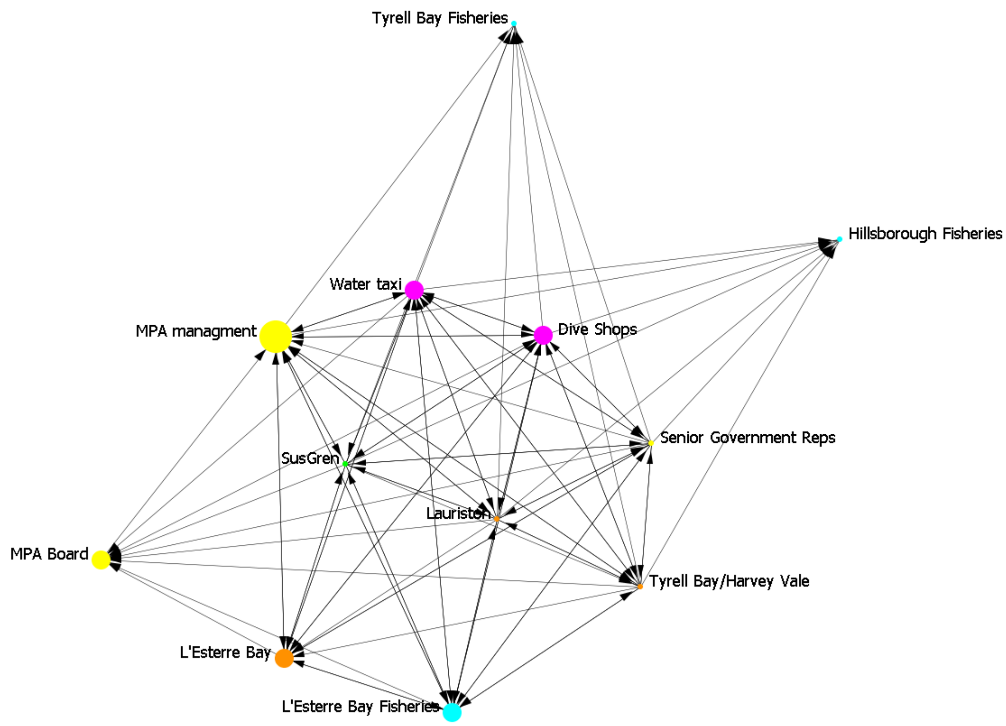

Figure 11. A visual representation of the networks of aid and support within the SIOBMPA stakeholder community. Node size is representative of in-degree centrality, where larger nodes represent groups that are recipients of more aid and support than smaller nodes. Arrows are representative of the directionality of aid provided from one group to another.

The average scale out-degree centrality value for aid and support is 0.770±0.237 S.D. (7.7 links of out-bound assistance), indicative that there is a high variation in the willingness of each stakeholder groups to help others in time of need. Scaled out-degree centrality values are highest for a number of groups, namely dive shops, Lauriston, senior government reps, SusGren and water taxi & tour operators, indicative that these groups are willing to offer aid and support to all other stakeholder groups if needed (Figure 12). Groups that have the lowest scaled out-degree values and thus are willing to provide aid and support to the least number of stakeholder groups are the MPA board, GCFI and L'esterre (Figure 12).

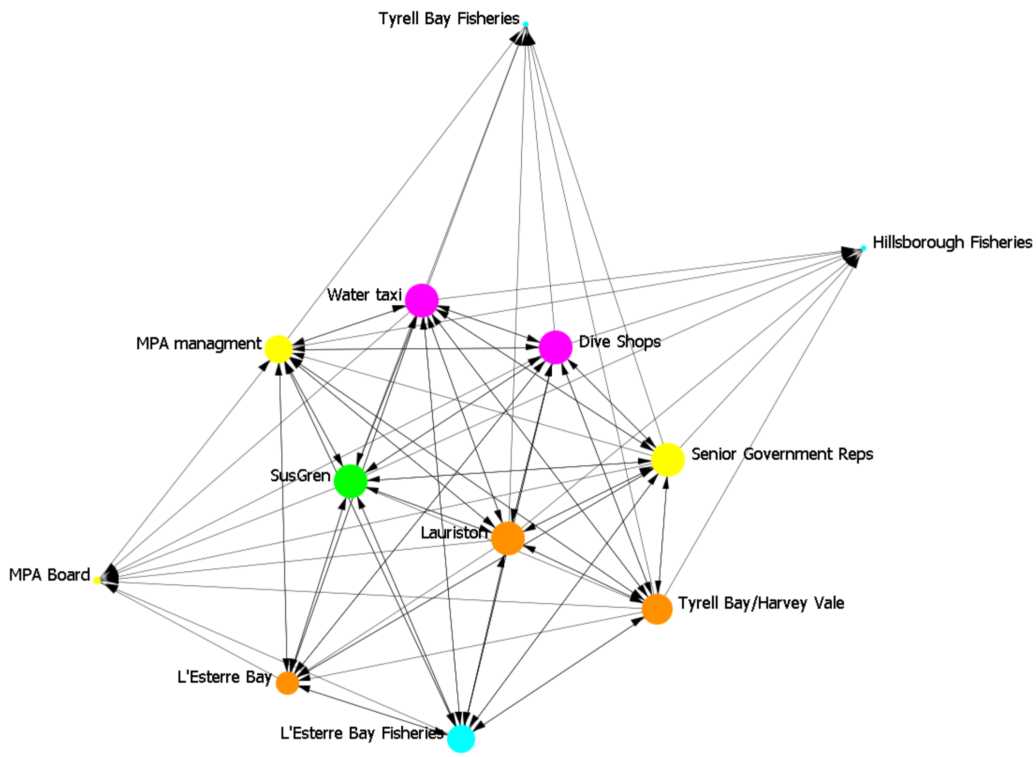

Figure 12. A visual representation of the networks of aid and support within the SIOBMPA stakeholder community. Node size is representative of out-degree centrality, where larger nodes represent groups that are providing more aid and support than smaller nodes. Arrows are representative of the directionality of aid provided from one group to another.

INFORMAL AND FORMAL INSTITUTIONS: WHAT DRIVES LOCAL BEHAVIOURS IN THE SIOBMPA?

Although efforts are underway to implement and enforce MPA regulations by increasing the capacity of the MPA management team, the behaviours and activities underway in the SIOBMPA are highly variable. Table 6 shows a list of activities that are considered unacceptable when within the marine boundaries of the SIOBMPA according to the five stakeholder categories. Out of a total of 48 statements gathered from participants during interviews, improper anchoring and mooring, fishing (any form) and dumping of garbage in the MPA are the top three most frequently repeated unacceptable behaviours. Some key informants stated that members belonging to their groups and that even themselves were unaware of the established MPA regulations and behavioural restrictions. There is a high variation in what is considered acceptable fishing practices in the MPA, from respondents stating that no fishing at all should take place, to others ruling out only certain fishing methods (like pot fishing) and catch sizes (small conchs). Instead of a community consensus, every stakeholder category has opinions that reflect their own best interest – for example only key informants from the tourism stakeholder category stated that tourists violating MPA regulations and diving without the supervision of a local dive shop was unacceptable. Various norms and informal rules established by each stakeholder categories thus governs the types of behaviours taking place in the MPA, which ultimately results in altercations and disagreement between stakeholder categories.

Table 6. A compiled list of activities and behaviours that are considered unacceptable when using the SIOBMPA by local stakeholder category.

Stakeholder category	**Activities of behaviours considered unacceptable by stakeholders**	**Frequency**
Government, NGO	Open violations of the MPA regulations	6% (3/48)
Community, Tourism, NGO	Dumping of garbage	14.55% (7/48)
Community, Tourism, Fisheries, NGO	Improper anchoring and mooring	20.8% (10/48)
Tourism, Community, NGO	Any fishing at all	16% (8/48)
Tourism	Any fishing except for seine fishing	4% (2/48)
Community, Tourism, Government	Fishing with pots	4% (2/48)
Community	Fishing is permitted in moderation (i.e. People can fish but should take too much)	2% (1/48)
Communities	Taking conchs of a small size or catching undersized fish	4% (2/48)
Tourism	People diving without Dive shops	6% (3/48)
Tourism	Behaviours that deliberately endanger divers and snorkelers (Driving boats and fishing around dive and snorkel sites, dropping nets that divers could get entangled in, spearfishing around snorkelers at sandy island…etc.)	6% (3/48)
Community	Not following the boating speed limit	2% (1/48)
Community	Cutting down mangroves	4% (2/48)
Tourism	Improper diving techniques	2% (1/48)
Fisheries, community	Sand mining	2% (1/48)

Community	Dredging	2% (1/48)
NGO	Destruction of all habitats (reef, coastline, seagrass beds, mangroves) in any way	2% (1/48)

Behaviours are also reinforced by formal institutions in which stakeholders are partisans. Formal institutions in which members of the SIOBMPA stakeholder community are members are listed in table 7. Note that many of the institutions are livelihood-related and that the only all-encompassing institutions mentioned during interviews are youth and religious groups.

Table 7. A compiled list of groups, associations, cooperatives or unions in which SIOBMPA stakeholders are active members. The most repeatedly mentioned groups were the Public Workers Union, the Fisherfolk Cooperative and the Grenada Diving Association

Formal Institutions
Public Workers Union
SusGren Board
Carriacou Fisherfolk cooperative
Youth groups
Religious groups
National Disaster Management Agency of Grenada (NaDMA)
Pure Dive Grenada (also known as Grenada & Carriacou Diving Association)
Water taxi association
Carriacou Environmental Committee

5.2 - CAPACITY FOR LEARNING

As illustrated in Figure 13, the SIOBMPA stakeholder community does not share a common understanding of the threats and opportunities brought about by climate change. The subject of climate change is rarely discussed among the community, and while some people believe that climate change is a serious threat to the health and livelihood of current and future generations, others do not. Similarly, there is a divide in community understanding of the potential impacts of climate change, and ideas of how to adapt to climate change are not shared among community members (Figure 13). Community members are however open to learning new skills and information, and have access to do so in various ways outside the school system, such as in community, NGO or government lead information sessions. Yet, attendance to such meetings are low. Communities are strongly inclined to trusting local and traditional sources of knowledge rather than local or foreign sources of scientific information (Figure 13). While community members often experiment with new techniques or methods to enhance their livelihood, they are not often willing to change their behaviours according to new knowledge and lessons they have learned. Similarly, when a change in the environment has been noticed, people in the community do not adjust by changing their behaviour in an environmentally conscious way (Figure 13). Table 1 in Appendix 2 depicts the median scores for each statement across individuals.

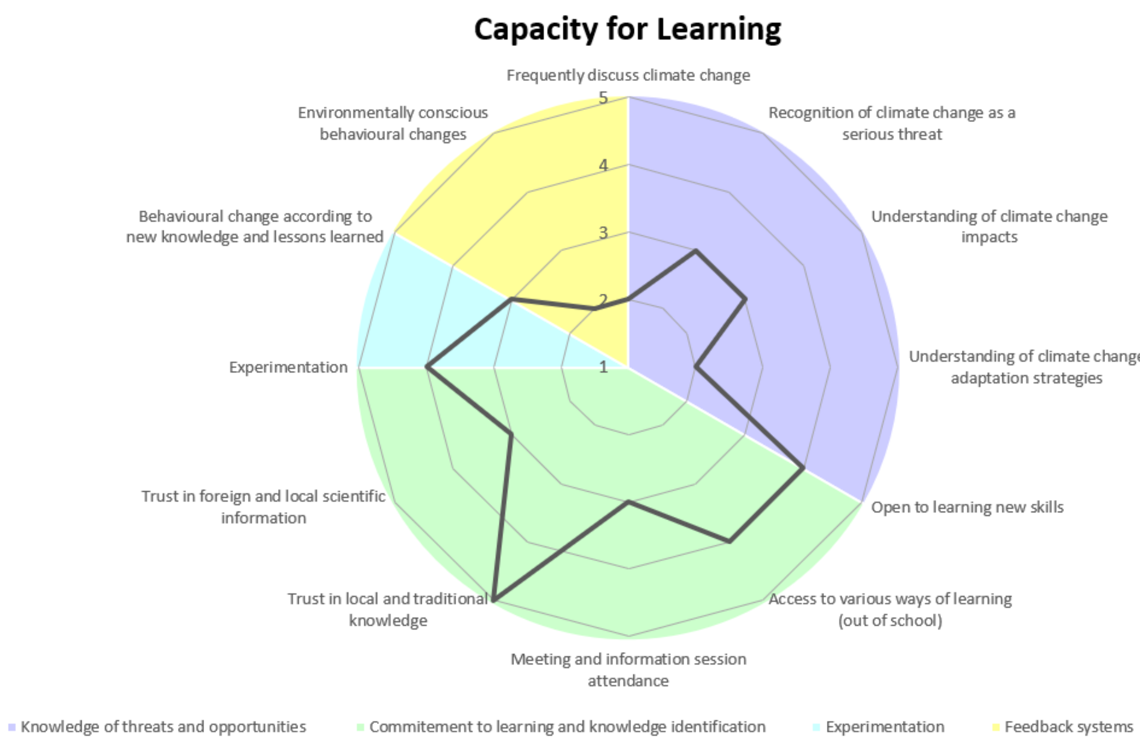

Figure 13. The SIOBMPA stakeholder capacity for learning. Median scores across individuals for each statement concerning knowledge of threats and opportunities, commitment to learning and knowledge identification, experimentation and response to feedback systems. A 5-point Likert measurement scale was used to capture the level of agreeance and resulting contribution to resilience. The scale is as follows: 1: Strongly Disagree (very low), 2: Disagree (low), 3: Neutral (average), 4: Agree (high) and 5: Strongly Agree (very high).

5.3 - ACCESS TO CAPITAL

Although access to good local health care is not perceived to be strong, it is generally agreed that people in the community are in good health (Figure 14). Community members are considered highly skilled in various ways and learn new skills from one another. They have access to primary and secondary education, and typically graduate from high school. Community members have access to post-secondary education, but attendance is not high (Figure 14). Community members typically own or have adequate access to the equipment, machinery or technology they need for their livelihood, however, when the equipment, machinery or technology is broken or needs maintenance, these repair services are difficult to find locally (Figure 14). Funding for community lead initiatives is considered relatively difficult to access, and is most often received through international or national non-governmental organizations (such as UNDP, USAID, etc.) rather than from the community itself or through the government (Figure 14). Many believe that the environment in and around the community is in good health while others do not. It is believed however that the environment provides the community with many sources of food and livelihood (Figure 14). Table 2 in Appendix 2 depicts the median scores for each statement across individuals.

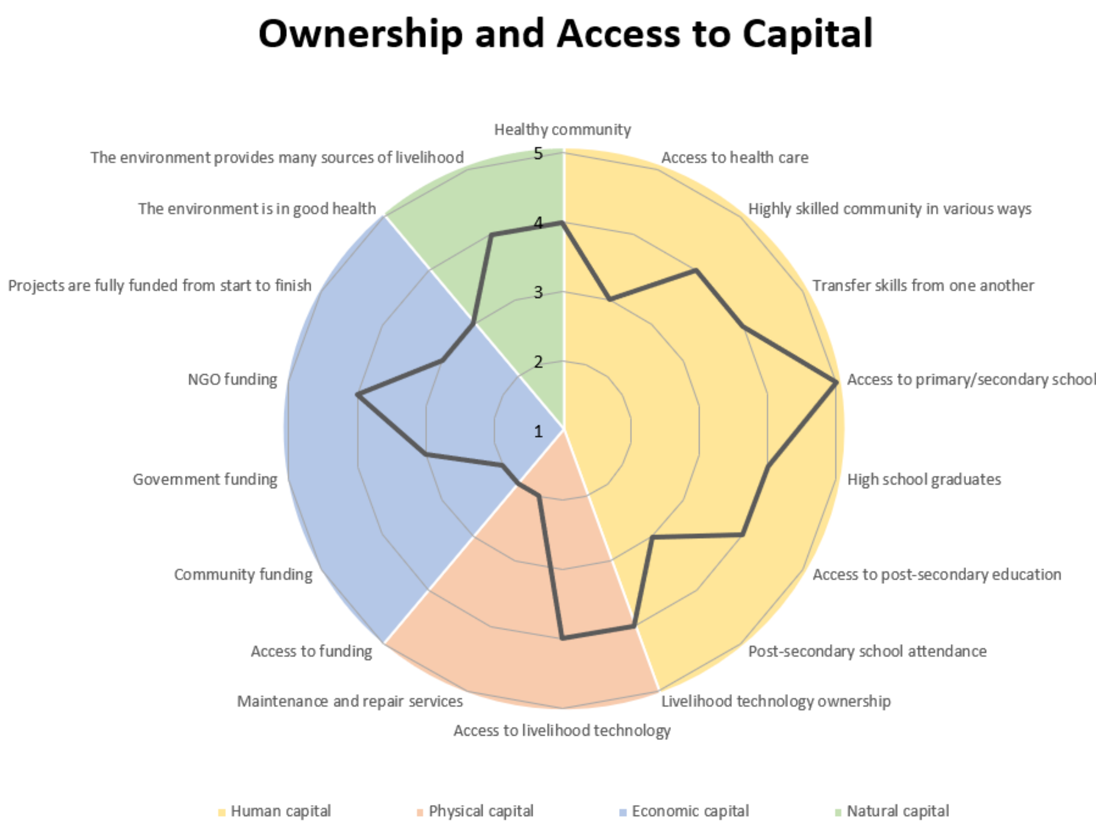

Figure 14. Ownership and access to capital in the SIOBMPA stakeholder community. Median scores across individuals for each statement human, physical, technological and natural capital. A 5-point Likert measurement scale was used to capture the level of agreeance and resulting contribution to resilience. The scale is as follows: 1: Strongly Disagree (very low), 2: Disagree (low), 3: Neutral (average), 4: Agree (high) and 5: Strongly Agree (very high).

5.4 – MONITORING FOR RESILIENCE

The indicators chosen for the 2016 Eastern Caribbean Coral Reef Report Card help translate the complex mechanisms that determine coral-dominated reef health (CaribNode, n.d). However, the way in which they directly contribute to enhancing reef resilience to climate change and other slow drivers of change in ECMMAN sites is ambiguous. Here we examine how and if this data can provide useful information to the MPA governance system for a coral reef resilience assessment of the SIOBMPA:

CORAL COVER

Identifying percent coral cover will tell very little about the resilience of the reef or where it is situated in reference to the phase-shift tipping point unless there is abundant historical data to provide information about local system dynamics and feedback mechanisms (which is not available for the SIOBMPA) (Hughes et al., 2010). Nonetheless, healthy coral coverage is sign that the reef has likely not passed the critical threshold, and that immediate measures should be taken to increase the likelihood that the reef will not undergo a phase shift.

MACROALGAE COVER

Macroalgae proliferation (specifically turf macroalgae) heavily reduces coral larval recruitment and settlement through various processes, including covering space and accumulating sediment as well as changing the chemical and microbial balance of the system which reduces the availability of suitable settlement space and conditions for coral recruits (Nystrom et al., 2008). As macro-algae grow they become less palatable, reducing the ability of herbivores to control algae coverage on the reef and ultimately converting the system to bottom-up control (Nystrom et al., 2008). High macroalgae cover can be indicative that the system is slowly moving towards a macroalgae dominated state, and therefore closely monitoring this indicator over time can allow managers to identify if, and how quickly, this trend is taking place in the system.

HERBIVOROUS FISH

Herbivorous fish play the predominant role in maintaining a healthy balance in coral to macroalgae coverage in the reef, and ultimately have control in where the system lies in relation the phase-shift tipping point. A classic Caribbean example that showcases this control relates to the disease-induced mass mortality of diadema (sea urchin) in 1983-84, which resulted in a 20-fold increase in macroalgae coverage across Caribbean reefs (Hughes et al., 2010). In Jamaica, recruitment decreased by 80%, and macroalgae cover increased from 2% to 20% (Hughes et al., 2010). Diadema, as well as other grazing species are essential in maintaining a coral-dominated state in Caribbean reefs (Mumby et al., 2007). Models by Mumby et al., (2007) demonstrate that all Caribbean reefs would exhibit an upward trajectory towards a higher coral-cover equilibrium (regardless of current coral cover) if herbivores graze upwards of 42% of the reef over a 6-month period.

COMMERCIAL FISH

Predatory fish contribute to maintaining the dynamics and ecological feedback systems necessary for healthy coral-reefs to remain in a coral-dominated state (Dulvy et al., 2004; McManus & Polsenberg, 2004).

The combined assessment and evaluation of the above indicators over time can help determine if the reef system is following a downward trajectory towards a tipping point that would prompt a phase shift into a macroalgae dominated state. However, it does little to contribute to the understanding of the reefs current potential for resistance and recovery.

Although current monitoring efforts are not intended for the assessment of ecological reef resilience, the AGGRA data collected in 2015 includes information regarding the abundance of coral by species (AGGRA, 2015), which could provide valuable information pertaining to the distribution and abundance of locally stress-resistant coral species and symbionts. It is recognized in the literature that coral reef resilience to long-term stressors is dependant on the interaction and genetic adaptation of both coral species and algal symbionts (Bay et al., 2016; Bourne et al., 2016; Howells et al., 2016; Putnam et al., 2017) although the molecular and genetic processes that generate resilience remain unclear. Resilient species are thus highly context and site specific, and no research has yet been underway to assess locally stress resistant coral genera and symbionts in the SIOBMPA. Nonetheless, the Grenadian Coral Reef Coordinator Denzel Adams (Marine Areas Unit in the Granada Fisheries Divisions of the Ministry of Agriculture, Lands, Forestry, Fisheries & the Environment) has made some observations of locally resilient corals which include some species of the Siderastrea, Porties and Acropora genera (email correspondence with Denzel Adams, 08/24/2017). He also notes that resilience in coral species may predominantly be attributed to genetic diversity among corals and the presence of variable environmental conditions within reefs (such as temperature and salinity variability), which is consistent with the current literature (Hughes et al., 2003; McClanahan et al., 2012; Nystrom et al., 2008). Therefore, resilience can be better assessed by monitoring coral diversity in the SIOBMPA, as well as identifying and recording the total coverage of coral genera that exhibit resistance to perturbations. Although the AGGRA data does not provide information regarding site-specific variability in temperature and salinity, recording these conditions would provide context when evaluating the abundance and location of stress-resistant species geographically. High levels of recruitment success are a defining characteristic of a resilient reef (McClanahan et al., 2012). The AGGRA data collected provides information regarding the density of small and large coral recruits, and benthos substrate in the SIOBMPA. Combining the information of macroalgae cover, and the abundance of juvenile coral recruits as well as the availability of suitable substrate for recruitment can help illustrate the recovery capacity of the reef.

The data shows high variation in mean resistant coral genera abundance, coral recruits and suitable substrate for recruitment within and between sampling sites (coefficient of variation exceeding 100%), indicating that a larger sample size in necessary to identify mean resistance and recovery values for the SIOBMPA. Furthermore, historical data is necessary for this assessment as functional feedback systems are reliant on the social system's ability to observe trends and deviations in the ecological system. A preliminary analysis should be carried out to determine the spatial and temporal scale needed for data collection that would effectively capture the structure and composition of the coral reef community.

CHAPTER 6 – DISCUSSION: SWOT ANALYSIS

The results yielded from this study shed light onto some of the social system components that will influence the SIOBMPA SES as whole. This section will demonstrate the predominant characteristics that may strengthened or weaken the community's ability to effectively respond to climate change, as well as some of the external opportunities and threats that may act as contributing factors:

6.1 - STRENGTHS

A FOUNDATION FOR SES RESILIENCE TO EMERGE

Results revealed through this study are indicative that many components of the social foundation on which social resilience can emerge are present in the SIOBMPA stakeholder community. Close-knit communities (defined by strong bonding capital) lying adjacent to the SIOBMPA, composed of members undertaking diverse livelihoods within marine related sectors has enhanced the relationships among stakeholder groups with competing interests. Communities are already tightly bound by frequent informal communication; daily communication being strongly embedded in cultural norms. It is not surprising for two busses crossing paths to stop and exchange greetings on a Monday morning commute, just as it is expected that all members of the community exchange greetings as they cross paths in town. Interconnected communities are the foundation upon which collaboration and collective action can emerge (Adger, 2003; Adger et al., 2002; Pelling and High, 2005; Wolf et al., 2010), and can be the common grounds upon which agreements and compromise can be shaped between groups with differing interests. Water taxi operators and fishermen have inherent opposing interests, abide to different norms and rules when using the SIOBMPA and are part of different formal institutions. Nonetheless, bridging capital remains strong between these groups due to the high overlap in stakeholder membership and the link they share with the community. These strong ties among diverse stakeholder groups is indicative of a community with high social capital. Social capital plays a defining role in raising the social resilience of a community by brining people together, stimulating knowledge and information exchange, and creating space for collaboration (Lochner, Kawachi & Kennedy, 1999; Pelling & High, 2005). It enables the formation of stewardship in natural resource management and is often a vital component to the development of new formal and informal institutions that drive collective thought and action (Adger 2003; Aldrick & Meyer, 2014). Social capital thus plays a central role in creating the building blocks necessary for community wide goals and objectives to be attained (Adger, 2003; Adger et al., 2002; Pelling and High, 2005; Wolf et al., 2010). The SIOBMPA stakeholder community also exhibits high networks of mutual aid and support, which in times of need, reinforce social capital and the community's ability to spread resources across the entire network (Keck & Sakdapolrak, 2013; Pelling et al, 2005).

The positionality of a stakeholder group and the ties it shares among the network ultimately determines the power held by this group in forming, influencing and propagating information and resources along communication pathways. Each stakeholder category relays knowledge based on information they have acquired from their interaction with the environment, other stakeholder groups and the external systems beyond the stakeholder community (e.g. books and online resources, national and international partners…etc.). Many stakeholder groups in the community are well positioned in the network to use their strengths to spread ideas and information that are central to building social resilience:

- **Water taxi & tour operators** have links with more groups (both well and poorly connected groups) than any other stakeholder group in the network. By virtue of their position in the network, water taxi & tour operators are "in the know" and have access to the beliefs, knowledge and ideas of many other groups. Because members of this group share membership and/or high communication with stakeholder groups of competing interests, they understand biases, opinions and reasonings that shape the diversity of behaviours taking place in the MPA. Furthermore, they trust many other stakeholder groups and are themselves well trusted. Water taxi & tour operators thus hold a position of power when it comes to influencing beliefs and mobilizing actions that will build the SES's capacity to cope, adapt and transform in response to climate change.

- **The MPA management team** have high scores in all forms of centrality (total degree, betweenness and eigenvectors), which not only indicates that this group is well connected, but that they bridge the gap between many groups as well. In addition, the MPA management team is the highest recipient in aid and support from the stakeholder community, indicating that many stakeholder groups are willing to help the MPA management team with endeavours relating to the SIOBMPA in times of need. Their positionality in the network could positively influence their ability to implement resilience-based management actions and enforce regulations, and thus positively contribute to raising SES resilience.

- **SusGren**, the local NGO, is a predominant source of scientific information, funding and external partnerships that enable local community-lead conservation and sustainable development projects to take place. SusGren doesn't hold any strong ties with any stakeholder group in the network; however, they hold the highest value in centrality betweenness indicating they are often present along the shortest communication pathways. This indicates their importance in bridging the gap between groups that may otherwise be disconnected or far apart in the network, such as senior government representatives and communities. SusGren entrusts many stakeholder groups, even though they themselves are only moderately well trusted. Nonetheless, their positionality is in-line with their mission and has helped them directly facilitate stakeholder meetings that increase information exchange and build partnerships within the stakeholder community.

The MPA management team currently holds an ideal position in the network to influence behaviours that are aligned with the conservation goals and objectives outlined in the new comprehensive management plan. Furthermore, the plan itself specifically addresses the impacts of climate change on coral reefs through a set of clearly defined actions within a five-year time frame. If effectively implemented by the MPA management team and supported by local partners and stakeholders, these actions will directly contribute to raising resilience of the reef. However, issues pertaining to the governance structure must be addressed (i.e. filling the vacant managerial position and operationalizing the MPA board) before activities of this calibre can be effectively implemented. The recent considerable efforts undertaken by the Ministry and partner organizations in addressing these issues thus represents the first concrete step towards building MPA management capacity and in turn the resilience of the system.

Social and integrated learning, skill transmission and experimentation within the SIOBMPA community positively contributes to raising the system's resilience by increasing the capacity for adaption and transformation when responding to the impacts of climate change. Social learning refers to the long-term process required for behavioural and attitudinal change at the individual level through community interaction (Tompkins & Adger, 2007), and is therefore a key component to the development of a shared vision for adaptation. As previously mentioned, the density and structure of the SIOBMPA communication network can enable information to be easily transferred between stakeholder groups, thus prompting network wide social learning. As climate change progressively alters the environment on which the social system depends, the community will seek to accelerate the rate of social learning in order to develop and implement effective adaption measures. This movement has already started to take place in Carriacou through a community-based "local Early Adaptation Planning (LEAP)" project for climate change adaptation lead by the MCPMF and local community members, implemented by Sustainable Grenadines Inc. with financial support from the NOAA Coral Reef Conservation Program through the Gulf and Caribbean Fisheries Institute. The SIOBMPA stakeholder community has access to various ways of learning in social environments (separate from the school system), which aim to increase livelihood sustainability and environmental stewardship. The community is open to learning new skills and information, especially as it pertains to traditional and local knowledge. Many cultural practices and traditional knowledge streams are shaped by the way communities interact with ecosystems and the ways in which they use natural resources. Integrating the local knowledge stream into climate change adaptation can ensure strategies are culturally relevant, supported by stakeholder groups and within the limits of the social dimensions required for their implementation (Adger et al., 2013, Armitage et al., 2007).

Access to formal education, technology, machinery and equipment for livelihood purposes, as well as funding for community projects from external NGOs, buffer the impacts of climate change on the SIOBMPA social infrastructure by providing the community with opportunities to diversify employment (within the limits of the island's resource base) and implement resilience-building community projects. Furthermore, the local environment is perceived to provide the community with many ecosystem goods and services, further promoting livelihood stability and in turn social resilience. The SIOBMPA community is healthy and highly skilled: sources of human capital that, when combined with organizational resources (such as institutions) and social capital can positively influence community capacity by raising human agency.

6.2 - WEAKNESSES

INTERNAL BARRIERS TO THE DEVELOPMENT OF SES RESILIENCE

The co-management governance structure is built upon the premise that all stakeholder groups should be given equal opportunity to participate in the governance process (Berkes et al., 1991). However, stronger relationships existing between government sources of power (i.e. MPA management team and senior government representatives) and the L'esterre and Lauriston communities could lead to the marginalization of the Tyrell Bay/Harvey Vale community. This assumption is reinforced by the lack of trust received by the Tyrell Bay/Harvey Vale community from other stakeholder groups. Every stakeholder group holds information and ideas that are of value in the development of methodologies and approaches that can increase the SES's capacity to cope, adapt and transform in response to climate change. When a group is disproportionately isolated in the network, the community loses the ability to access this group's knowledge base (Tompkins & Adger, 2004). Not only does this reinforce the group's isolation, it can heavily skew the direction of social change away from a solution that can be endorsed by the stakeholder community as a whole. Fortunately, the SIOBMPA network is too small to truly alienate any local primary stakeholder group. Nonetheless, there does exist groups that are significantly less connected within the community. These groups are not well situated in the network to use their strengths towards building SES resilience:

- Members of the **dive shop** stakeholder group are in direct contact with the coral reef environment on a day-to-day basis and actively take part in the monitoring of ecological health indicators in SIOBMPA coral reefs. Through their internal NGO programs, they play a predominant role in ongoing conservation related efforts such as lion fish control, Reef Check data collections and coral nursery monitoring, and often contribute to short-term research projects with other NGO partners. As tourism operators, they also attract international visitors which provides the local economy with external sources of economic capital. Dive shops however have very low internal bonding capital; contention fuelled by opposing ideas and opinions has lead to low communication among dive shops. Given their strong knowledge base both in local and scientific knowledge, and their ability to closely monitor the environment on a regular basis, the community at large would benefit from dive shops holding a more central position in the network of communication.

- **The MPA co-management board** is a central component to the SIOBMPA governing structure and although the group has been operational in the past, the board is no longer functional due to reasons that are beyond the scope of this study. The board is poorly connected within the network and holds low scores in total-degree, betweenness and eigenvector centrality, and no strong ties with any other stakeholder group. The board is also less likely to provide aid and support or entrust any of the stakeholder groups in time of need. As previously mentioned, the lack of a functioning governance structure diminishes the ability of the MPA management team to enforce regulations and implement activities that will directly raise the ecological resilience of coral reefs in the SIOBMPA. Fortunately, results indicate that the MPA board still remains as one of the highest recipients of trust among the community network, which may be an essential component in recovering its functionality as a co-management board.

There is a lack of an established consensus as to what activities are prohibited in the SIOBMPA. While the management plan specifies different zones for specific uses, boundaries are not clear to users. This may be a result of poor communication between the MPA management team and the stakeholder community. The management plan, regulations and zones must be communicated and enforced to ensure users are compliant with established rules. This will ensure that local anthropogenic threats are diminished and that management actions intended to enhance coral reef resilience to climate change are supported by the stakeholder community.

Although the SIOBMPA stakeholder community is generally open to learning new information and skills through initiatives like the LEAP project, attendance in the past has been generally low. Motivation for adaption stems from the community's perception of the threat and the urgency at which issues need to be addressed. Schwarz et al. (2011) state that "perceptions of risk, preference, belief, knowledge, and experience are key factors that determine, at the individual and societal level, whether and how adaptation takes place". Although SIDS are internationally recognized as being highly vulnerable to climate change, the topic is not often discussed at the local level. There is a divide in community understanding of the potential impacts brought about by climate change and communities generally do not perceive it as being a serious threat to current and future generations. The community's understanding of the impacts of climate change on the SIOBMPA are divided, as is their knowledge of the potential adaptation strategies available to them. The lack of a community-wide understanding of the threat diminishes their capacity to accurately assess their vulnerability and prepare accordingly. Given that climate change is a scientific concept based on projections and models, the communities lack of trust in local and foreign scientific knowledge undoubtedly shapes the way climate change is perceived. Formal institutions such as government bodies, NGOs and community-based organizations play a role in structuring the perception of environmental risk and variability attributed to climate change (Agrawal, 2010).

Local formal institutions identified by key informants are predominantly membership-based and related to industry and livelihoods (e.g. the public workers union, the Carriacou fisherfolk association, Grenada & Carriacou Diving Association, etc.). While groups, unions and associations can promote kinship, collective action and strong bonding capital, they can also reinforce interest-based opinions among members, resulting in stronger disconnect between groups. When groups are of conflicting interests, these forms of established formal institutions reduce the ability of the entire stakeholder community to create and attain collective goals. Alternatively, all-encompassing formal institutions such as youth, community and religious groups allow for stronger ties to form between members of all stakeholder categories and thus promote higher bridging and linking capital. The lack of SIOBMPA stakeholder membership in inter-disciplinary formal institutions in which various sources of knowledge strains can be integrated may therefore contribute to shaping the community's perceptions of climate change related threats and opportunities as well as generate issues when establishing collective goals.

"The capacity for learning connotes adaptive management, implying that a resilient SES is a learning system that incorporates previous experiences into current action and thus has memory (ibid)." (Speranza Chinwe & Rist, 2014, p.114). Perhaps the most prominent weakness of the SIOBMPA stakeholder community is its inability to appropriately change behaviours according to lessons learned. Functioning feedback systems are central to learning as they allow stakeholder to identify signals in the external environment and respond accordingly. They help increase social memory and are thus a defining characteristic of resilient SES. Furthermore, while various monitoring efforts conducted in the SIOBMPA are taking place to analyse reef health, they have little use to managers in the face of uncertainty. Monitoring and evaluation efforts will need to be reformulated to better address climate change as a predominant threat.

Diversity in livelihood characteristics and processes is indicative of a social system that will be more resilient to long term stressors (Speranza Chinwe & Rist, 2014). Diversity provides freedom of choice and flexibility so that individuals can change employment when socio-ecological conditions are altered and can no longer support prior livelihoods. Livelihood diversification is inherently minimal on Carriacou; the ability for SIDS to undertake climate resilient sustainable development is bound by a limited natural and human resource base. Fishing, construction, retail, government and tourism represent the leading industries in Carriacou, many of which are reliant on the same resource base (Harvey, 2013). Remoteness and small geographic scale also incur difficulties in providing citizens with local needs and services such as good healthcare. In many instances, resilience building in the SIOBMPA is restricted by their heavy reliance on the mainland and the international market.

6.3 - OPPORTUNITIES

SUPPORT FROM THE GLOBAL COMMUNITY

In recognition of the disproportionate burden placed on SIDS, the global community (in the form of international and national aid organizations) is facilitating and funding a variety of climate change resilience building projects in SIDS worldwide, Grenada included (Nakhooda et al., 2015). The country has already undertaken a number of projects, including the Pilot Program for Climate Resilience (PPCR) which aimed to "strengthen its institutions and human capacity and better integrate natural hazard and climate risk considerations into planning processes" (CIF, n. d) and The Nature Conservancy's At the Water's Edge project (AWE), designed to "improve the community's capacity to respond to climate change through strong community engagement, and the implementation of nature-based solutions" (Reef Resilience Network, n. d). Large multinational organizations such as the United Nations Development Program (UNDP), the Global Climate Change Alliance (GCCA), the Global Environment Facility (GEF), etc. are funding and supporting regional, national and community lead initiatives, to strengthen SIDS capacity and reduce vulnerability.

ECOLOGICAL MONITORING AND EVALUATION ADVANCES

Anticipated climate change-induced bleaching events and other growing anthropogenic impacts such as pollution and overfishing have provoked coral reef resilience research to increase 36-fold between 1990 and 2007 (Nystrom et al., 2008). Although efforts are continually underway to understand the components of a resilient reef, the ever-growing decline in reef abundance and diversity at a global scale demonstrates how management efforts thus far have failed to prevent degradation (Hughes et al., 2017; Pandolfi et al., 2003). At the moment, monitoring efforts are concentrated on collecting information concerning the status of reef health, which provides limited capacity in determining reef resilience to climate change. The TNC Reef Resilience Network recommends the use of McClanahan and colleagues' (2012) list of prioritized indicators as a a tangible way to examine components of the reef that enhance ecosystem resistance and recovery. However, there are other, potentially more effective, opportunities to understand the ecosystem processes and mechanisms underlying resilience through a series of approaches that are within the means of SIDS marine managers. The functional group approach (Bellwood et al., 2004; Cheal et al., 2009; Hughes et al., 2010; Nystrom et al., 2008; Nystrom et al., 2006; Green & Bellwood, 2009) is based on understanding response diversity and redundancy in coral reef functional groups (such as grazers, predators and primary producers) (Nystrom et al., 2008). Response diversity relates to the range of responses taken by species belonging to the same functional group, while redundancy refers to the functional complementarity that these species share (Nystrom et al., 2008). As stated by Nystrom and colleagues (2008), "Functional group comparisons could serve as one route to take where routine monitoring data, such as species richness and relative abundance (evenness) can provide constructive information." Species richness (the number and type of species within a functional group), serves as insurance, so that if species go locally extinct when environmental conditions change, ecosystem functions remain. Because it requires species to go extinct, this represents a slow response to climate change. Species evenness however quickly changes as the ecosystem undergoes stress or disturbance (Nystrom et al., 2008). By combining the assessments of the two, biodiversity can serve as a resilience indicator that can be fully understood and monitored. Other approaches include monitoring for demographic skewness (Hughes & Tanner, 2000) or measuring discontinuities (Allen et al., 2005). Given ecological monitoring is already taking place in the SIOBMPA on a regular basis, integrating system-based ecological resilience approaches when evaluating the data can help managers discern the resilience of the reef.

OBSERVED CORAL ADAPTATION

A study by Baker et al (2004) reveals that corals containing thermally tolerant symbionts are significantly more reoccurring in reefs that have been severely impacted by bleaching events. This adaptive shift in coral reef symbiont uptake indicates that these reefs are more likely to resist future bleaching events when exposed to warmer temperatures. A growing number of studies are attributing coral resistance through adaptation in the form of heat tolerant symbionts following bleaching events (Bay et al., 2016; Berkelmans & Van Oppen, 2006; Howells et al., 2016). Given adaptation only occurs after a bleaching event has taken place, this phenomenon can only take place in coral reefs that have been subject to limited DHW and have subsequently survived. Nonetheless, this does provide a silver lining in what is to be a challenging future for the world's coral reefs.

6.4 - THREATS

SIOBMPA IN ISOLATION

Although the SIOBMPA is part of a network of MPAs across the Grenadines Islands (ECCMAN), it's lack of direct proximity to other protected coral reef systems could potentially reduce the systems resilience. As previously discussed, reef resilience is often attributed to diversity, both in species and genetics (Hughes et al., 2003). Reefs that have access to a larger gene pool from neighboring healthy reefs are more resilient due to their increased diversity in genetic supply and mobile links (i.e. migrating predators) (Hughes et al.,2003; Nystrom et al, 2008).

LOCAL IMPACTS

Approximately 75% of the worlds reefs are threatened by a combination of local anthropogenic stressors and climate change induced thermal stress (Burke et al., 2011). While slow drivers of change such as SST and ocean acidification represent significant and growing threats, local sources of pressure such as fishing, coastal development and pollution can also prompt a phase-shift into a macroalgae dominated state from which the reef cannot recover due to hysteresis (Burke et al., 2011; Wear, 2016). Although current levels of local anthropogenic impacts are considered low, many of these threats are not unfamiliar to the SIOBMOA. Fishing in the MPA (all methods) continues to be a growing management issue, even if specific fishing zones and method regulations have been implemented into the management plan (Harvey, 2013; MCPMA, 2015). Furthermore, mangrove destruction and intensive coastal development has been approved within the SIOBMPA in order to create a new marina in Tyrell bay (Caribbean News Now, 07/02/2014). Although it is widely recognized that decreasing local pressures is the best way to prolonged reef survival (Burke et la., 2011), development and sustenance through the exploitation of the SIOBMPA ecosystem services takes precedence over conservation in an area of minimal job opportunity (Caribbean News Now, 07/02/2014).

ADDITIONAL CLIMATE CHANGE THREATS

Conservation and management efforts are also at the mercy of sudden large-impact disturbances such as hurricanes (Gardner et al., 2005). Air temperatures, which are expected to rise a minimum of 1.5°C and exceed 2°C under high emissions scenarios (RCP 6 & 8.5) between years 2081-2100, influence important climate aspects such as precipitation levels and storm intensity. Recent assessments agree that extreme weather events such as tropical cyclones should intensify as sea and air temperatures warm (although there is a lack of a consistent trend among modelling studies to gather concrete estimates) (Walsh e

t al., 2016). Following a hurricane, an average of 17% coral coverage is lost in Caribbean reefs in the next year (Gardner et al., 2005), which could easily push the reef past a phase-shift tipping point if it's already subject to other anthropogenic stress. Furthermore, coral reefs take an average of 8 years to recover into their pre-hurricane state (Gardner et al., 2005). Since 1999, Grenada has been subject to three severe tropical hurricanes (TNC, 2016). Adaptation to slow drivers of change requires coral reef ecosystem to undergo, withstand and survive changes in environmental conditions (Baker et al., 2004). Exposure to severe and frequent natural disasters could therefore undermine natural and social efforts to increase resilience to climate change.

CHAPTER 7 - RECOMMENDATIONS AND CONCLUSION

7.1 RECOMMENDATIONS FOR MANAGEMENT

Integrating resilience principles into adaptive co-management will be key in bridging the gap between resilience theory and practical conservation and management (Anthony et al., 2015). Adaptive co-management encompasses the beneficial features of community co-management such as a shared common goal, joint control across multiple levels and high levels of interaction among collaborating stakeholder groups, with the added benefit of flexibility in learning and the recognition of uncertainty (Armitage et al., 2007). Given that maintaining SES resilience is a function of observing and responding to ecological feedback systems, stakeholder involvement is a key component to resilience based management (Hughes et al., 2005). It is recommended that the SIOBMPA management team strive to attain goals following the principle of adaptive co-management in order to build resilience to climate change. Based on the results yielded from this study, here are a list of specific management recommendations for the SIOBMPA management authority:

BUILD UPON THE EXISTING SOCIAL-ECOLOGICAL FOUNDATION TO PROMOTE RESILIENCE

Approaching long-term changes in the ocean's physical and chemical properties highlight the need to take adaptive management measures as soon as possible. The current state of the SIOBMPA system represents a solid foundation for resilience to emerge. Comprehensive management goals comprised of coral bleaching preventative and responsive measures proposed in the MPA management plan combined with stronger regulation enforcement to reduce local anthropogenic impacts will help build the resilience of the reef. Establishing a community-wide vision for the MPA and effectively communicating goals, objectives and regulations will be key in ensuring the management plan is followed and supported by all stakeholder groups. By strategically using existing networks of communication and trust, the MPA management team can effectively transmit information to all stakeholder groups and enhance regulation compliance. By building rapport and cooperating with water taxi and tour operators in transmitting information, MPA managers can ensure that key messages are communicated to other stakeholder groups in the network by well trusted community members. Furthermore, by keeping SusGren informed of management decisions, threats and opportunities, the management team can more efficiently transmit information along the entire network. SusGren can also aid in hosting public stakeholder meetings in order to increase communication pathways, knowledge transferal as well as trust and understanding between groups of varying interests and positions. The MPA management team should encourage the formation of formal institutions that foster better inter-sectoral communication, environmental stewardship and discussion about climate change.

ENCOURAGE THE INTEGRATION OF SCIENTIFIC AND TRADITIONAL KNOWLEDGE

Ensure the SIOBMPA stakeholder community is aware of the threats brought about by climate change by encouraging the integration of local traditional knowledge and science. This means creating a platform for scientists, government representatives and local community members to discuss knowledge and observations that will foster a community-wide understanding of the threat, the projected impacts as well as the opportunities for adaptation available to the community. Invite scientists to discuss climate change in a way that is comprehensible and relevant to the community. This integration of both knowledge streams will increase the trust bonds between communities and local sources of scientific knowledge from government and NGO stakeholder groups. The Local Early Adaptation Planning (LEAP) Project lead by SusGren represents a recent initiative in bridging the gap between science and local knowledge. It is recommended that both the stakeholder system capitalize on external sources of funding to continue initiatives such as this one, and initiate new projects that will increase local capacity.

SHOWCASE THE BENEFITS OF FUNCTIONAL FEEDBACK SYSTEMS

Seek national and international NGO funding to implement joint government-stakeholder projects that will enhance community resilience to climate change by showcasing the benefits of functional feedback systems. Projects should be especially focused on decreasing the predominant local threat of unregulated fishing, particularly of herbivorous fish species, which will play a predominant role in decreasing the level of macroalgae coverage on the reef, and increase the quantity and quality of fish in waters surrounding the MPA. Demonstrating how functional feedback systems increase the internal resilience of both the ecological and social system may prompt stakeholders to be observant and alter their behaviours according to changes taking place in the coral reef environment, thus enhancing adaptive capacity in the face of uncertainty.

PERFORM RESILIENCE BASED MONITORING AND EVALUATION WITH PARTNER ORGANIZATIONS

Reassess the temporal and spatial scope at which the coral reef should be sampled to better understand the structure and dynamics of the reef system. Use the functional group approach to monitor and evaluate reef resilience using data collected by partner organizations and the MPA management team. Considering the growing issue of macroalgae proliferation and herbivorous fish decline on the reef, the conventional functional group of "herbivory" should be further categorized into the group's three predominant roles: grazers, scrapers and bioeroders (Bellwood et al., 2004). Given each subgroup plays an important role in maintaining the reef in a coral-dominated state by ensuring space availability for recruitment post disturbance and promoting reef growth and health, the response diversity within this group will play a predominant factor in enhancing the resilience of the SIOBMPA. Monitoring and evaluating the reef for resilience and implementing actions accordingly, will play an important role in increasing SES resilience by enhancing the reef's capacity for resistance and regeneration. It is recommended that management develop an island-wide methodology and monitoring database to increase consistency in sampling and enhance the significance of local monitoring efforts. This will also increase communication and perhaps foster stronger bonds between members of the dive shop stakeholder group.

7.2 CONCLUSION

Climate change and variability are often proposed as some of the fundamental drivers of human evolution. It is hypothesized that changes in global climate is responsible for hominin speciation and global dispersal, enhanced cognitive capacity and bipedalism as well as cultural innovation (Behrensmeyer, 2006). Climate change will undoubtedly change the way in which modern human populations interact with the external environment for survival. As illustrated in this study, social-ecological resilience is enhanced and impeded by numerous subsystem attributes – functional group diversity and low anthropogenic influence on ecological systems enhance coping capacity when faced with long-term climate driven impacts, while the social system's ability to build institutions that foster communication, trust, social learning and effectively use available capital, promote adaptation and transformation. The success at which communities will cope, adapt and transform in response to climate change will be determined by their ability to self-organize and collectively address and respond to changing ecological dynamics and feedback systems. With change comes the possibility to drastically alter the current state of affairs into a system that enhances present and future well-being. As ocean properties are drastically altered by a changing climate, transformation will be necessary, and will require communities to come together despite differences, participate in decision-making and create institutions that improve community wellbeing while fostering social-ecological robustness.

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APPENDIX 1

The survey questions that guided the semi-standardized interviews with study participants.

Survey Number:

MPA Stakeholder Survey

Component 1: Network structure and content

PLEASE NOTE: this section will be conducted using participatory mapping and a set of qualitative questions.

<u>Mapping the social network of MPA stakeholders:</u>

What stakeholder group(s) do you identify with?

<u>Bonding social capital: links between individuals within a group</u>

Approximately how many members belong to this stakeholder group?

How often to people from this group speak with each other? (daily, weekly, monthly, 1-2X yearly, never)

How formal are the relationships between members of this group? (can be measured by how much people speak outside of work, and how formal their language and method of communication is (i.e. email, phone, text, in-person) (VI,I,N,F,VF)

Is there a key member of this group that acts as the group representative or coordinator (can be formal or informal)? Does he or she do a good job at communicating the interests and opinions of this stakeholder group? (Ask this after asking bridging questions)

<u>Bridging social capital: links between distinct groups</u>

Do people in your stakeholder group communicate with anyone from [stakeholder category named here] about their job, the MPA or other marine-related issues? (do this for each other stakeholder group). If yes draw a line between groups in red and ask:

How often do people from the two stakeholder groups speak with each other? (daily, weekly, monthly, 1-2X yearly)

How formal are the relationships between members of each group? (can be measured by how much people speak outside of work, and how formal their language and method of communication is (i.e. email, phone, text, in-person) (VI,I,N,F,VF)

Is there a key member of this group that acts as the group representative or coordinator (can be formal or informal)? Does he or she do a good job at communicating the interests and opinions of this stakeholder group?

Linking social capital: Networks of trust between stakeholder groups and authority gradients

Do people from your stakeholder group trust any of the other stakeholder groups with information about their job, the MPA or other marine-related issues? Draw and arrow to the trusted stakeholder groups in green.

Do people from your stakeholder group provide help or assistance to any of the other stakeholder groups when encountering issues related to the MPA or the marine environment? Draw and arrow to these stakeholder groups in blue.

Institutions and membership – Societal norms, rules and formal groups and organizations

Are people from your stakeholder group part of any unions, associations or cooperatives? What are they?

Is your stakeholder group or any of the above unions, associations or cooperatives involved in decisions making or management relating to the MPA? How?

Would your stakeholder group generally agree that the MPA management plans are flexible and responsive to changes in the community and the MPA?

What sort of behaviours ar e completely unacceptable when using the MPA according to your stakeholder group?

Component 2: Entitlements and Endowments (ownership and access to capital)

PLEASE NOTE: A 5-point Likert measurement scale will be used to capture the contributions to resilience for the following section statements:

1: Strongly Disagree (very low);

2: Disagree (low);

3: Neutral (average);

4: Agree (high);

5: Strongly Agree (very high)

<u>Human Capital – Health, skills and knowledge</u>

- People in my community are in good health.
  (1 2 3 4 5)
- People in my community have access to good local healthcare.
  (1 2 3 4 5)
- People in my community are highly skilled.
  (1 2 3 4 5)
- People in my community learn new skills from one another. Ex: Skilled elders teach younger persons in my community.
  (1 2 3 4 5)
- People in my community have access to primary and secondary school education.
  (1 2 3 4 5)
- People in my community typically graduate from high school.
  (1 2 3 4 5)
- People in my community have access to post-secondary education (college or university).
  (1 2 3 4 5)
- People in my community typically attend post-secondary school (college or university).
  (1 2 3 4 5)

Notes:

<u>Physical Capital – technology, machinery and equipment</u>

- People in my community typically own the equipment, machinery or technology they need for their livelihood (ex: boat, fishing gear, recreational gear…etc.)
  (1 2 3 4 5)
- People in my community have access to the equipment, machinery or technology they need for their livelihood (ex: boat, fishing gear, recreational gear…etc.)
  (1 2 3 4 5)

- When equipment, machinery or technology is broken or needs maintenance, these services are easy to find locally.
  (1 2 3 4 5)

Notes:

Financial Capital – Money and investments

- Funding for community projects is relatively easy to access.
  (1 2 3 4 5)
- Projects in my community are typically self-funded by people who live in the community.
  (1 2 3 4 5)
- Projects in my community are typically funded by the government.
  (1 2 3 4 5)
- Projects in my community are typically funded by international or national non-governmental organizations (such as UNDP, USAID, TNC or GEF)
  (1 2 3 4 5)
- When a project is started in my community, there is usually enough funding to support it from start to finish.
  (1 2 3 4 5)

Notes:

Natural – environment and resources

- The environment in and around my community is in good health.
  (1 2 3 4 5)
- The environment provides my community with many sources of food and livelihood.
  (1 2 3 4 5)

Notes:

Component 3: Capacity for learning

Knowledge of threats and opportunities

- People in my community often talk about climate change.
  (1 2 3 4 5)
- People in my community think climate change is a serious threat the health and livelihood of current and future generations (their children and grand-children)
  (1 2 3 4 5)
- People in my community understand how climate change will impact them
  (1 2 3 4 5)
- People in my community have ideas as to how to adapt to climate change
  (1 2 3 4 5)

Notes:

Commitment of the SES to learning & [Knowledge identification

- People in my community are open to learning new skills and information.
  (1 2 3 4 5)
- People have access to various ways of learning in a social environment, outside the school system. Ex: community, NGO or government lead information sessions.
  (1 2 3 4 5)
- People in my community typically attend meetings or sessions to learn new skills or information
  (1 2 3 4 5)
- People in my community trust local experts for their traditional knowledge which is passed on from one generation to the next.
  (1 2 3 4 5)
- People in my community trust local and foreign scientist for their new scientific information about the local environment.
  (1 2 3 4 5)

Notes:

Experimentation

- People in my community often experiment with new techniques or methods to enhance their livelihood (i.e. new fishing techniques, searching for new dive spots…etc.)
  (1 2 3 4 5)

Notes:

Feedback Systems

- People in my community change their behaviours according to new knowledge and lessons they have learned (ex. If a diving or fishing practice was found to be destroying coral reefs, do people in the community stop using this practice)
  (1 2 3 4 5)
- When a change in the environment has been noticed, people in the community adjust to the change by changing their behaviour (ex. If fishers notice less parrotfish on the reef, they will stop fishing the species and target another type of fish)
  (1 2 3 4 5)

Notes:

APPENDIX 2

Table 1. Median scores for each statement concerning across individuals. A 5-point Likert measurement scale was used to capture the level of agreeance and resulting contribution to resilience. The scale is as follows: 1: Strongly Disagree (very low), 2: Disagree (low), 3: Neutral (average), 4: Agree (high) and 5: Strongly Agree (very high).

Category	**Statement**	**Graph title**	**Median Score**	**SD**
Knowledge of threats and opportunities	People in my community often talk about climate change.	Frequently discuss climate change	2	1.213352
	People in my community think climate change is a serious threat to the health and livelihood of current and future generations (their children and grand-children)	Recognition of climate change as a serious threat	3	1.001729
	People in my community understand how climate change will impact them	Understanding of climate change impacts	3	1.097339
	People in my community have ideas as to how to adapt to climate change	Understanding of climate change adaptation strategies	2	0.973703
Commitment to learning and knowledge identification	People in my community are open to learning new skills and information.	Open to learning new skills	4	0.931281
	People have access to various ways of learning in a social environment, outside the school system. Ex: community, NGO or government lead information sessions.	Access to various ways of learning (out of school)	4	0.916246
	People in my community typically attend meetings or sessions to learn new skills or information	Meeting and information session attendance	3	1.067187
	People in my community trust local experts for their traditional knowledge which is passed on from one generation to the next.	Trust in local and traditional knowledge	5	0.600925

	People in my community trust local and foreign scientist for their new scientific information about the local environment.	Trust in foreign and local scientific information	3	1.015452
Experimentation	People in my community often experiment with new techniques or methods to enhance their livelihood (i.e. new fishing techniques, searching for new dive spots…etc.)	Experimentation	4	1.095727
Feedback systems	People in my community change their behaviours according to new knowledge and lessons they have learned (ex. If a diving or fishing practice was found to be destroying coral reefs, do people in the community stop using this practice)	Behavioural change according to new knowledge and lessons learned	3	0.957427
	When a change in the environment has been noticed, people in the community adjust to the change by changing their behaviour in an environmentally conscious way (ex. If fishers notice less parrotfish on the reef, they will stop fishing the species and target another type of fish)	Environmentally conscious behavioural changes	2	0.950958

Table 2. Median scores for each statement across individuals. A 5-point Likert measurement scale was used to capture the level of agreeance and resulting contribution to resilience. The scale is as follows: 1: Strongly Disagree (very low), 2: Disagree (low), 3: Neutral (average), 4: Agree (high) and 5: Strongly Agree (very high).

Capital	Statement	Graph Title	median	SD
Human Capital	People in my community are in good health.	Healthy community	4	0.897527
	People in my community have access to good local healthcare.	Access to health care	3	1.067187
	People in my community are highly skilled.	Highly skilled community in various ways	4	0.957427
	People in my community learn new skills from one another. Ex: Skilled elders teach younger persons in my community.	Transfer skills from one another	4	0.62113
	People in my community have access to primary and secondary school education.	Access to primary/secondary school	5	0.471405
	People in my community typically graduate from high school.	High school graduates	4	0.729981
	People in my community have access to post-secondary education (college or university).	Access to post-secondary education	4	0.848365
	People in my community typically attend post-secondary school (college or university).	Post-secondary school attendance	3	0.856484
Physical Capital	People in my community typically own the equipment, machinery or technology they need for their livelihood (ex: boat, fishing gear, recreational gear…etc.)	Livelihood technology ownership	4	0.890623
	People in my community have access to the equipment, machinery or technology they need for their livelihood (ex: boat, fishing gear, recreational gear…etc.)	Access to livelihood technology	4	0.785674
	When equipment, machinery or technology is broken or needs	Maintenance and repair services	2	0.890623

	maintenance, these services are easy to find locally.			
Economic Capital	Funding for community projects is relatively easy to access.	Access to funding	2	1.191086
	Projects in my community are typically self-funded by people who live in the community.	Community funding	2	1.161364
	Projects in my community are typically funded by the government.	Government funding	3	1.116653
	Projects in my community are typically funded by international or national non-governmental organizations (such as UNDP, USAID, TNC or GEF)	NGO funding	4	0.675831
	When a project is started in my community, there is usually enough funding to support it from start to finish.	Projects are fully funded from start to finish	3	1.042356
Natural Capital	The environment in and around my community is in good health.	The environment is in good health	3	1
	The environment provides my community with many sources of food and livelihood.	The environment provides many sources of livelihood	4	0.785674

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