Applying Adaptive Management Approaches to Data Limited Fisheries: The Case of Bermuda's Shallow Water Snapper Species

by

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Abstract

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The sustainable management of ecosystems, marine resources, and resource users is essential to ensure ecosystem health and resilience. A vast majority of global fish stocks lack adequate data to determine fish stock health using conventional fish stock assessment methods. These fisheries are often left unmanaged causing dramatic declines in fisheries health and potential economic and socio-cultural losses to coastal communities. To address these data limitations, fisheries managers are incorporating data-limited methodologies to scientifically assess fish stocks, estimate overfishing and set catch limits. With the dynamic nature of the natural environment, it is important that management strategies are adaptive and continually restructured. With limited biological data available for the shallow water snapper species in Bermuda, and limited resources to collect additional data, new methods of managing these species need to be considered. This research examines the options for adaptively managing Bermuda's shallow water snapper species by incorporating fishers' knowledge with current data-limited approaches.

KEYWORDS: Bermuda; shallow water snapper; data-limited fisheries; adaptive management; fisher knowledge; Lane snapper; Grey snapper; Yellowtail snapper; ecosystem-based fisheries management; FISHE framework; compliance; enforcement

Abbreviations and Symbols

ABC- Acceptable Biological Catch

B/B_{MSY}- The ratio of the observed biomass to the biomass that would provide the highest maximum sustainable yield for a given fish stock

B_{MSY}- The biomass that would provide the highest maximum sustainable yield

CCAMLR- Convention on the Conservation of Antarctic Marine Living Resources

DBSRA- Depletion-Based Stock Reduction Analysis

DCAC- Depletion-Corrected Average Catch

DLS- Data Limited Stocks approach

DLSA- Data Limited Stock Assessment

EEZ- Exclusive Economic Zone

EU- European Union

FAO- Food and Agriculture Organization of the United Nations

FISHE- Framework for Integrated Stock and Habitat Evaluation

FL- Fork length

FMP- Fisheries Management Plan

ICCAT- International Commission for the Conservation of Atlantic Tunas

ICES- International Council for the Exploration of the Sea

IOTC- Indian Ocean Tuna Commission

IUU- Illegal, Unreported and Unregulated

MAFMC- Mid-Atlantic Fishery Management Council

MPA- Marine Protected Area

MSFCMA- Magnuson-Stevens Fishery Conservation and Management Act

NOAA- National Oceanic and Atmospheric Association (the United States of America)

TAC- Total Allowable Catch

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"Let the wise hear and increase in learning, and the one who understands obtain guidance"

Proverbs 1:5

Chapter 1: Introduction

1.1 The Global Fishery Situation

The world's oceans are facing a severe problem as global fisheries are becoming increasingly difficult to manage. Scientists suggest that while large fisheries in industrialized nations are either healthy or in the process of recovery, the majority of global fisheries are heading towards stock depletion (California Environmental Associates, 2012; Food and Agriculture Organization of the United Nations, 2014). On a global scale, the fishing industry is extremely competitive. It is also an industry struggling with tremendous uncertainties. The fishing industry is exposed to uncertain science used to assess variable fish stocks, it is challenged with an inadequate understanding of the natural and biological ocean environment, and it is faced with increased pressure and demand for edible fish from limited fish stocks (FAO, 2014). Without adequate management, the increasing pressure and uncertainty means that overexploitation of fisheries may be inevitable.

Assessments on the status of worldwide fish stocks indicate that over half are fully exploited and 29% are overfished to a biologically unsustainable level (FAO, 2014). These assessments however only represent a small proportion of the world's fish stocks. Costello et al. (2012) indicate that only a small few of the world's fish stocks have been scientifically assessed. In addition, of the approximate 10,000 stocks subject to global fishing only a small proportion have catch data, biological data or management strategies (Costello et al., 2012). In industrialized countries, the proportion of assessed fish stocks ranges from ten to fifty percent. In developing countries, the fraction of fish stocks with

catch, survey, or biological data is even lower at five to twenty percent (Carruthers et al., 2014). Without catch history and biological data, management of these fish stocks becomes extremely challenging.

Worm et al. (2006) calculated that if current trends of fish stock collapse continued, all global fisheries would be collapsed by 2048. In a follow-up publication, Worm et al. (2009), produced a new assessment of global fisheries that relied on fish stocks with accessible data. This assessment found that 14% of global fisheries with stock assessments were collapsed and 63% of these assessed stocks were in need of rebuilding (Worm et al., 2009). Unlike previous frightful predictions, Worm et al. (2009) found that approximately half of the fisheries in need of rebuilding had reduced exploitation rates below the fishing mortality rate resulting in maximum sustainable yield.

Further analysis points toward the suggestion that unassessed fish stocks are in a far worse state than assessed fish stocks. In the developing world, most fish stocks are unassessed. In Asia, Africa, and South and Central America, most fish stocks are overexploited and have weak management capacities. As populations continue to grow in these areas, so does the demand for coastal resources (California Environmental Associates, 2012). Costello et al. (2012) developed a method to estimate the status of the world's unassessed fish stocks. They estimated that 64% of unassessed fisheries have a biomass below B_{MSY} (the biomass that would provide the highest maximum sustainable yield). In addition, they calculated that 18% of unassessed fish stocks were collapsed (Costello et al., 2012). These scientists concluded that both large and small scale

unassessed fish stocks are in decline. However, large unassessed fisheries seem to be performing at an equal level to assessed fisheries of the same size (Costello, et al., 2012).

Developing countries have limited resources to conduct monitoring and assessments. In smaller nations, institutional management initiatives are minimal or nonexistent partially due to the high cost associated with formal stock assessments (Apel, Fujita, & Karr, 2013). Thus, many developing countries' fish stocks are overexploited. FAO landings records indicate that the landings of lower to middle income fishing countries have increased by approximately 70% since 1988 (FAO, 2012). In these countries, fishing efforts have increased in an effort to keep up with demand for food and employment. According to FAO (2014), in 2012 84% of all people employed in the fishing industry were in Asia, followed by Africa and Latin America and the Caribbean at more than 10% and 3.9% respectively.

In addition to fish stock overexploitation at the regional and national level, fisheries on the high seas are at an even greater risk of overexploitation due to illegal, unreported and unregulated (IUU) fishing. (Gianni & Simpson, 2005). Even developed countries face difficulties when attempting to manage and prevent the overexploitation of these fisheries. Regional fisheries management organizations such as the International Commission for the Conservation of Atlantic Tunas (ICCAT), Convention on the Conservation of Antarctic Marine Living Resources (CCAMLR), and the Indian Ocean Tuna Commission (IOTC) have adopted a number of measures to help to manage and restore high seas fish stocks (Gianni & Simpson, 2005).

The status and health of a fish stock is generally tied to the country or countries exploiting it. In many developed countries, fisheries that were once overexploited are now stabilizing and rebuilding. In countries such as Australia, Iceland, New Zealand, Norway, and the United States, the health of majority of their fish stocks has been maintained. In addition, these countries have significantly reduced the number of overfished stocks (California Environmental Associates, 2012). NOAA indicates that in the US 83% of all federally managed stocks are being sustainably harvested and 77% are no longer overfished (NOAA Fisheries Service, 2012). Though many countries in the developed world are making positive changes resulting in healthier fisheries, there are still many developed countries that struggle with overexploitation. Many European fish stocks are overfished with 70% of stocks below $B_{MSY,}$ and overfishing continues to happen (California Environmental Associates, 2012). In Southern Europe, approximately 90% of commercially important fish stocks are below B_{MSY} and 55% are beyond what is considered to be a 'safe' biological limit (California Environmental Associates, 2012).

In developed countries, part of the answer to overfishing and stock overexploitation is transitioning from a single stock management approach to an ecosystems approach to fisheries management. The ecosystem approach to managing fisheries moves away from the traditional management of individual stocks and takes into account the various interactions within ecosystems, the effects they have between species, and the relationship the human element has within the system. It can be seen as a new method of sustaining fisheries. As alternative fisheries management practices are

introduced, positive steps can be made towards preventing the further overexploitation of the world's fish stocks (Pikitch, et al., 2004).

1.2 Management Regimes of Global Fisheries

1.2.1 Data Rich Fisheries

Overexploitation has caused many of the world's fish stocks to collapse. Unintended consequences of overfishing have caused ecosystem degradation. This is because as fish stocks decline, trophic gaps and shifts are created that may cause changes in ecosystem structure and function (Pikitch et al., 2004). Many fisheries management regimes have been ineffective at mitigating ecosystem degradation because they focus on maximizing catch rates for a single fish stock. Fisheries for which the resources to collect and analyze stock data and to undertake formal scientific assessments of the component fish stocks are known as 'data rich fisheries' (Pikitch et al., 2004). Many fisheries within the United States of America can be considered data rich fisheries. These fisheries in the United States are managed using a highly developed management framework.

Within US EEZ waters, management of living marine resources follows the congressional legislation of the Magnuson-Stevens Fishery Conservation and Management Act (MSFCMA), originally passed in 1976 (Restrepo & Powers, 1999). The US fisheries are divided into eight fisheries management councils whose mandates are in accordance with the MSFCMA. Management under the MSFCMA can be broadly characterized as a precautionary approach to fisheries management. Generally,

MSFCMA indicates that control laws are put in place in order to define limits, targets for healthy stocks, and targets for overfished stocks (Restrepo & Powers, 1999).

The Mid-Atlantic Fishery Management Council (MAFMC) manages the marine fisheries in the 200-mile limit of the Mid-Atlantic region of the US. In their recently developed strategic plan 2014-2018, the MAFMC outlined their fisheries management goal of "developing fishery management strategies that provide for productive, sustainable fisheries" (Mid-Atlantic Fishery Management Council, 2013). The MAFMC manages their fishery by incorporating the economic and social entities of management into the decision making process. Their strategy to accomplish this management goal is to evaluate cumulative social and economic impacts of management measures, to incorporate multi-year management approaches, and to ensure the use of terms of reference that aid in identifying relevant socio-economic and cultural issues. The MAFMC also encourages efficient commercial and recreational fishing businesses, and is particularly supportive of advanced gear designs that can increase efficiency, reduce discards and costs in commercial fisheries. In addition, the MAFMC also develops management approaches that account for uncertainty in commercial and recreational catch estimates. This fishery council plans to develop management strategies that aid in reducing regulatory discards. Another strategy is to develop models and analyses that can evaluate alternative bag, size and seasonal limits for both commercial and recreational fisheries. In addition, they seek to ensure fair access to recreational fisheries throughout the Mid-Atlantic region. Lastly, the MAFMC incorporates innovative ecosystem approaches into fisheries management. This management alternative considers all species

interactions into their management plans. In addition, this strategy will identify relationships between key fish habitat and productivity of marine resources and incorporate those into management decisions. The overall strategy of the MAFMC's implementation of the Ecosystem Approach to Fisheries Management is to limit the the negative impacts to the ecosystem (Mid-Atlantic Fishery Management Council, 2013).

1.2.2 Data Limited Fisheries

Data-limited fisheries are an issue seen across the globe. Many countries including Australia, New Zealand, United States, and Europe have developed management approaches to address their data-limited fisheries. Data-limited fisheries can be described as fisheries for which little to no data is available, data is poor in quality, or raw data has not been analyzed (Newman, Carruthers, MacCall, Porch & Suatoni, 2014). With a growing demand for sustainable fish products, many fisheries that lack catch and biological data are employing new methods for estimating overfishing thresholds and setting catch limits (Fujita, Karr, Battista, & Rader, 2013). These methods are known as data-limited methodologies.

The EU addresses the issue of data-limited fisheries by improving the assessment of data-limited fish stocks or through changing management advice that would be required to employ current data-limited assessment methods. Records indicate that approximately half of the landings in European Atlantic waters are from data-limited fish stocks. As of 2011, only 41 of the 146 stocks in EU Atlantic waters had been fully assessed (Le Quesne, Brown, De Oliveira, Casey, & O'Brien, 2013). The lack of data can be attributed to inadequate data collection and reporting, inadequate management

controls that permit unreported fishing, limited biological information, and resource limitations. For example, small vessels (<12 m) are generally more dependent on these data-limited stocks than larger vessels yet, small vessels operate under minimal reporting requirements. Of the data-limited stocks in European Atlantic waters, pelagic fish stocks have had more formal assessments completed than demersal stocks, while invertebrate stocks have had very few completed assessments (Le Quesne et al., 2013).

The International Council for the Exploration of the Sea (ICES) is the chief body responsible for conducting stock assessments in European Atlantic waters and the Baltic (Le Quesne et al., 2013). Prior to 2012, ICES was only able to provide qualitative advice for data limited stocks. ICES now provides quantitative advice for data-limited stocks based on their new Data Limited Stocks (DLS) approach (Le Quesne et al., 2013). This DLS approach moves away from the simple classification of data-rich or data-limited to a more advanced form of classification that utilizes all useful data. The DLS approach recognizes that though limited data is not the optimal management scenario, it is preferable to taking no action at all due to the absence of ideal data. In the DLS approach, stocks are assigned to one of the six data categories that range from fully assessed data-rich stocks to by-catch species with virtually no data or information (Le Quesne et al., 2013). The DLS approach uses data availability to define stock categories. Each stock category has different assessment procedures and management control rules. Management control rules also vary within data categories with decisions being based on MSY substitutes or common sense rules that have no specific biological foundation. ICES also incorporates the use of a Management Strategy Evaluation (MSE). The MSE is

a simulation method that evaluates the robustness of paired data-limited assessment methods and management control rules in situations of uncertainty (Le Quesne et al., 2013). Data-limited management advice for fish stocks within the Atlantic EU waters is that stocks that do not have assessments, but have strong evidence that suggests that the stocks are outside 'safe' biological limits, are to have Total Allowable Catches (TACs) set at levels that would not allow an increase in fishing mortality rates. In addition, for stocks that have an unknown status but are not considered high risk stocks, there should be no expansion of fisheries (Le Quesne et al., 2013).

In the US, 59% of Acceptable Biological Catches (ABCs) are based on data-limited methodologies. ABCs refer to the recommended annual catch level for a species or group of species that is determined based on life history and reproductive data, vulnerability to overfishing, and the degree of uncertainty of the recommendation (NOAA, 2006). The South Atlantic, Gulf of Mexico, Caribbean, Atlantic Highly Migratory Species, and Western Pacific regions have the highest amount of ABCs set using data-limited methods (Newman et al., 2014). Data-limited methodologies for stock management include: Depletion-Based Stock Reduction Analysis (DBSRA), Depletion-Corrected Average Catch (DCAC), Catch Scalars/Zero Landings, Zero Contribution to Complex, and Percent of Assessed Stock Habitat. Like ICES for EU stocks, the US also incorporates MSE into their data-limited methodologies. After evaluating various data-limited methodologies, US scientists have concluded that cost effective methods, for example, sampling catch, age, and length data, provides better output information for data-limited approaches than methods that rely on current stock status. In addition,

methods such as DBSRA and DCAC were found to be inappropriate for short-lived species that have low biomasses (Newman et al., 2014).

The value of data-limited methodologies for fisheries managers can not be overstated. Many managers around the world have limited access and knowledge of emerging data-limited methodologies. Even when data-limited methodologies are known, many scientists and managers are not able to apply these methods to their fisheries.

1.3 Research Question

Bermuda has three commonly fished shallow water snapper species: *Lutjanus synagris* (Lane Snapper), *Lutjanus griseus* (Grey snapper), and *Ocyurus chrysurus* (Yellowtail snapper). In addition to commercial fishing pressures, recreational fishers target all three species. The Lane Snapper is targeted particularly heavily and is the most commonly caught recreational species, both in terms of the number of people that target them and the amount of fish caught (Pitt & Trott, 2013). The biological data available varies significantly between species; catch history and good age, growth and reproduction data are available for the Lane Snapper (Luckhurst et al., 2000), but only catch histories and patchy age and growth data are available for the other two species. The Lane snapper is managed with a minimum size limit of 25 cm FL and a recreational bag limit of 30 fish per boat per day. The Yellowtail snapper is managed via a 30 cm FL minimum size limit only. At present, there are no direct management measures for Grey snappers. Recreational fishers are not licensed and are not required to submit catch data, therefore it is difficult to determine the amount of snappers landed by the recreational fishery (Pitt &Trott, 2013).

With limited biological data available for the shallow water snapper species in Bermuda, and limited resources to collect additional data, new methods of managing these species need to be considered. With the island being the most northern range of many Caribbean fish species and very isolated, Bermuda represents a unique ecosystem. By utilizing data-limited fishery methodologies, catch limits can be incorporated into the management strategy of these species. In addition, data limited methodologies will aid in cutting the costs of fisheries management, expand the range of fisheries that can be managed, and reduce the risk of overfishing. Within the proposed management strategy, new methods will be recommended to require commercial and recreational fishers to accurately report catch and landings data. The natural environment is constantly changing and evolving, and management decisions have to adapt to these changes. With a proposed adaptive method of data collection, management strategies for the three snapper species can be continually restructured. This research aims to answer the following question and sub-questions:

What specific management options for adaptive management of the shallow-water snapper fishery in Bermuda emerge by incorporating fishers' knowledge within the existing data-limited context?

Sub-questions:

- What options exist for adaptive management to ensure a sustainable shallow water snapper fishery in Bermuda?
- What knowledge do fishers possess that may be used in managing the data limited shallow water snapper fishery in Bermuda?

Chapter 2: Historical Overview and Management of the Bermuda Fishery

Bermuda is a semi-tropical archipelago comprised of seven main islands located approximately 1360 km directly below Halifax, Nova Scotia and approximately 1000 km east of North Carolina, USA (*Figure 1*). Bermuda was first discovered in 1503 by a Spanish explorer, Juan de Bermudez, first settled on by British colonists in 1609, and became a crown colony in 1684. The island is a self governing territory of England that drafted its first constitution in 1968 (Forbes, 2012). Bermuda's governmental structure resembles the British government, a parliamentary government structure with the Queen as chief of state and a head of government. The legislative branch in Bermuda is a bicameral Parliament made up of the Senate and the House of Assembly and its judicial branch is comprised of the Supreme Court, Court of Appeal and Magistrates Courts (Forbes, 2012).

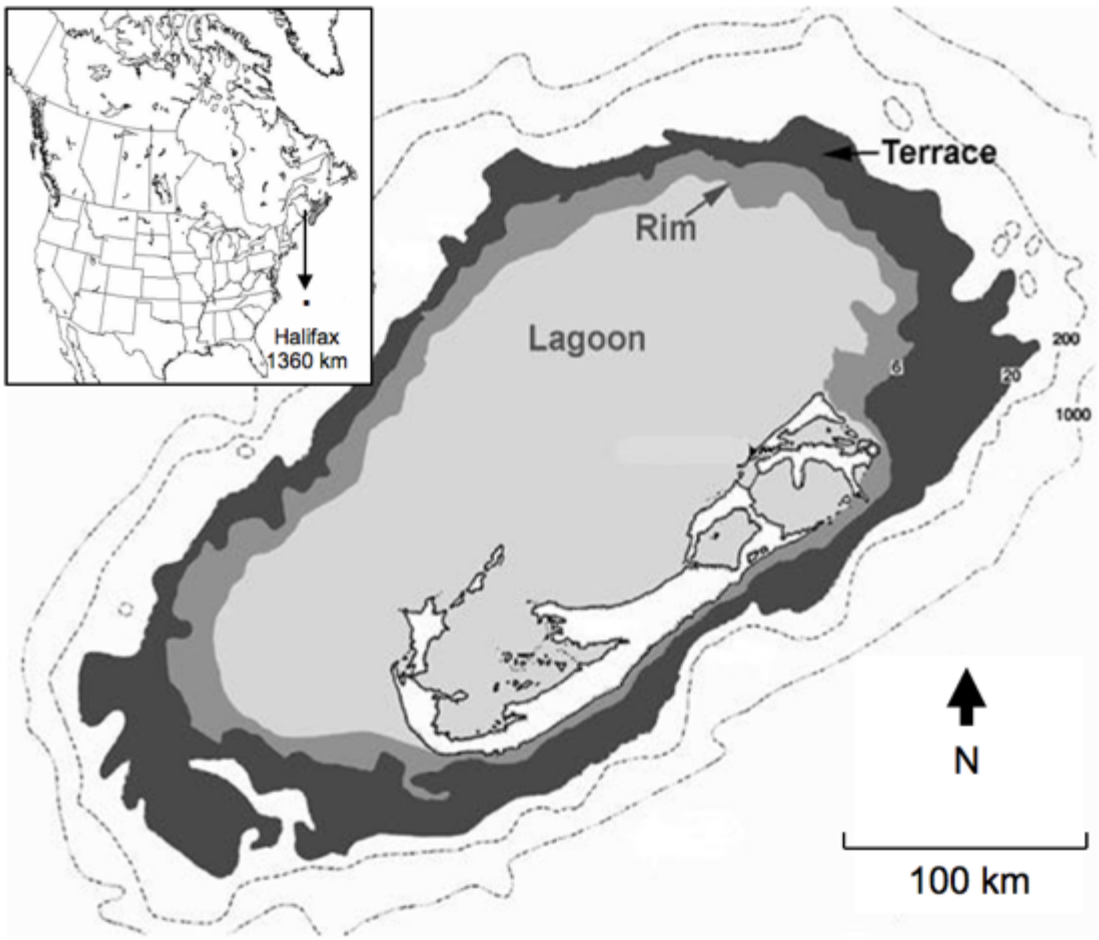

Figure 1: Map of Bermuda indicating global position and reef contour. *Modified from bermudadiving.com*

Bermuda is comprised of more than 150 islands and islets that combine to form a 34 km long island chain with an average width of 1.6 km. The island's topography is made up of low rolling hills separated by a few sea-level marshlands and very fertile flat areas where majority of the island's agriculture occurs. The highest point in Bermuda is Town Hill at only 76 m. Bermuda has no natural rivers or freshwater lakes and its main natural resource is limestone used for building. The island's subtropical climate is considered to be mild throughout most of the year, although strong winds are prevalent

throughout the winter with hurricanes occurring from June to November (Coates et al., 2013).

Bermuda lies within the Sargasso Sea with an average sea surface temperature of 23 °C, and an average salinity of 36.5 ppt. Although Bermuda lies north of the tropics, the island's warm oceanic conditions are able to support small mangrove forests, seagrass beds and extensive coral reef ecosystems (Murdoch, et al., 2008). Habitats that can be found throughout the Bermuda reef platform include: small bays and harbors, large lagoons, an extensive rim reef system, and several thousand inshore patch reef habitats (Murdoch, et al., 2008).

2.1 The Commercial Fishery

Since the first settlement in Bermuda in 1609, the island has been known for its abundant marine life. The island's population has grown to over 65,000, which far surpasses the carrying capacity for high quality living in a 21 square mile tropical island (The Goverment of Bermuda Ministry of the Environment, 2000). Just over 10 years into Bermuda's history, man had already begun to negatively impact environmental resources. Green sea turtles were the first marine resource to be protected in 1620 under a law that governed the harvesting of juvenile green turtles (The Goverment of Bermuda Ministry of the Environment, 2000). Since then, laws and regulations protecting additional species and restricting various fishing gears have been put into place.

The first governing body responsible for fisheries management was established by the Board of Trade Act 1921. In the early 1950s these responsibilities were transferred to the Ministry of Tourism formerly known as the Trade Development Board. Comprehensive fisheries regulations were passed by the Ministry in 1952, which specified minimum sizes for fish and lobster catches and established protected areas that prohibited the use of fish pots. In 1961, fisheries responsibilities were transferred to the Department of Agriculture and Fisheries. The Department of Agriculture and Fisheries instituted crucial regulations in 1963 that defined various types of fishing nets, outlined additional areas that prohibited the use of fish pots, restricted the use of spears to one nautical mile from the shoreline, banned the use of scuba or any other breathing apparatus for taking fish of any kind and instituted the requirement that all commercial fishers were required to register with the Department of Agriculture and Fisheries (The Goverment of Bermuda Ministry of the Environment, 2000). After the institution of fisher registration, fishers became more involved in the management of Bermuda's fisheries. A Commercial Fishermen's Association was created in an effort to ensure that regulations were enforced and that the islands fish and lobster stocks were sustained for future generations. In 1972, the Fisheries Act was passed and Bermuda extended its fishing jurisdiction to 12 nautical miles from the base of the territorial sea. The Fisheries Act 1972 allowed the island to have control over foreign fishing, provided the opportunity to protect selected species and areas of Bermuda's exclusive economic zone. In addition, the Act paved the way for enforcement powers, control of the importation and exportation of fish, and provided the Minister with the power to make regulations to control the fishing industry and protect Bermuda's marine resources. The first of these

regulations required commercial fishers to have a license and to report catch and effort statistics to the Department (Government of Bermuda, 1972).

There have been many issues in the past with commercial fishing vessel licensing in Bermuda. Most of these issues revolve around the fact that a fishing vessel license is a license to sell fish. Therefore, anyone has the legal right to catch fish but in order to sell fish it must be caught on a licensed fishing vessel and sold by a registered fisher (The Goverment of Bermuda Ministry of the Environment, 2000). The confusion that is created by this legality is that a registered fisher with a fishing vessel license cannot legally sell a fish that is caught off the shoreline or in an unregistered boat. There are currently 198 commercial fishing vessels and approximately 300 commercial fishers. Even with the moratorium on new fishing licenses instituted in 1984, the number of active fishing vessels varies from year to year (The Goverment of Bermuda Ministry of the Environment, 2000). The issuing of fishing vessel licenses is done so by the chairperson of the Commercial Fisheries Council on the advice of the Director of Environmental Protection and is valid for one year. Each year, fishers are required to renew their fishing vessel licenses after completion of vessel inspections and verification of catch and effort data. Additional commercial license types include: high seas fishing, charter fishing, spiny lobster, guinea chick lobster, and deep-water fishing licenses (Bermuda Fisheries Regulations, 2010).

Management of the commercial fishery in Bermuda is geared towards managing the fishers rather than fishery resources. Significant declines in landings of key reef fish

species in the early 1980s, led to the realization that Bermuda's fish stocks could be at risk of stock collapse. It was thought that the uncontrolled use of fish pots was responsible for these declines. Fisheries managers decided to try and prevent a collapse of the fish stocks by reducing the number of participants in the fishery and the number of fish pots. However, more pressure was placed on fisheries resources as fishers who were still allowed to use pots increased their fishing effort. This led to the overall ban of the use of fish pots in 1990. This effort succeeded in reducing the pressure directed toward reef fish (The Goverment of Bermuda Ministry of the Environment, 2000). Going forward, fisheries managers have taken a precautionary approach to the management of Bermuda's fisheries because the catch and effort data used to evaluate fish stocks is largely based on data from fishers, and it is recognized that this data can be reported incorrectly for a variety of reasons (The Goverment of Bermuda Ministry of the Environment, 2000).

Fisheries regulations that have been implemented for the commercial finfish fishery range from restricted areas where fishing nets are prohibited to a limitation on the number of hooks allowed on a line before requiring a special license. According to The Bermuda Fisheries Regulations (2010), bait nets are not allowed to exceed a depth of 5.5 m. In addition, these nets cannot be set within the EEZ in certain areas or for more than a period of six days from the time it was set. Recreational fishers are prohibited from the use of any fishing net other than a cast net not exceeding 2.4 m. Additionally, fishing nets can only be used to take bait fish (i.e. herring, anchovies, half beaks etc.), jacks, mackerel, Yellowtail snapper, and flying fish. Fisheries regulations prohibits the use of a

fishing line rigged with more than five hooks unless the fisher has been issued a license by the chairperson. The Bermuda Fisheries Regulations (2010) also indicates that fishers are prohibited from taking more than one of the following fish per 24-hour period: *Mycteroperca interstitialis* (Yellowmouth grouper) and *Mycteroperca bonaci* (Black grouper). In addition, fishers are prohibited from taking more than 10 *Epinephelus guttatus* (Red hind) per day between the period of May 1st and August 31st of every year (Bermuda Fisheries Regulations, 2010).

As it pertains to protected fish in the Bermuda fishery, all fishers are prohibited from taking, injuring, selling, or purchasing any protected fish. Fish that are protected with minimum size limits include: the Caribbean spiny lobster (*Panulirus argus),* at 92 mm measured from the ridge at the base of the horns to the end of the carapace (back shell); Black grouper (*Mycteroperca bonaci),* at 95 cm (FL); Yellowmouth grouper (*Mycteroperca interstitialis)* at 50 cm (FL); Red hind (*Epinephelus guttatus)* at 35 cm (FL); hogfish (*Lachnolaimus maximus*) at 45 cm (FL); the Yellowtail snapper (*Ocyurus chrysurus)* at 30 cm (FL); and the Lane snapper (*Lutjanus synagris*) at 25 cm (FL). As it pertains to the protection of large pelagic fish, The Bermuda Fisheries Regulations (2010) follow ICCAT regulations which indicate that the minimum weight for a Yellowfin tuna (*Thunnus albacares*), Bigeye tuna (*Thunnus obesus*), and Wahoo (*Acanthocybium solandri*) is 3.2 kgs. The minimum weight for Bluefin tuna (*Thunnus thynnus*) is 30 kgs while the minimum weights for Swordfish (*Xiphias gladius*), Blue marlin (*Makaira nigricans*), and White marlin (*Tetrapturus albidus*) are 25, 114, and 23 kgs respectively (Bermuda Fisheries Regulations, 2010).

2.2 The Non-Commercial/ Recreational Fishery

Recreational fishing in Bermuda has always been a popular pastime. It serves as a means of subsistence in many households and has an incredible socio-cultural value. Recreational fishing includes hand-line or rod and reel fishing from the shoreline or a vessel, lobster diving, cast netting, spear fishing, collecting ornamentals, and sport fishing. Historically, fisheries management in Bermuda has failed to account for the impact the recreational fishery may have had on fish stocks. Instead, most fisheries management efforts have been targeted toward reducing the impact of commercial fishers by limiting the number of fishing vessel licenses allowed in the commercial fishing industry. Recreational fishers, with the exception of lobster divers and spear fishers are not required to submit catch and effort data. Therefore, data on the recreational fishery is extremely limited. The only data on recreational fishing conducted on the reef platform comes from an economic evaluation study on Bermuda's reefs by The Department of Conservation Services in 2008 and a survey conducted in 2011 by the Department of Environmental Protection. These studies revealed that recreational fishing in Bermuda is conducted primarily for leisure and social reasons rather than for food. In addition, the 2008 survey revealed that up to 16,000 people in Bermuda fish recreationally with annual landings approximately equaling two-thirds of the annual commercial fishery landings (Bermuda Department of Environmental Protection, 2011). The survey completed in 2011 disclosed that shoreline fishers were more active than boat owners; however, boat owners caught twice as many fish on average. The survey also suggested that recreational landings are equal to 82% of commercial landings (Bermuda Department of

Environmental Protection, 2011). These studies reveal that the recreational fishery potentially has a tremendous impact on Bermuda's marine resources.

Though considered recreational fisheries, lobster diving and spearfishing require licenses that are issued by the Director of Environmental Protection. Licensed spear fishers and lobster divers are required to submit reports of catch and effort statistics and the license is subject for renewal every year on August 31st. Spearfishing is prohibited within one nautical mile of the shoreline. In addition, there is a limit of two fish per day of one species using a spear. Lobster divers are limited to two lobsters in a 24-hour period and can only take the Caribbean spiny lobster between September 1st and March 31st of every year (Bermuda Fisheries Regulations, 2010).

Recreational hook and line fishers are subjected to the same minimum fish sizes and bag limits as commercial fishers with the exception of the Lane snapper (*Lutjanus synagris*), where they are only permitted to take up to 30 fish per day by either land or fishing vessel (Bermuda Fisheries Regulations, 2010).

Chapter 3: Bermuda's Shallow Water Snapper Species

3.1 History and Overview

Bermuda's native fish fauna is less diverse than in other locations throughout the Northwestern region of the Atlantic. Locke et al. (2013) indicates that Bermuda's fish species are thought to have derived from Bahamas, Florida Keys, and the Carolinian Bight (the area of the US east coast included in the Warm Temperate Northwest Atlantic

province). Bermuda shares 238 common species with the Carolinian Bight, 245 species with Florida Keys and 253 species with the Bahamas (Smith-Vaniz, Collette and Luckhurst, 1999). There are approximately 430 described species of fish native to Bermuda. Of these, 362 species from 79 families are known to have significant interactions with coral reefs and similar habitat types shallower than 200m (Locke, et al., 2013).

Historically, snapper species have been an important food source to many Bermudian households. In the 1950s, it was estimated that snappers constituted approximately 20% of total fish food landings (Luckhurst, 1996). By the time mandatory catch and effort data reporting for commercial fishers was instituted in 1975, snapper species only made up approximately 9.8% of total fish food landings. Species catch composition had continued to change due to a variety of environmental conditions and various changes in fisheries regulations. However, between 1975 and 1992 snapper landings were relatively stable ranging from 25,000 to 70,000 kgs.

There are a variety of snapper species that are found and caught in Bermuda. These include the shallow water snappers: Yellowtail snapper (*Ocyurus chrysurus*), Grey snapper (*Lutjanus griseus*), Lane snapper (*Lutjanus synagris*) and other snapper species found in deeper water such as: the Red snapper (*Lutjanus vivanus*), Vermillion snapper (*Rhomboplites aurorubens*), Queen snapper (*Etelis oculatus*) and the Wenchman snapper (*Pristipomoides macrophthalmus*) (Luckhurst, 1996). Of these snapper species, the most

heavily targeted and commercially landed species since 1975 are the shallow water snappers: Grey, Lane and Yellowtail snappers (*Figure 2*).

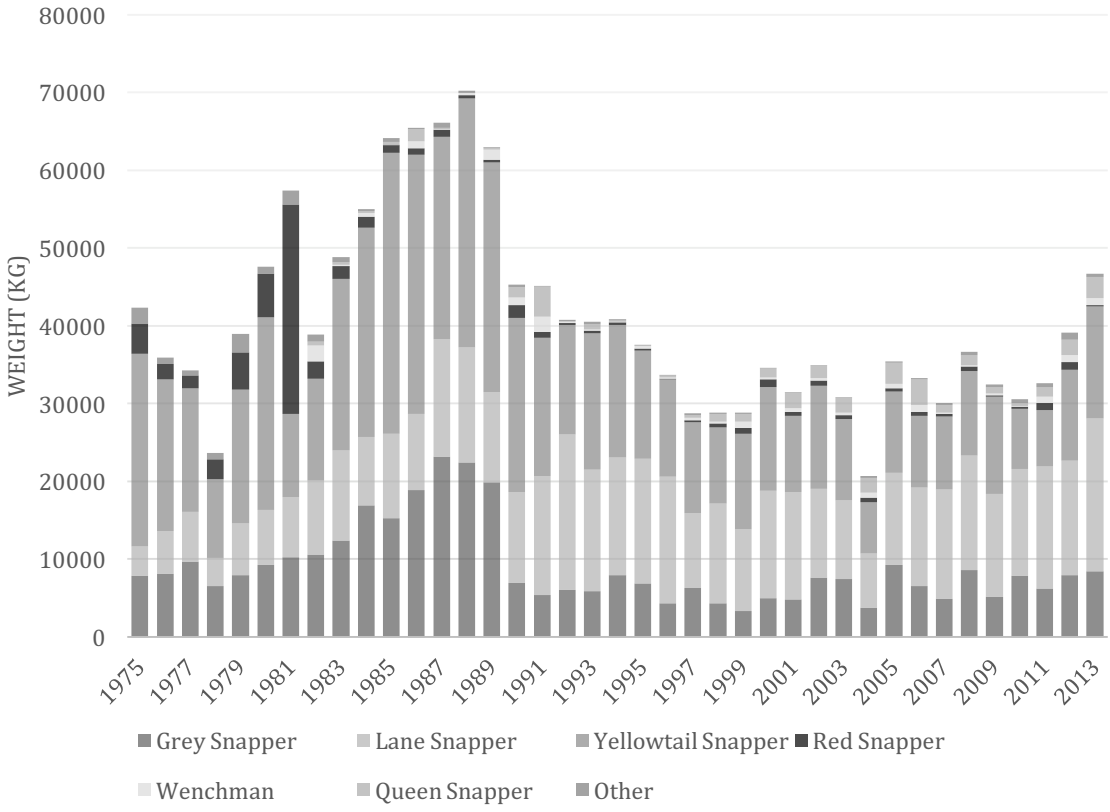

Figure 2: Bermuda Snapper Species Commercial Catch History Years: 1975-2013. *Shallow water snappers illustrated in dark grey (Grey snapper), light grey (Lane snapper) and grey (Yellowtail snapper) have dominated total commercial landings between the years 1975 to 2013.*

The Yellowtail snapper has had the greatest volume of catch of the snapper species landed in Bermuda and comprised approximately 50% of all snapper landings between 1975 and 1992 (Luckhurst, 1996). With the fish pot ban in 1990, Yellowtail snapper and Grey snapper landings took a dramatic decline while Lane snapper landings remained relatively stable throughout the years (*Figure 3*). Figure 3 also illustrates that from 2011 to 2013, the landings of all three shallow water snapper species have shown a gradual increase.

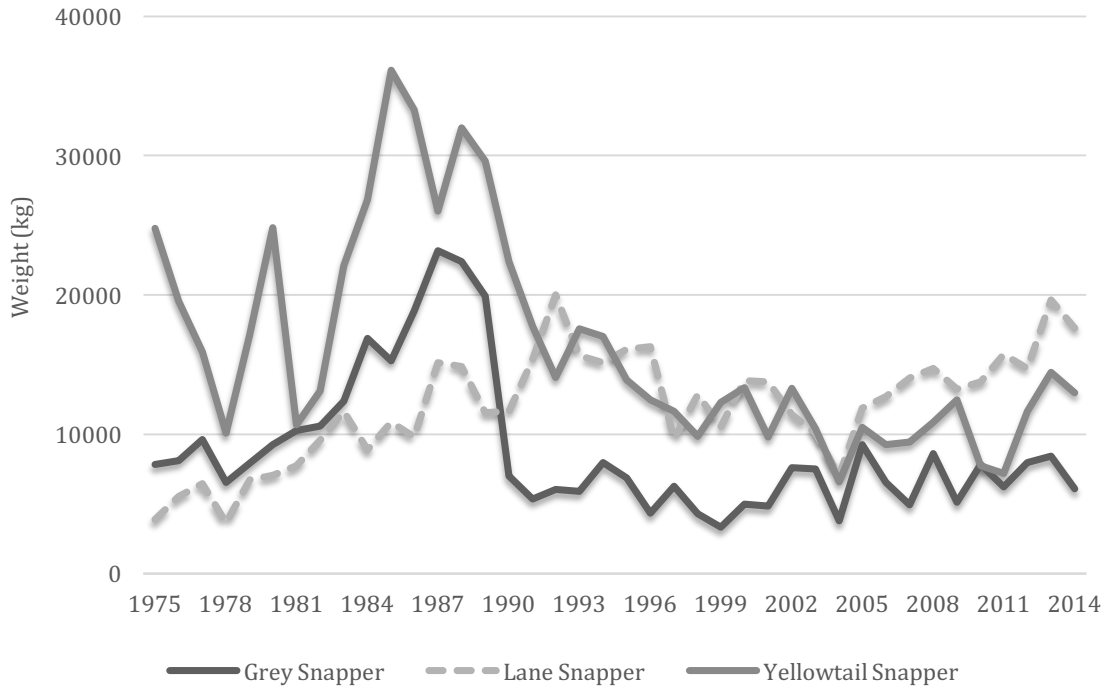

Figure 3: Reported Shallow Water Snapper Landings of Commercial Fishers Years: 1975-2014. *Shallow water snappers are the most commercially important snappers in Bermuda. Yellowtail snappers have dominated commercial landings since 1975 however, Yellowtail and Grey snapper landings took a dramatic decline with the fish pot ban in 1990.*

The landings of these commercially important snapper species have had varying responses to changes in gear type. Fish pots were proportionally the greatest contributor to Yellowtail snapper landings peaking between 1984 and 1987. Within the first five years after the fish pot ban, Yellowtail snapper landings were reduced by 50%, proving that the fish pot ban had a detrimental effect on the fishery. Grey snapper landings relied heavily on fish pots with 83-90% of total landings using fish pots as the primary gear type prior to 1990 (Luckhurst,1996). Since the fish pot ban, neither Grey snapper nor Yellowtail snapper landings have been able to reach the landings reported in the late 1980s with Grey snapper landings only reaching 32% of pre pot ban landings.

Conversely, hand line fishing has been the dominant gear type used to catch Lane snappers. The fish pot ban of 1990 did not seem to have a negative effect on landings of this species. Contrarily, Lane snapper landings seemed to increase by 32% before and after the fish pot ban. Increased landings after the pot ban is likely due to an increase in hook and line fishing effort particularly at night as effort was displaced from pot fishing (Luckhurst,1996).

3.2 Lane Snapper- *Lutjanus synagris*

The Lane snapper (*Lutjanus synagris*) is a very important species caught throughout most of the Caribbean. Lane snappers can be found in a variety of habitats including coral reefs, rocky bottoms and muddy brackish water (Luckhurst, Dean, & Reichert, 2000). Lane snappers are distributed throughout sub-tropical waters ranging from Bermuda, the most northern point of its range, down to southern Brazil. Lane snappers have been extensively studied in many regions including: Brazil, Cuba, Jamaica, United States, Trinidad, Puerto Rico and Mexico. In Bermuda, however, the only studies conducted on Lane snappers were a tagging study in 1958, which looked at Lane snapper feeding and movement patterns (Bardach, Smith, & Menzel, 1958), and a 2000 study assessing the age, growth and reproduction of Lane snappers (Luckhurst et al., 2000).

In Bermuda, Lane snappers are a very important species both commercially and recreationally. Lane snappers, commonly known as Whitewater snappers or Silk snappers in Bermuda, have been consistently caught in the commercial fishery since 1975 (*Figure 3*). In addition, they are a seasonal species that are heavily targeted throughout the

summer months and primarily caught with a hand line or rod and reel. Of the three shallow water snapper species, Lane snappers have been the most studied and assessed in Bermuda.

Bermuda's position, at the northern limit of these species' ranges, leads many scientists believe that temperature has a significant effect on size distribution and growth rates there. Luckhurst et al. (2000) determined that Lane snappers in catches in Bermuda ranged from less than 23 cm fork length (FL) to 38 cm FL with an average of 28 cm FL for the years 1993 to 1996. Luckhurst et. al (2000) also concluded that with the recorded size of Lane snappers in the population, fishing mortality had not reached a level that would affect the size of the fish. In other areas such as Cuba where Lane snappers were considered to be heavily exploited, fish sizes were significantly smaller. Although thought to be a gonochoristic species, Luckhurst et al. (2000) found that males dominated the larger size classes of greater than 33 cm FL. Through analyzing otoliths from Lane snappers caught by hand line, Luckhurst et al. (2000) discovered a maximum age of 19 years. This recorded age far exceeds the age recorded from other Caribbean locations with the previous maximum age being 10 years old in Cuba. The colder temperatures during the winter months in Bermuda are thought to slow down growth rates and produce longer lived fish (Luckhurst et al., 2000). Both the large size and the longevity of this species suggests that, up until 2000, the exploitation rate on Lane snappers was fairly light. With regard to reproductive activity, Lane snappers are summer spawners, with peak spawning occurring from June until August of each year. According to Luckhurst et al. (2000), Lane snappers begin spawning at the end of May and continue until early September with peak spawning occurring from June until August of each year. The warm

summer temperatures in Bermuda, which range from 22 to 28°C, seem to be the spawning cue for this shallow water snapper species. In areas throughout the Caribbean, Lane snappers are known to spawn for six months or more from March until September (Luckhurst et al., 2000).

3.3 Grey Snapper- *Lutjanus griseus*

Grey snappers are a tropical and subtropical species that has a wide distribution ranging as far north as Massachusetts and throughout the western Atlantic from Florida to Brazil including Bermuda, the Caribbean and the Gulf of Mexico (Burton, 2000). Grey snappers occupy a number of different habitat types from inshore grass meadows, mangrove habitats, coral reefs, estuaries and lagoons to deep channels and offshore reefs at depths ranging from 30-60 m (Starck & Schroeder, 1971). Adult Grey snappers are often found offshore at deeper depths than the juveniles, which prefer mangroves and grassy flats. Adult Grey snappers are also found around wharves, ledges of beach rock and isolated patches of offshore coral (Starck & Schroeder, 1971).

Currently, there have been no scientific assessments of Grey snappers (*Lutjanus griseus*) in Bermuda's waters. The only data on this shallow water snapper species in Bermuda is the data recorded from commercial fishers since 1975 (*Figure 3*). Grey snappers, also known as mangrove snappers have been caught using a variety of fishing gears in the past; however, they are now only caught commercially by hand line and recreationally using both hand line and spearfishing. Since the fish pot ban, commercial

landings have been reduced significantly. In the last 5 years, Grey snapper landings have remained relatively consistent at approximately 9,000 kgs per year (*Figure 3*).

Spawning areas for Grey snappers are thought to be offshore with eggs and larvae traveling to inshore shallow sea grass, mangrove and other nursery habitats via strong currents. These snappers move offshore between ages 3-4 according to studies on Grey snapper populations in Florida (Burton, 2000). Burton's (2000) study revealed that size-at-age for Grey snappers vary from 13 cm at age one, 23 cm at age two, 51 cm at age 15, and 74 cm at age 24. The oldest Grey snapper measured in the study between 1994-1997 was 24 years old with a total length of approximately 76 cm (Burton, 2000). Other scientists have found that Grey snappers reach sexual maturity at 2 years of age with a total length of approximately 30 cm; males mature at slightly smaller sizes than females (Starck & Schroeder, 1971). In the US, Grey snappers have been found to spawn from April until November in offshore groups peaking in the summer throughout July and August. The lunar cycle has a great influence on spawning activity. It has been documented that during tides surrounding the full moon Grey snappers spawn in large aggregations (Starck & Schroeder, 1971). According to Starck & Schroeder (1971), Grey snappers are considered euryphagic organisms as they have a very broad diet. Grey snapper larvae have been known to feed on various species of zooplankton while juveniles feed on crustaceans, fishes, molluscs and polychaete worms. As adults, Grey snappers are nocturnal predators that feed on cephalopods, gastropods, small fish, shrimp and crabs (Starck & Schroeder, 1971).

3.4 Yellow Tail Snapper- *Ocyurus chrysurus*

Yellowtail snappers (*Ocyurus chrysurus*) have the highest recorded commercial landings of all the snapper species in Bermuda. In 1985 alone, the total landings for Yellowtail snappers was over 36,100 kgs (*Figure 3*). Yellowtail snappers are reported from Massachusetts to southeastern Brazil which includes Bermuda, Bahamas and the Caribbean region (McClellan & Cummings, 1998). This snapper species is often found throughout coastal waters and coral reefs at a wide range of depths down to 180 m. Yellowtail snappers prefer rocky irregular bottom types including wrecks, the edges of banks and artificial reef structures (McClellan & Cummings, 1998). Like Grey snappers, Yellowtail snappers can also be considered euryphagic organisms with their diverse diets. As adults feeding predominantly at night, these snappers have been known to prey on small fishes, crustaceans, worms, gastropods and cephalopods (McClellan & Cummings, 1998). Historically, Yellowtails were caught in commercial fisheries using a variety of gear types including: hook and line, long lines, fish traps, trawls, trammel and gill nets, beach seine, dive gear, and electric and hydraulic rigs.

Yellowtails are external fertilizers that spawn year round in many regions. They reach sexual maturity at approximately 20 to 33 cm which corresponds to an age of one to two years. Spawning and reproductive cycles in Yellowtail snappers coincide with spring tides at the new and full moon. These snappers spawn in open waters over coral reefs, banks or shelves. In Jamaica and Florida Yellowtails spawn year round; however, they peak from April to August and August to October. Spawning in other regions is more restricted. In Cuba, Yellowtail snappers spawn anywhere between March and September and in the Gulf of Mexico during the spring and summer months. In addition,

large spawning aggregations have been observed in Florida throughout the summer months as spawning peaks between April and August (McClellan & Cummings, 1998). The reported maximum age of Yellowtail snappers from the southeastern US is 14 to 16 years old, in the Virgin Islands maximum age is 17 years old and 5 to 8 years old in Cuba with the maximum size of Yellowtail snappers being approximately 56-76 cm (FL) (McClellan & Cummings, 1998).

Chapter 4: Current Management Measures

4.1 Shallow Water Snapper Management Plan in Bermuda

Bermuda currently has a limited management plan for shallow water snapper species however, there is no generalized management plan for all shallow water reef fish. Regulations pertaining to shallow water snapper species only include minimum size limits for Yellowtail snappers and minimum size limits and a recreational 30 fish per day bag limit for Lane snappers. However, many reef fish, including snapper species, are indirectly protected by marine protected areas (MPAs) (*Figure 4*) where fishing is prohibited; such areas were originally designed to protect heavily targeted species such as grunts, groupers and hinds. Additionally, shallow water snapper species have fishing gear limitations where they are only fished commercially using hand lines or rod and reel and recreationally using hand lines as well as spear.

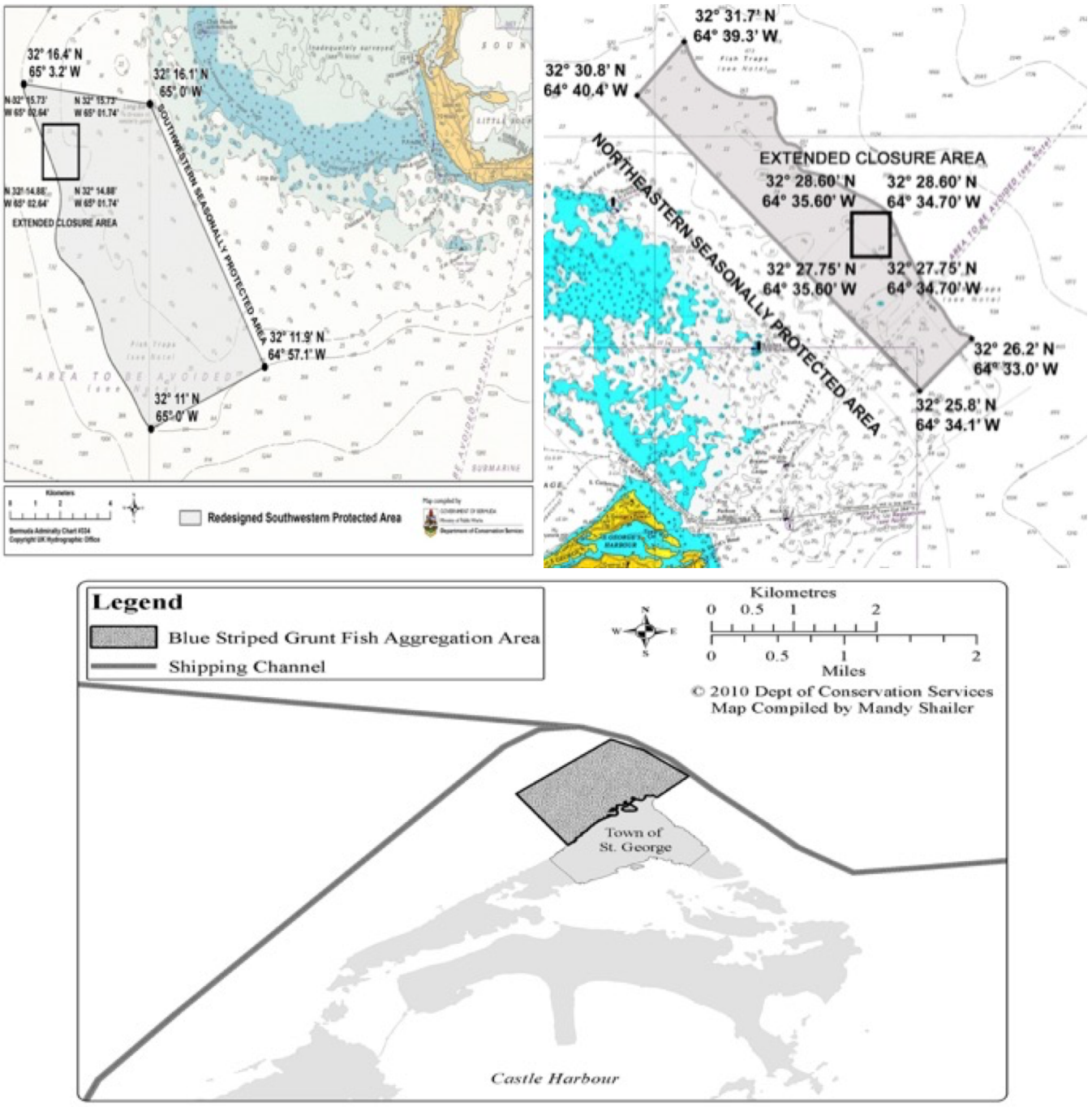

***Figure 4*: Seasonal Closure Areas on the Bermuda reef platform.** *Fishing of any kind is prohibited in the seasonally protected areas from May 1st until August 31st every year and the Blue Striped Grunt Aggregation areas in May and June of each year. ©Department of Conservation Services*

4.2 Shallow Water Snapper Management Plan in Similar Small Scale Fisheries

Many small island nations have opted out of developing single species management plans. As an alternative, more marine managers are choosing to manage fisheries with the entire ecosystem and therefore many linked species as the management target. Effective management measures in these and many other fisheries are put in place to prevent the overexploitation of fisheries resources, to aid in rebuilding depleted resources and to ensure that resources are sustainably used in the present and preserved for future generations (Pikitch, et al., 2004).

Barbados is a Caribbean island with a similar country profile and similar fisheries resources as Bermuda. Barbados Fisheries Division, under the Ministry of Agriculture and Rural Development, developed a 2004-2006 fisheries management plan (FMP) that is still being utilized today. The Barbadian fishery is an open access fishery where fisheries resources have not been effectively managed in the past. The vision of fisheries management in Barbados is to move away from the government dictated management of resources. Instead, fisheries stakeholders hope that fisheries management will be more of a collaborative effort where all stakeholders in the fishing industry will share the responsibility of managing resources. The Barbados FMP outlines various strategies used to manage the fishing industry and ensure social, economic and environmental sustainability (Barbados Fisheries Division, 2004).

The Barbados FMP groups species together based on similar life cycles, habitats, and fishing gear used to capture each species. Snapper species are grouped along with

groupers and small tunas and are referred to as the Deep-slope and Bank reef fishes. Currently, this fishery is believed to be overfished as fishers have reported reduced catch per unit effort and fish size. In addition, the Barbados Fisheries Division (2004) identifies that the fishery lacks accurate catch and effort data and has limited access to data from comparable reef fisheries in other areas. Additional concerns in this fishery include the negative affects of habitat degradation and overfishing which have led to reduced fish populations in some areas as well as user and use conflicts between tourism related activities and recreational users. Current management measures in place to mitigate various issues in the Deep-slope and Bank reef fisheries include: minimum sizes, regulations to reduce ghost fishing for fish traps, prohibiting the use of entangling nets, seasonal closure areas for species and fishing methods, and no-take marine reserves. Additional management measures Barbados plans to utilize are: increased minimum mesh sizes for fish traps, a permit system for the use of spear guns, reducing the depth range and effort of spearfish harvesters by prohibiting the use of SCUBA for spear fishing, and managing the coastal area with an integrated coastal zone management approach (Barbados Fisheries Division, 2004). The Barbados Fisheries Division recognizes that the success of their management plan requires co-management and the cooperation of all fisheries stakeholders to manage the complex issues surrounding this fishery.

Chapter 5: Methodology

This research was designed to determine how Bermuda's snapper fishery can be more efficiently managed. Firstly, desktop research was conducted to determine life history and biological data of the three shallow water snapper species: *Lutjanus synagris* (Lane snapper), *Lutjanus griseus* (Grey Snapper), and *Ocyurus chrysurus* (Yellowtail Snapper). In addition, with the help of the Bermuda Environmental Protection, 24 (5 recreational fishers and 19 commercial fishers) fishers were selected for interviews. Using a stratified targeted approach, fishers were selected by the researcher from the fishery database at the Department of Environmental Protection. Fishers that had recorded catching any of the shallow water snapper species were then chosen at random from a catch frequency matrix developed by the researcher. The catch frequency matrix categorized fishers into sub-categories that allowed the researcher to identify catch frequency and catch effort of fishers. The interviews conducted were qualitatively analyzed and aided in determining catch history, landings records and other relevant information regarding fisheries management in Bermuda.

5.1 Fisher Identification, Classification and Recruitment

All fishers were recruited to participate in the fisher's knowledge interviews via telephone communication. Because recreational fishers are not required to have licenses, a formal recruitment method was not used. Recreational fishers were identified via word of mouth and recommendations from other fishers. Commercial interview participants were recruited using a stratified targeted approach. Commercial fishers were selected from the fishery database for the years 2010-2014 at the Department of Environmental

Protection. Fishers that had recorded catching any of the shallow water snapper species were placed into a catch frequency matrix developed by the researcher. The catch frequency matrix was used to categorize fishers into sub-categories that assisted the researcher in identifying catch patterns based on catch frequency, total catches and fishing effort of fishers for shallow water snappers. An initial qualifying score number was used to determine catch patterns of each commercial fisher (see *Table 1*). Each fisher was scored based on whether the fisher took frequent trips throughout the year catching a few fish of one species, took frequent trips throughout the year and landed many fish of one species, went on few trips throughout the year and landed many fish of one species, or took few trips throughout the year only catching a few fish of one species. For the purpose of this matrix, 'frequent trips' were considered to be more than 10 trips in a year with 'few trips' being less than 10 trips in a fishing year. For Yellowtail and Grey snappers, a 'few fish' was considered to be approximately 10 fish in a trip; while a 'few fish' for Lane snappers was recorded when there were less than 25 fish landed per trip. A recording of 'more than a few fish' was given when greater than 25 Lane snappers were landed in a trip and when 20 or more Yellowtail or Grey snappers were landed in a single trip.

Table 1: Commercial Fisher Scoring Used to Identify Catch Patterns.

Score Number	Score Identification
0	Landing less than 5 fish of a species
0.5	Landing 5-20 fish of a species
1	Landing a few fish in a few trips

1.5	Landing a few fish taking 5-10 trips
2	Landing a few fish and taking a moderate amount of trips (>10)
2.5	Trips have both large and small catches taking a moderate amount of trips (>10)
3	Landing more than a few fish in <5 trips
3.5	Landing more than a few fish in 5-10 trips
4	Landing more than a few fish in >10 trips

Commercial fishers were further categorized based on whether they frequently targeted all three shallow water snapper species, if they frequently targeted two species or if they only targeted a single species. The scores used to identify catch patterns for each commercial fisher were then summed together for the five-year period (2010-2014) according to each of the three snapper species and given an overall categorized scoring (*Table 2*). This process produced an overall score number assigned to each fisher. Fishers with total scores below 7 were eliminated from the potential participant list because it can be assumed that their history of landing snappers in the last five years was more of an incidental catch rather than specifically targeting snapper species.

Table 2: Overall Categorized Commercial Fisher Ranking.

Overall Categorized Scoring Number	Scoring Description
High	Total scoring number > 15
Medium	Total scoring number 10.5-14.5

Low	Total scoring number 7-10
Not Targeted	Total scoring number < 7

The final recruitment list was narrowed down to 50 fishers by randomly selecting fishers that fell into each score category with focus being placed on fishers that were given initial scores higher than 2 (landing few fish and taking a moderate amount of trips) and overall scorings in the low to high category. It can be assumed that fishers outside of these categories do not specifically target shallow water snappers and would not have the experience to adequately contribute to the interview results.

5.2 Interview Process

Interviews were conducted with two fisher groups, commercial fishers and recreational fishers, that have had experience fishing for shallow water snappers in Bermuda. There were 19 commercial fisher interviews and 5 recreational fisher interviews conducted during the summer of 2015 throughout the island of Bermuda. Commercial fishers' experience ranged from only 4 years as a primary operator to over fifty years. However, of the nineteen commercial fishers interviewed over half of them indicated that they have been fishing all of their lives. Recreational fishers' experience ranged from twenty-three years to over forty years of fishing activities. Of the twenty-four interviews conducted, twenty-three fishers were male and only one fisher was female. Each interview was conducted at the fisher's residence, fishing dock or at a neutral location chosen by the interview participant.

5.3 Commercial Fisher Database Analysis

The Department of Environmental Protection's Fisheries Database revealed a fair amount about Bermuda's shallow water snapper fishery. Majority of the shallow water snapper fishing in Bermuda is conducted throughout the summer months. This seasonality is related to an overall increase in effort in the summer months as well as fishing effort switching to other fisheries as shallow water snapper catches decline. This timing also corresponds to previous research (Luckhurst et al., 2000; Burton, 2000, Starck & Schroeder, 1971) on shallow water snapper species, their spawning activities and the time of the year they are fished. Between 2010 and 2014 landings peaked in June and July with improved landings totals beginning in May and lasting until October of each year (*Figure 5*). On average, approximately 90% of yearly landings for each species occur between May and October. Snapper landings were seen to increase each year from 2010 through 2013 however, a slight decline is seen in 2014. The cause of the decline in snapper landings has not been determined however, this decrease in landing totals can be attributed to a presumed decrease in fishing effort due to natural causes such as high winds and inclement weather throughout the summer of 2014, followed by two consecutive hurricanes in October of 2014.

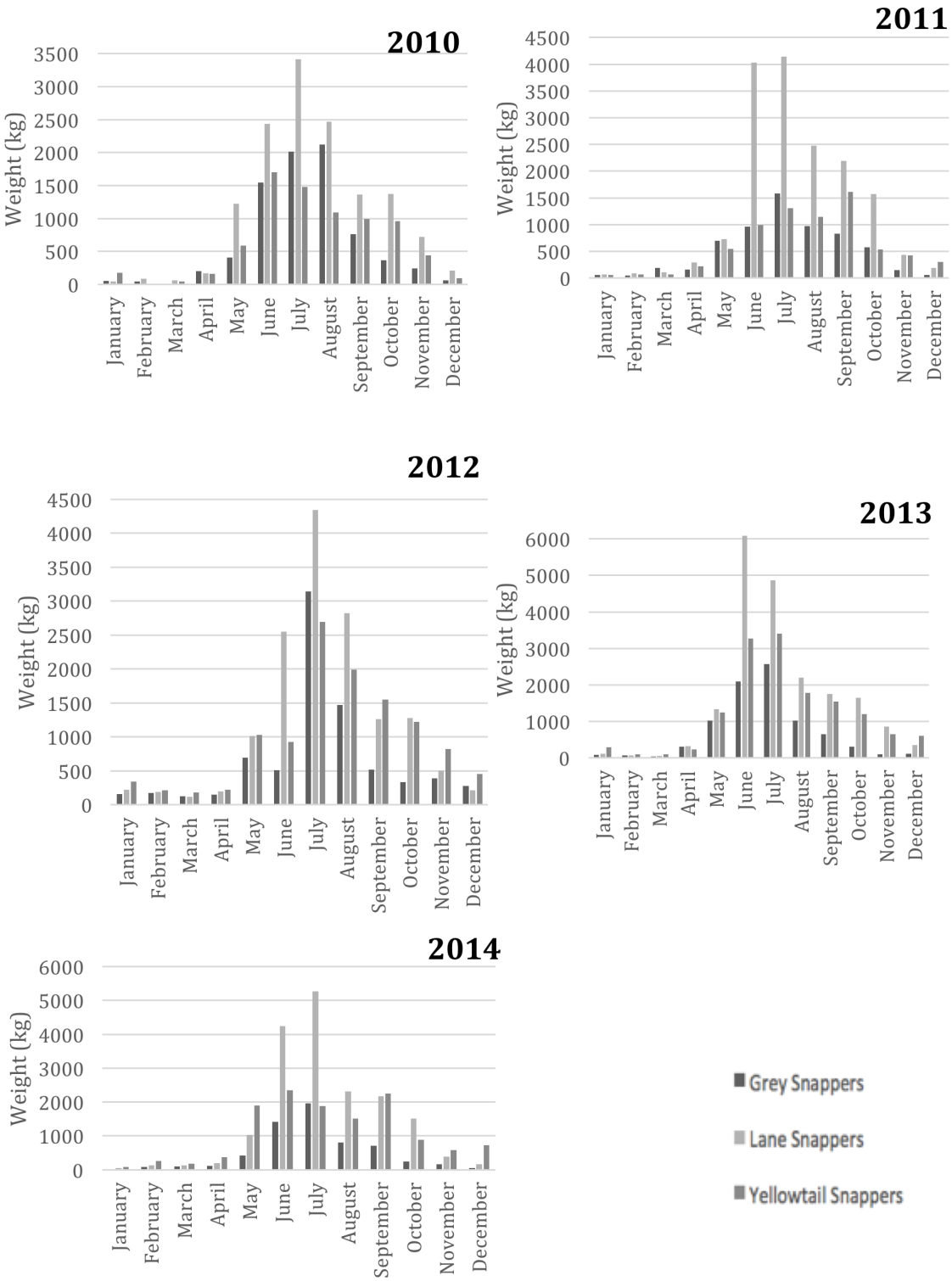

Figure 5: Commercial Fisher Monthly Landing Weights (kg) for 2010-2014.

5.4 Interview Data Analysis and Results

Interview data was analyzed using a deductive approach to qualitative analysis. This approach incorporates both a descriptive form of content analysis which determines what the data are and an interpretive form of content analysis that aids in determining what is meant by the data (Elo & Kyngas, 2008). In addition, a narrative analysis was conducted to transcribe various experiences of fishers outlined throughout the interview process.

- **Fisher Knowledge**

Throughout the interview process, the knowledge variances between commercial and recreational fishers became apparent. Recreational fishers were observed to have less knowledge about several aspects of fishing industry. This knowledge difference is likely due to the time spent fishing and gaining knowledge about the fishery as recreational fishing is a leisure activity rather than a fulltime occupation. Commercial fishers spend an average of approximately 10 hours fishing each day during the fishing season and are required to record a minimum of 800 hours at sea (100 days) to renew their license the following season. While recreational fishers spend most of their time fishing on weekends and holidays for an average of 9.3 hours per day.

- **Target Species and Gear Type**

Although Lane snapper commercial landings have exceeded both Grey and Yellowtail snapper landings in the last five years, fishers have indicated that more effort is placed on targeting Yellowtail snappers. Of the 19 commercial fishers interviewed, 18

indicated that they targeted Yellowtail snappers while only 15 and 12 fishers indicated that they targeted Grey and Lane snappers respectively. A theme that emerged for why some fishers preferred targeting Grey and Yellowtail snappers over Lane snappers is the low income associated with Lane snapper fishing combined with the extraordinary effort and resources needed to invest in Lane snapper fishing. Recreational fishers portrayed a more generalized view to snapper fishing where many of them indicated that they had no fishing strategy simply, "whatever bites the hook" as stated by a few fishers. While commercial fishers are restricted to traditional hook and line fishing for shallow water snapper species, recreational fishers use traditional hook and line fishing for 79% of their fishing activities and spears for 21% of their time spent fishing for shallow water snappers. The results of Pitt & Trott's (2013) survey revealed similar statistics for recreational fishers using hook and line (78%) while only 5% had used a spear; the other 17% of fishers used cast nets. The dramatic difference in the use of spears for fishing activity can be attributed to the low sample size of recreational fishers (five) for this project.

- **Fishing Quality**

Commercial and Recreational fishers identified the quality of fishing and species availability throughout the year for each of the shallow water snapper species. The number of fishers that identified the quality of fishing during each month of the year was recorded. For commercial fishers, (*Table* 3) a rating of 'good' was given when more than 10 fishers identified the quality of fishing as good for a particular species in a month. A rating of 'fair' was recorded when 5-9 fishers identified fishing quality as good for a

particular species in a month. If 6 or more fishers identified a poor quality of fishing in the same month a rating of 'poor' was given. For recreational fishers (*Table 4*), a rating of 'good' was given if 3 to 5 fishers identified fishing quality as good for a species in a month. A rating of 'fair' was given when 2 fishers identified the quality of fishing as good for a species in a month. And a rating of 'poor' was recorded if 3 or more fishers identified the quality of fishing as poor for a species in a month.

Table 3: Annual Fishing Quality and Species Availability for Commercial Fishers

Species	J	F	M	A	M	J	J	A	S	O	N	D
Lane Snapper	🔴	🔴	🔴	🟡	🟡	🟢	🟢	🟢	🟢	🟡	🔴	🔴
Grey Snapper	🔴	🔴	🟡	🟡	🟡	🟢	🟢	🟢	🟢	🟡	🔴	🔴
Yellowtail Snapper	🔴	🔴	🔴	🟡	🟢	🟢	🟢	🟢	🟢	🟡	🔴	🔴

Legend
🟢 -Good 🟡 -Fair 🔴 -Poor

Table 4: Annual Fishing Quality and Species Availability for Recreational Fishers

Species	J	F	M	A	M	J	J	A	S	O	N	D
Lane Snapper	🔴	🔴	🔴	🔴	🟡	🟢	🟢	🟢	🟢	🟡	🔴	🔴
Grey Snapper	🔴	🔴	🔴	🟡	🟡	🟢	🟢	🟢	🟢	🟢	🔴	🔴
Yellowtail Snapper	🔴	🔴	🔴	🔴	🟡	🟢	🟢	🟢	🟢	🟡	🔴	🔴

Legend
🟢 -Good 🟡 -Fair 🔴 -Poor

❖ Total Catch

Commercial fishers identified approximately how many units of catch they land of each species per fishing day. On average, 43 kgs of Lane snappers, 47 kgs of Grey snappers and 34 kgs of Yellowtail snappers are caught each day. While 80% of recreational fishers did not choose to go on record indicating that they go over the thirty fish bag limit for Lane snappers, one recreational fisher indicated that they catch up to 150 Lane snappers in a fishing day. Thus, four of the five recreational fishers interviewed revealed that bag limits have an effect on almost every trip that is taken. Recreationally, Grey and Yellowtail snappers are caught infrequently when compared to Lane snappers with fishers catching an average of only four fish of each species per trip.

❖ Undersized Fish

Fourteen of the nineteen interviewed commercial fishers indicated that they encounter undersized fish that have to be thrown back every trip. In addition, most of the undersized fish caught are Lane snappers. Five commercial fishers revealed that undersized Yellowtail snappers are only found inshore; while in deeper offshore waters they average 2.5-4 kgs with a more distinct color pattern. Eighty percent of recreational fishers indicated that they encountered undersized fish that had to be released. One fisher stated that "small fish breed and the larger fish don't that is why they are protected". However, the majority of the minimum size limits are instituted allow fish to reach reproductive maturity before recruiting to the fishery and hopefully allowing it contribute to the next generation (Luckhurst et al., 2000; Burton, 2000, Starck & Schroeder, 1971).

- **Seasonal Effects**

Commercial fishers introduced another theme throughout the interview process involving temperature and the timing of spawning events. Fishers believe that temperature is a spawning cue. In addition, temperature also triggers shallow water snapper movement and feeding regimes. Commercial fishers state that snappers are more active in temperatures between 22-24 degrees Celsius, with one fisher stating "as the water cools their metabolism slows down and they don't feed as much".

- **Lunar Periodicity**

An emerging theme throughout commercial fisher interviews was the confirmation that shallow water snapper fishing is a nighttime fishery that is highly dependent on lunar activity (McClellan & Cummings, 1998). Fourteen of the nineteen commercial fishers interviewed indicated that they take overnight fishing trips throughout the fishing season. In addition, eighteen fishers identified that snappers bite better around the full moon throughout the summer months. The moon is significant because it is the source of tidal changes. Scientifically, this is known as lunar periodicity which is known to have an effect on spawning cycles for many organisms (Cordell, 1974). Two fishers stated that snappers breed and eggs hatch within twenty-four hours of the full and new moon. Recreational fishers were also aware of the moons significance in snapper fishing however, they were not able to provide as much detail when compared to commercial fishers.

❖ Changes in the Snapper Fishery

Commercial and recreational fishers explain that both negative and positive changes have occurred in the snapper fishery in Bermuda. The most notable positive change was the ban of fish pots. According to one commercial fisher, the fish pot ban has helped to increase the amount of snappers found inshore. They stated, "when I first got into the industry over 35 years ago, I would only fish offshore because there wasn't much inshore; but, the fishery seems to be coming back, the numbers are up". The most common negative theme among both commercial and recreational fishers was that the populations of snappers are diminishing, especially the Lane snapper. Many fishers recall catching considerably more Lane snappers in a trip than they currently do. One fisher stated, "they (lane snappers) used to be like piranhas behind the boat, I could catch 400-500 fish in one night". Though fishers seem to have dramatically opposing views, indicating that numbers are up and diminishing at the same time, catch data on Lane snappers suggests that they have been caught in greater numbers in the past five years than before (*Figure 3*).

❖ Frequented Fishing Areas

Commercial fishers were able to identify frequented fishing areas for catching shallow water snapper species around the Bermuda platform (*Figures 6-8*). In addition to the areas located on each heat map fishers indicated that they frequently fish two very popular offshore sites that are beyond the scope of the map, Argus and Challenger Banks. Fishers identify that they target Yellowtail and Grey snappers on "The Banks". One fisher said "I have yet to see an undersized Yellowtail on The Banks". According to

commercial fishers interviewed, snappers landed at these offshore sites tend to be significantly larger than snappers caught closer to shore. Lane snappers were seen to be fished almost exclusively near shore. In addition, the same Lane snapper fishing areas were frequented by more fishers than areas identified as Grey and Yellowtail fishing areas. Of the nineteen fishers, nine identified that they fished in the exact same area for Lane snappers. This verifies the observations of six fishers that have noted that Lane snappers are shallow water, schooling fish that prefer flat sandy bottom type habitats that are approximately 10 fathoms (18 m) deep. In addition, they also acknowledged that Lane snappers prefer structures that they can hide in such as wrecks and reefs. Yellowtail and Grey snapper fishing areas appear to be more scattered around the edge of the platform. Because these fishing areas are spread across a larger area, the heat maps display less of an overlap between commercial fishers targeting Yellowtail and Grey snappers than those fishers targeting Lane snappers.

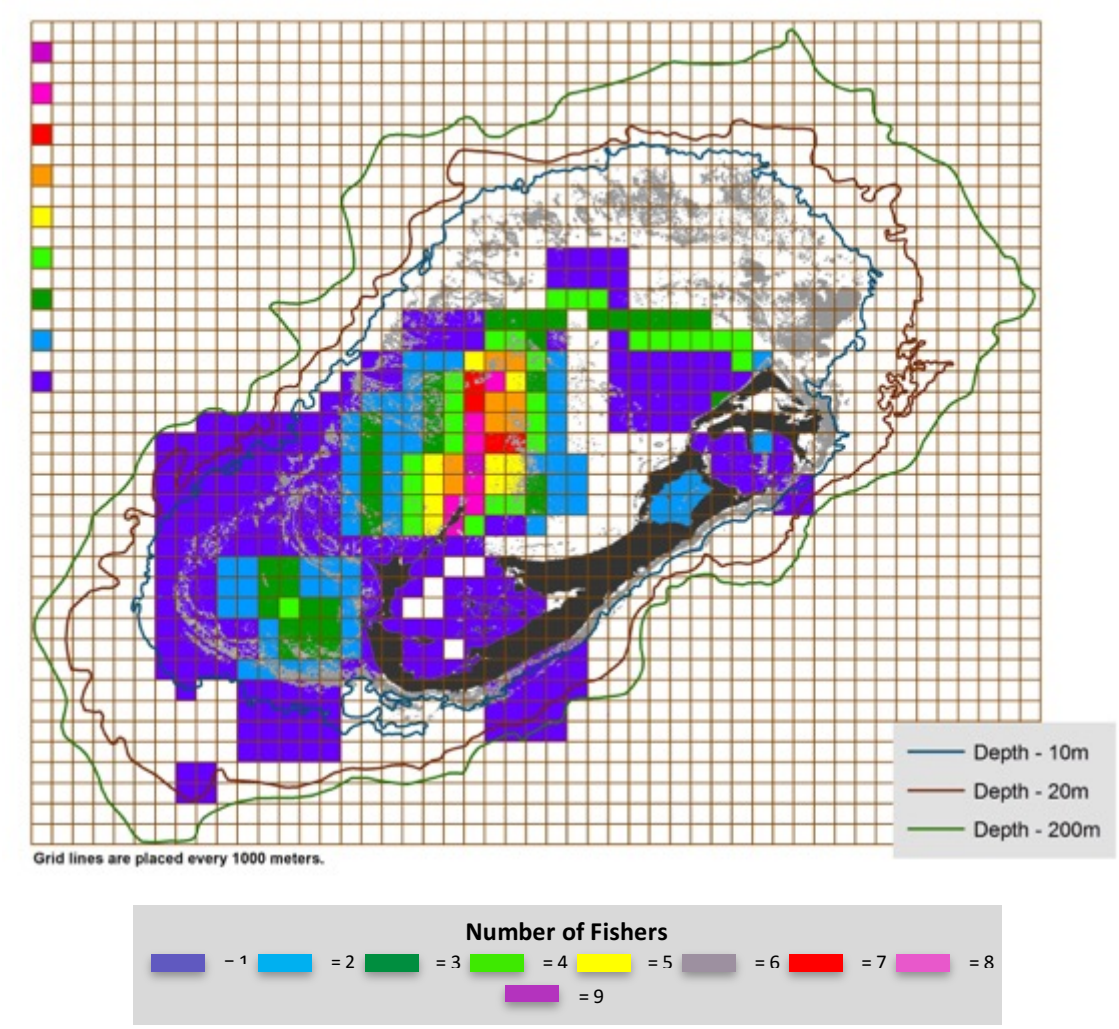

Figure 6: Heat Map of Frequent Commercial Fishing Areas for Lane Snappers on the Bermuda Platform.

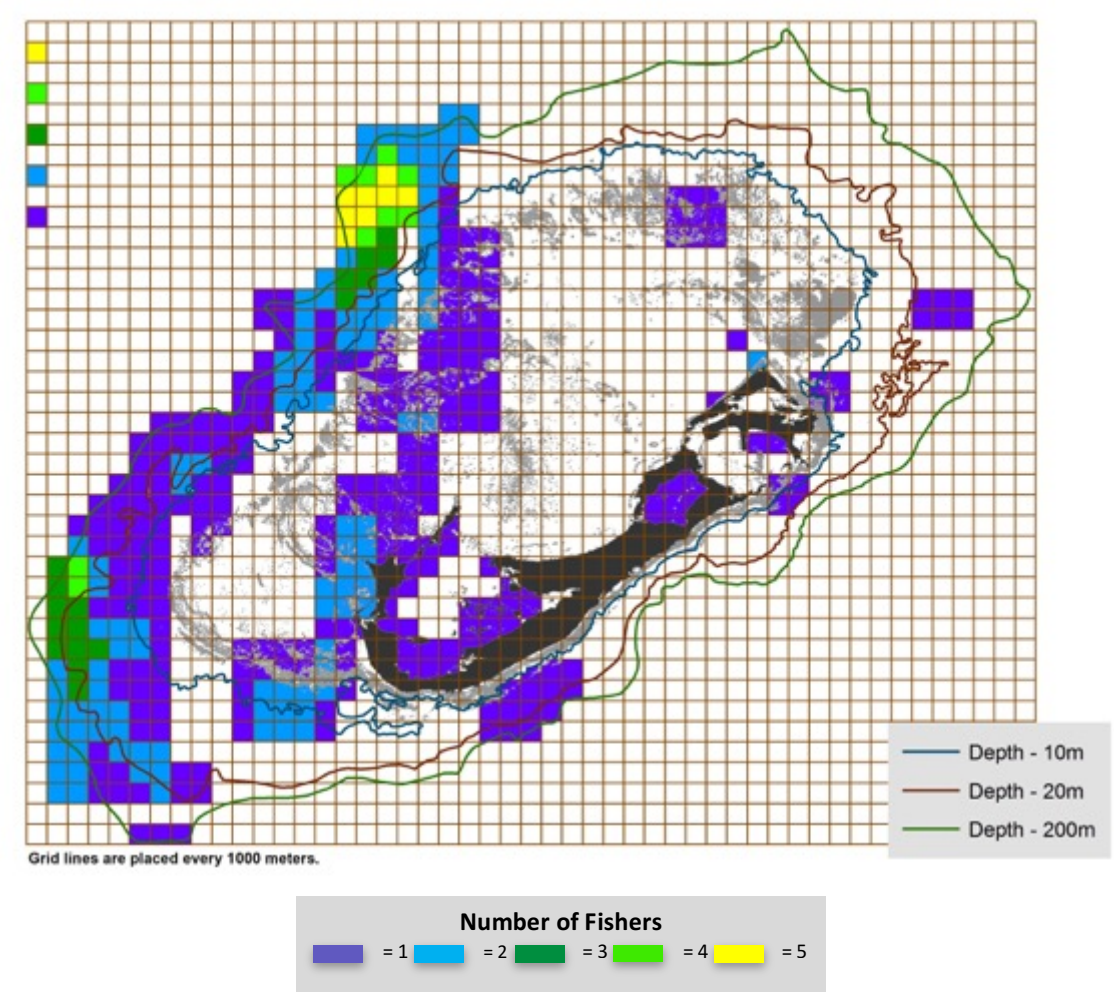

Figure 7: Heat Map of Frequent Commercial Fishing Areas for Grey Snappers on the Bermuda Platform.

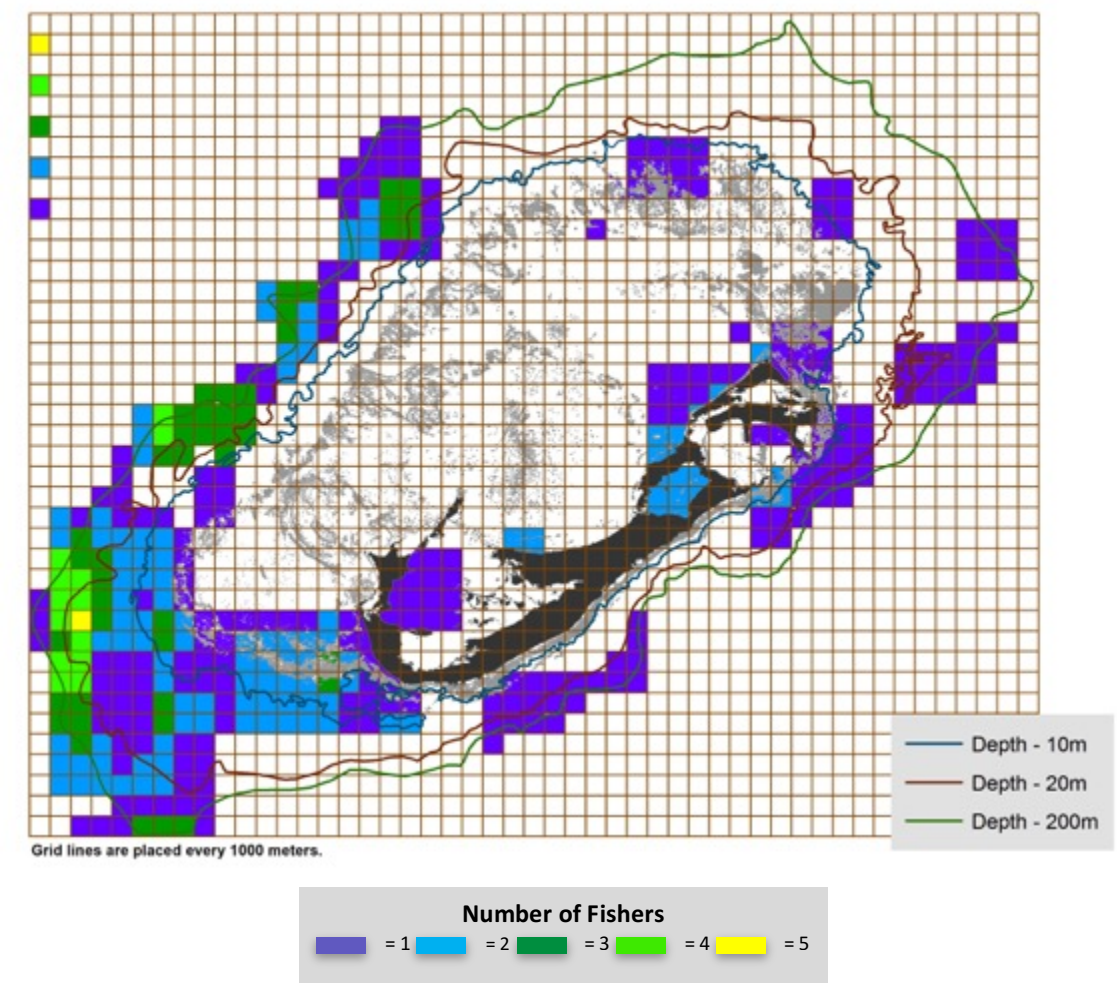

Figure 8: Heat Map of Frequent Commercial Fishing Areas for Yellowtail Snappers on the Bermuda Platform.

❖ Possible Snapper Aggregations

Identification of possible aggregation sites is important for the management and conservation of fisheries resources. Commercial and recreational fishers were asked to identify possible aggregation sites of the three shallow water snapper species. Commercial fishers identified sites where Grey snapper aggregations were found in the same areas as Yellowtail snapper aggregations (*Figure 9*). Identified Yellowtail aggregation sites also overlapped with identified Lane snapper aggregation sites. Approximately 16% of commercial fishers identified the same inshore Lane snapper

aggregation sites. While the highest overlap between commercial fishers for Yellowtail and Grey snappers was approximately 11% corresponding site identification. Recreational fishers identified possible aggregations sites were Grey and Lane snappers overlapped at three inshore locations (*Figure 10*). In addition, recreational fishers did not identify any potential inshore Yellowtail snapper aggregation sites. Commercial and recreational fishers identified similar inshore aggregation sites for Lane snappers. However, identified aggregations for Yellowtail and Grey snappers differed between recreational and commercial fishers. Commercial fishers identified that aggregations occur between May and September each year. However, 47% of these fishers specifically identified June and July as the months when aggregations are most prominent. Recreational fishers were able to identify that snapper aggregations occur throughout the summer with one fisher indicating that Grey snapper aggregations occur throughout the year.

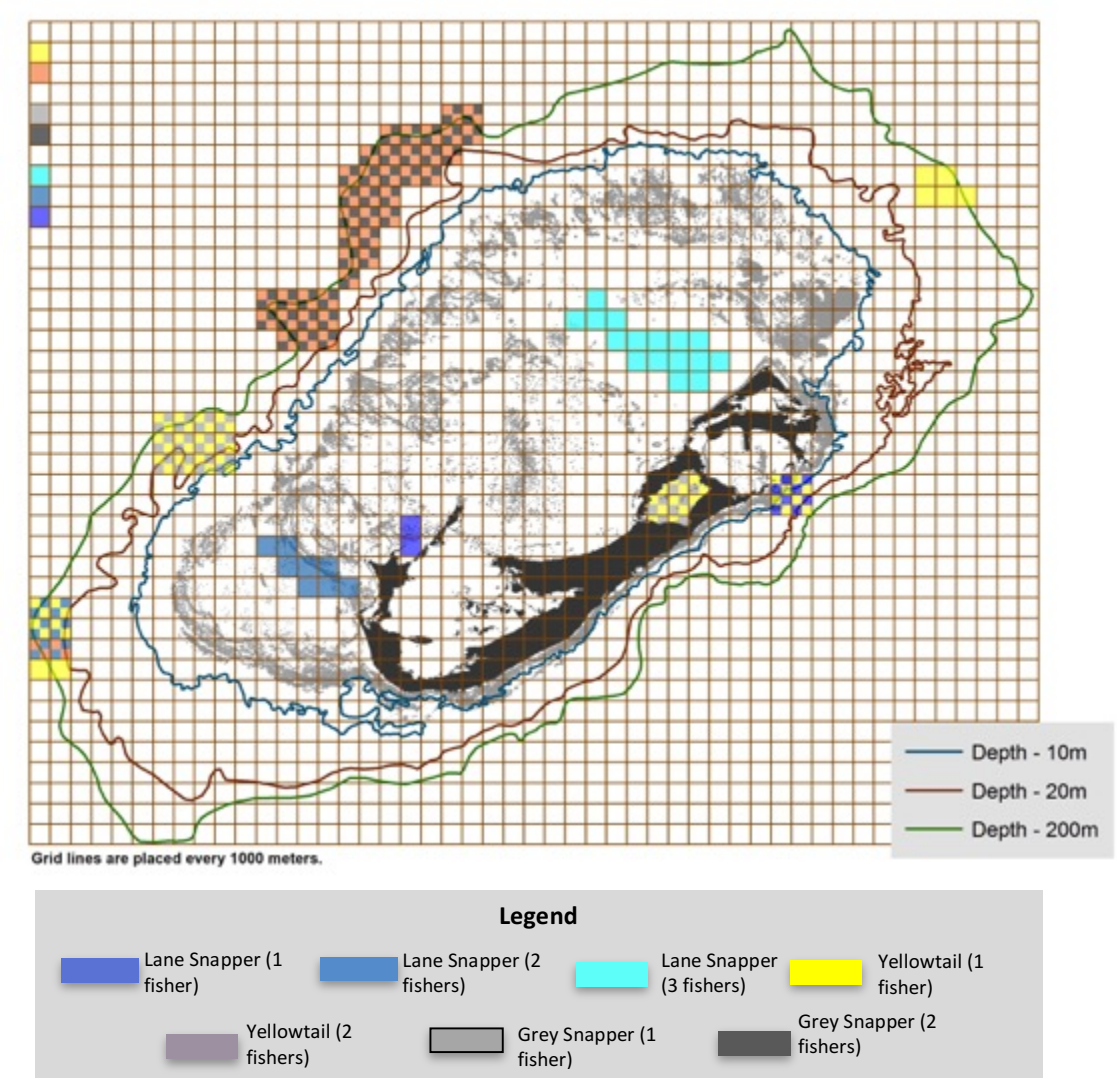

Figure 9: Heat Map of Identified Potential Spawning Areas on the Bermuda Platform by Commercial Fishers.

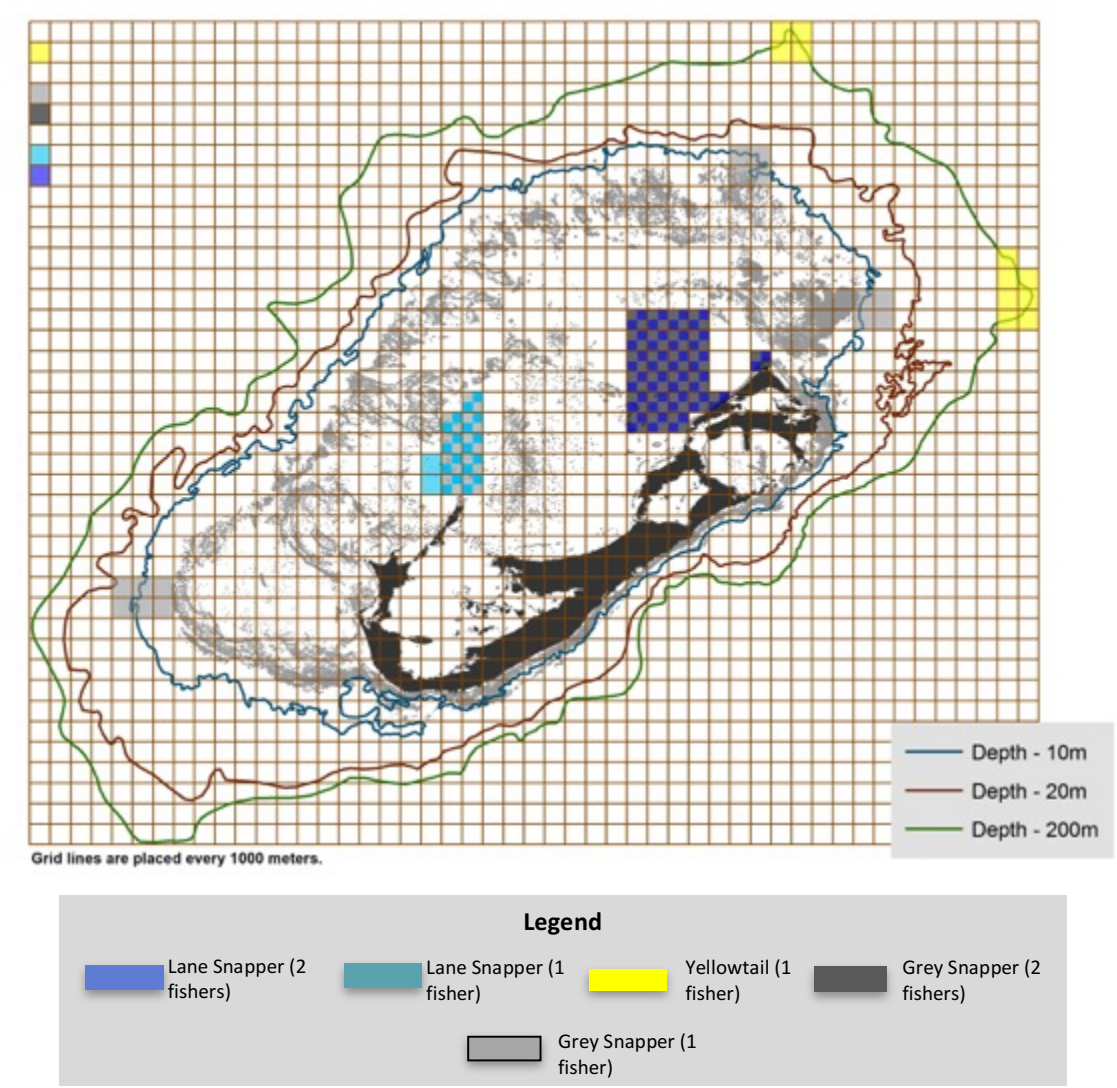

Figure 10: Heat Map of Identified Potential Spawning Areas for Shallow Water Snappers on the Bermuda Platform by Recreational Fishers.

❖ Fishers' Awareness and Management Recommendations

Awareness of current management regulations was good for both commercial and recreational fishers. In addition, participants were very supportive of the management measures in place. However, participants suggested the management measures in place require more effective enforcement. As survey participants, both recreational and commercial, were all boat owners or conducted most of their fishing activities on boats,

participants support for management corresponds with Pitt & Trott's (2013) findings that many recreational fishers, particularly boat owners were more aware of all fisheries regulations. Boat owners are considered to have a higher degree of specialization than shoreline fishers. Because specialization is linked to greater support of regulating fishing activities, (Pitt & Trott, 2013) it is no surprise that both recreational and commercial fishers recommended increased enforcement and effective regulations. Of the 19 commercial fishers, 10 indicated that increased enforcement and regulations should target recreational fishers that far exceed bag limits, illegally sell fish, catch undersized fish and have no pressure put on them to adhere to current management measures. Many commercial fishers suggested that recreational fishers should be required to have licenses that would require them to report data and allow fisheries managers to have better control over recreational fishing activities. Additional management suggestions from commercial fishers included: protection for Grey snappers, increased minimum size limits for Yellowtail snappers, eliminating multiple fishers on a single license, and to play a larger role in management where fishers opinions are utilized. Recreational fishers also suggested that commercial fishers should be regulated with bag limits and develop more protected reef areas or areas along the shoreline where fishing is prohibited. Despite many fishers' negative attitude toward fisheries wardens and managers, many fishers recognized the limited power fisheries wardens possess and recommended that they be given the "tools to do their job" as one fisher stated.

5.5 Limitations

Due to the time constraints of this research, primary data collection was limited to a two-month period in which a limited amount of surveys (24 total surveys: 19 commercial fishers and 5 recreational fishers) had been conducted. This timeframe had an additional limitation as it was during the busiest season for shallow water snapper fishing. Therefore, many fishers where unavailable and reluctant to participate in the interviews. In addition, this research was also limited by the lack of data available for snapper species in Bermuda.

Chapter 6: Adaptive Management

An important aspect to consider in the management of Bermuda's shallow water snapper fishery is that of continued improvement as time progresses. The state of natural resources is dynamic and constantly changing in response to varying environmental conditions. Therefore, it is crucial that management practices and decisions recognize resource shifting and adapt accordingly. Williams (2011) refers to adaptive management as a process of learning by doing and making changes based on what has been learned. It is centered on the recognition that natural resources are not fully understood and emphasizes the importance of acquiring more knowledge about these resources to improve management. Adaptive management is an informative process in which management strategies are amended with improved understanding (Williams, 2011).

The adaptive management framework can be divided into two phases: a setup phase in which key components are implemented and an iterative phase where the key components of the adaptive process are linked in a dynamic cycle of decision making (Williams, 2011). The setup phase consists of stakeholder engagement, identifying objectives, defining management actions and alternatives, developing models and monitoring protocols. The iterative phase of adaptive management includes a three phase learning cycle: decision-making phase, monitoring and evaluation phase and the feedback phase.

Because Bermuda's shallow water snapper fishery is data limited, the adaptive management process is even more important. With an adaptive decision making process, knowledge can be acquired about both the ecological processes and the decision making process itself. Williams (2011) outlines that an efficient management strategy provides learning opportunities for both ecological processes and decision-making processes. Understanding the temporal element in adaptive management is crucial because learning occurs on different time scales (Williams, 2011). Adaptive management is not a panacea for the management of the shallow water snapper fishery in Bermuda; however, it is a viable process that should aid in the sustainable management of this fishery.

Building adaptive capacity is a key component of not only environmental resource governance but governance in general. Adaptive capacity can be defined as the ability of a socio-ecological system to be vigorous and have enough resilience to be able to respond to actual or anticipated change or disturbance (Armitage & Plummer, 2010).

Fostering adaptive capacity can help managers, scientists and resource users to collaborate and decide on ways to address issues and challenges. Cultivating environmental adaptive capacity in times of crisis can be achieved by exercising four key elements: 1) learning to live with uncertainty; 2) developing diversity for resilience; 3) utilizing various forms of knowledge as a learning tool; and 4) providing opportunities for self-organization in order to achieve social and ecological sustainability (Armitage & Plummer, 2010).

The approach to adaptive capacity and in turn adaptive management is integrative and interdisciplinary. Adaptive capacity can be seen as a tool to bridge the gap between various theoretical disciplines, social classes, science, and local or traditional knowledge thereby strengthening relationships between resource managers and resource users. In complex social and ecological environments adaptive capacity can enable the structuring of a complex governing system (Armitage & Plummer, 2010). Adaptive capacity seeks to combine social, ecological, and even political environments to achieve a stronger and more cohesive environmental governance system. Instead of targeting one socio-ecological element, adaptive capacity building combines all socio-ecological elements thus providing an increased scope of governance regimes.

Bermuda experiences many of the same issues that affect coastal areas globally. Although threats and issues are often addressed by many different departments in other places, due to the size of the island, ecosystem issues and threats are often managed by the same Government departments. However, the policies and regulations of other Government departments often conflict or take precedent over resource management. For

example, fishing vessel licenses along with inspections of these vessels are managed by the Department of Environmental Protection, while other passenger vessel licenses and vessel inspections are managed by the Department of Marine and Ports. Thus, a charter fishing vessel must be licensed by both Departments. In addition, both the Department of Environmental Protection and the Department of Conservation Services are responsible for managing protected habitats and species. With various policies governing resources, many issues to solve, and a lack of manpower and resources to solve these issues, a complex governance challenge is created.

The ways in which the governance conditions mentioned above play out is partially dependent upon Bermuda's capacity to adapt. Theoretically, incorporating adaptive management into the management of Bermuda's shallow water snapper species relies heavily upon the resilience of managers and the resource, incorporating various factors that integrate across spatial and temporal scales and maintaining diverse avenues of communication and knowledge. Adaptive capacity is enhanced by the appropriate understanding of a problem and the possible solutions to these problems (Armitage & Plummer, 2010). It is clear that fisheries management strategies in Bermuda are in need of well-defined adjustments. To protect the environment and create a more sustainable fishery, these adjustments will have an effect on both commercial and recreational fishers. Understanding resources users' capacity to adapt and cope with these changes is crucial to the further management and protection of Bermuda's fisheries resources.

Chapter 7: Data Limited Fisheries

7.1 Approaches and Methodology

The Framework for Integrated Stock and Habitat Evaluation (FISHE) is a low cost and effective resource used to manage data- limited fisheries. This framework stems from Hobday's et al. (2011) research on Ecological Risk Assessments on the Effects of Fishing (ERA/EF) methodologies. In addition, FISHE is based on the guide Science- Based Management of Data-Limited Fisheries, by Apel et al. (2013). This guide aids managers in simplifying the fishery assessment process by incorporating a step-by-step framework that combines multiple methods. Step one of this six-step integrated framework is assessing the ecosystem status and impacts of fishing. The first step is achieved through a semi-qualitative assessment of the marine ecosystem using local and expert knowledge. Apel et al. (2013) identifies that the second step of FISHE is to assess the vulnerability of stocks to fishing pressure. This is achieved through the use of basic biological and fishery information. The third step of this data-limited methodology is the estimation of stock depletion. Without catch records, depletion status can be estimated using fish density data from reference areas such as marine protected areas (MPAs), catch-based length information or visual survey data. The fourth step of FISHE is the prioritization of stocks for further assessment and precautionary management. This is achieved through the use of a risk prioritization matrix. After prioritizing stocks, the next step is to assess the high priority stocks using data limited assessments. These assessments aid in developing catch limits and other fishing mortality controls (Apel et al., 2013). The final step of this framework according to Apel et al. (2013) is the collection of additional data for future stock assessments. The additional assessments can

aid in achieving more precise reference points for maximum sustainable yield, economic yield and other management goals. This framework is designed to continually improve management as the quality and quantity of data increases.

7.1.1 Designing and Applying the Adaptive Management Framework

A key step in the FISHE framework is the monitoring of fish stocks and managing them adaptively. Managers in data and resource limited situations are faced with difficult management decisions regarding how and by how much fishing pressure should be adjusted. These managers cannot use conventional stock assessment methodologies; the FISHE methods allow them to still make decisions based on science even with data and resource limitations. When utilizing adaptive management methods in management it is important that the process is participatory, drawing on the knowledge from scientists, resource users, government departments, and other stakeholders. Participation from all stakeholder groups helps to create common goals for the fishery, reduce conflict and uncertainty and increase compliance with management regulations (Wilson, McDonald, Fujita, & Karr, 2013).

Designing an adaptive framework within FISHE begins with defining goals for target species while incorporating ideas from both managers and stakeholders. After defining goals and identifying key species, appropriate quantifiable indictors are chosen (*Table 5*). Managers then have the opportunity to develop a data collection and data management strategy calculated using data limited stocks assessments (DLSA). The chosen indicators are given reference points and assigned harvesting control rules.

Harvest control rules are then used to evaluate the indicators against the reference points in order to determine appropriate management actions. Most importantly, indicators are re-evaluated annually to assess the health of the fishery as well as to determine if management changes are required (Wilson et al., 2013).

Table 5: Examples of Performance Indicators and Reference Points for Data limited Stock Assessments. *Adapted from (Wilson, McDonald, Fujita, & Karr, 2013).*

Performance Indicator	**Data Requirements**	**Single Species/Multi-Species/Ecosystem**	**Target Reference Point Example**	**Limit Reference Point Example**
Total Landings	Catch Data	Single/Multi/Ecosystem	Total Landings Increasing	Rapidly Decreasing Total Landings
Density	Fishery-independent Surveys	Single/Multi/Ecosystem	D_{TARGET} = 500kg/Ha	D_{LIMIT} = 200kg/Ha
Catch /Unit Effort (CPUE)	Catch and Effort Data	Single/Multi	CPUE Increasing	CPUE Decreasing
Fishing Mortality	Fishery-dependent lengths, Life History Information	Single	F_{TARGET} = 0.75M (natural mortality)	F_{LIMIT} = 2M (natural mortality)
Local Knowledge	Primary Research	Single/Multi/Ecosystem	Increasing awareness and knowledge of regulations and ecosystem services	Increasing awareness and knowledge of regulations and ecosystem services

7.1.2 Using Data Limited Stocks Assessments in an Adaptive Framework

Whether the outlined goal of a fishery is to maximize harvest or to increase fish biomass, the goals of the fishery guide the entire management process. To begin the adaptive framework, fisheries managers must identify target species. Target species are identified based on three key reasons: the species is economically important, has a special cultural or biodiversity value, or it is a vulnerable or resilient species (Wilson et al., 2013). Managers then choose performance indicators which are data streams that aid in evaluating how things are going or the current status of the target population. To gain a complete understanding of the fishery, each species should have several indicators from different data streams. The adaptive management framework is a repetitive process that allows for harvest regulations to be implemented over time while performance indicators move towards their reference points and the fishery progresses towards its goals (*Figure 11*).

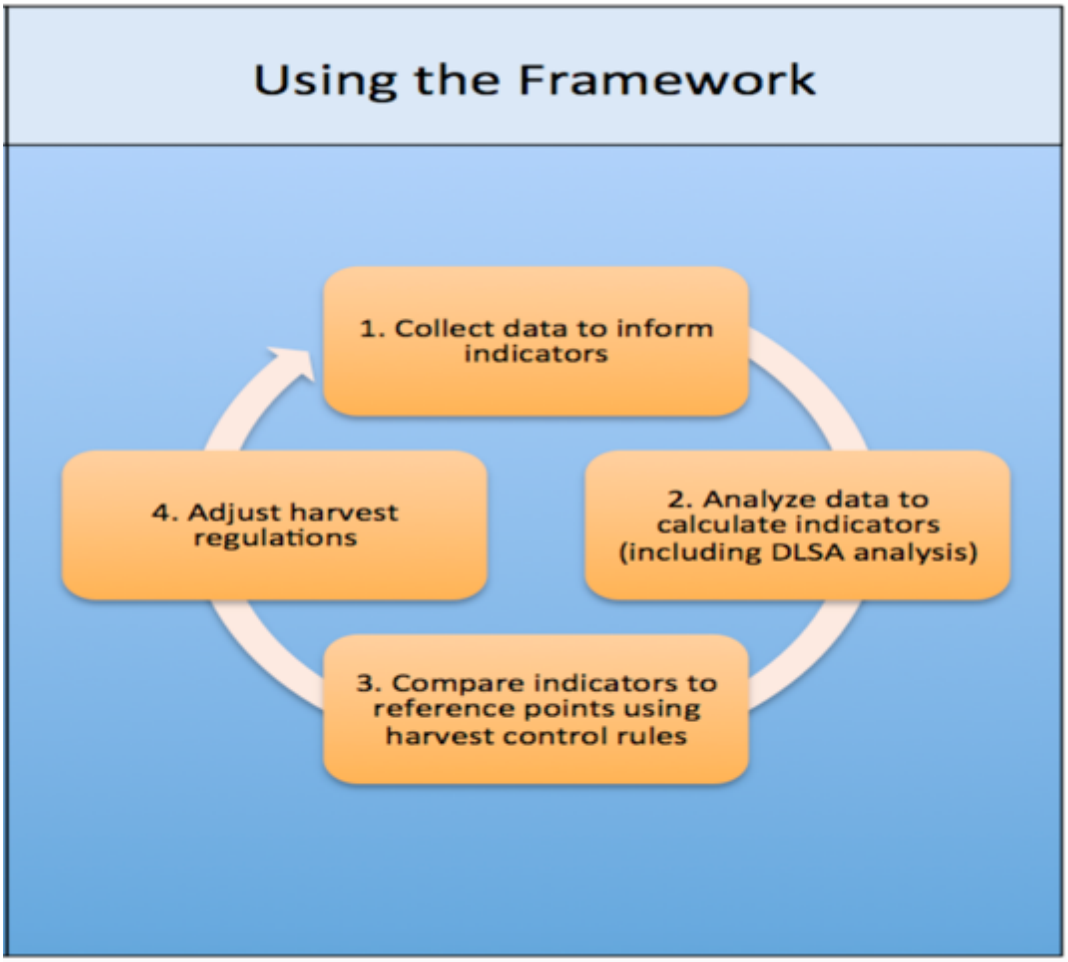

***Figure 11*: Using the Adaptive Fisheries Management Framework.** *Taken from (Wilson, McDonald, Fujita, & Karr, 2013).*

Shallow water snappers are both ecologically and economically important coastal species. Snappers help to maintain the health of coral reef ecosystems as predator species of grazing herbivores such as wrasses, and damsels that can kill off many coral reef species (Murdoch, 2014). In addition, snappers are a very important commercially targeted species in Bermuda. Because of their economic and ecological importance, snappers are an appropriate target species for the data-limited adaptive management framework. A reasonable amount of data, including life history and fishery survey information, is required to begin using this framework in Bermuda. The data required for

DLSA analysis of the commercial snapper fishery is readily available through landings records dating back to 1975 and a few studies (Bardach & Mowbray, 1955; Luckhurst, 1996; & Luckhurst et al., 2000) depicting the life history and behaviors of snapper species in Bermuda. However, to collect current data for shallow water snapper species, particularly for Grey and Yellowtail snappers, additional fishery surveys should be completed. The recreational fishery needs regulations that require fishers to submit landings data in order to achieve a better understanding of the status of shallow water snapper fish stocks. Finally, local surveys of both commercial and recreational fishers should be regularly conducted to add data to the current primary research database. The indicators listed in *Table 5* are realistic performance indicators for the shallow water snapper fishery in Bermuda. Furthermore, these indicators can be adjusted based on the resources available and the current needs of the fishery. In this way, the data-limited adaptive management framework will be beneficial to all fisheries stakeholders and can be used to develop harvest regulations based on science for better management of Bermuda's shallow water snapper fishery.

Chapter 8: Recommendations

It can be recognized that management at the species level is only a superficial solution to a larger ecosystem problem. Single species management is not adequate in most situations. To achieve a truly sustainable fishery it is important to have management plans in place that aim to protect all species that are targeted by commercial and recreational fishers. In addition, these management plans have to be based on

substantiated biological, ecological and socio-cultural data. Although fisheries resources are renewable they are not infinite. It is even more so important to recognize this in a country such as Bermuda that is home to a variety of species that are at the edge of their distribution range. Bermuda has had a long history of marine conservation and management beginning in 1620 with the protection of green sea turtles (The Goverment of Bermuda Ministry of the Environment, 2000). Because of the positive management decisions made over the last few decades, Bermudians can continue to rely on the sea for both recreational and commercial uses. However, if positive and adaptive management decisions are not continually made marine resources will not be available for future generations.

8.1 Overall Recommendations

This section examines the general recommendations for the adaptive management of the shallow water snapper fishery in Bermuda. These recommendations can aid managers to overcome challenges associated with Bermuda's data limited shallow water reef fish stocks by incorporating issues identified by local fishers.

- **Increase Communication Avenues**

Effective communication between all fisheries stakeholders is an important aspect of sustainably managing Bermuda's marine resources. Increasing communication avenues between the Department of Environmental Protection, Commercial Fisheries Council, Marine Resources Board, commercial and recreational fishers, other Governmental Departments, Bermuda Institute of Ocean Science, Bermuda Underwater

Exploration Institute, Bermuda Zoological Society and other educational and research institutions, NGOs, and the general public will help to strengthen relationships and build trust. In addition, communication is vital for ensuring participation in the implementation of management decisions relating to shared resources and in reducing conflicts that may arise between stakeholders (Jahan, Belton, & Viswanathan, 2014). For example, the frustration commercial fishers have with recreational fishers for illegally selling fish because it takes away from their livelihood. This frustration has increased the conflict between commercial fishers and the Department of Environmental Resources. Effective communication between the two stakeholder groups would allow for the discussion of frustrations, and facilitate the incorporation of solutions into management decisions.

- **Strengthen Stakeholder Relationships**

Effective communication must be paired with the continual strengthening of relationships between stakeholder groups, particularly between fishers and the Department of Environmental Protection. An occasional meeting or workshop is not sufficient to overcome decades of mistrust. By strengthening communication as well as long-term relationships, both groups will gain a better understanding of each others goals and intentions for the fishery. This research has revealed fishers' discontent with the current strategy for enforcing fisheries regulations. In addition, many fishers suggest that their opinions are not built into management decisions. Strengthening the relationship between stakeholder groups will help stakeholders understand each others objectives and enable them to work together to develop sustainable management decisions that reflect each stakeholder group's point of view. Specifically, fisheries managers can build trust

by maintaining complete transparency and involving fishers in pre-management decisions. Chuenpagdee & Jentoft (2007) confirm this theory in their paper addressing the pre-implementation of co-management in fisheries. Giving fishers the opportunity to play a key role in the decision making process would aid in promoting a trusting environment with strong stakeholder relationships.

- **Increase Local Education and Understanding of Marine Resources**

Education is important for raising environmental awareness. Awareness and education can also aid in minimizing the negative impacts humans have on living marine resources, drive change and encourage the need to preserve these resources (Branchini et al., 2015). If locals can become more aware of what impact their behaviors have on the environment, they may be more concerned about the health of marine resources and more reluctant to engage in activities that can negatively affect marine resources. For example, if more people had knowledge about the impacts of keeping undersized fish and the negative effects it can have on fish populations, more fishers would be willing to use fishing methods that can aid in avoiding undersized fish such as larger hook sizes. Increasing local knowledge and education can aid in changing behaviors which can make resource users more responsible for their individual actions. With increased knowledge comes increased responsibility, all resource users ought to be accountable for preserving Bermuda's marine resources.

8.2 Fisheries Management Recommendations

To date, an adaptive fisheries management plan based on existing data limited methods has not been implemented in Bermuda's shallow water reef fishery. This

research has revealed that this fishery requires additional management decisions that incorporate both commercial and recreational fishers' knowledge. In addition, this research has also revealed that a management plan for shallow water snappers and other similar species is needed. With limited resources and man power, a management plan that addresses a broad range of species groups rather than a single species group could be better suited for Bermuda's fishing sector. It can be recommended that this plan include shallow water snapper species as well as other shallow water reef species that occupy similar habitats, have similar life histories, and are targeted with similar gear types.

- **Incorporate Data Limited Fisheries Management Approaches**

The FISHE framework represents one of the many approaches to adaptively managing data limited fisheries. It is recommended that Bermuda apply this six-step adaptive approach to effectively and more efficiently manage shallow water reef fish. By incorporating the FISHE framework into fisheries management, managers and scientists will be able to conduct simplified, step-by-step science based stock assessments with limited resources. With the application of the FISHE framework in Bermuda's shallow water fishery, as the quality and quantity of data increases, management efforts can be continually improved.

- **Incorporate an Ecosystem- Based Fisheries Management Approach**

Understanding that the ecosystem is dynamic and constantly evolving is key when making management decisions that can have long-term effects on ecosystem dynamics. The most significant impact of fisheries is overexploitation. However, there are many

other human activities that negatively impact fisheries which include: land-based pollution, the introduction of invasive species, and climate change. All of these activities interact with each other and the ocean causing even more stress on marine ecosystems (Koehn, Reineman, & Kittinger, 2013). Many management decisions have not accounted for the impacts of human interactions and have not been able to adapt to the changes these interactions have had on the environment. Addressing these issues from a more holistic approach to management, taking into consideration the entire ecosystem, including humans, will aid in producing a healthy, productive and resilient environment that can provide a full range of goods and services for future generations (Koehn et al., 2013). By moving away from a single species approach to management, fisheries managers can resolve multiple connected issues and reach targeted initiatives with a single management system.

- **Increase Compliance and Enforcement**

Without effective compliance and enforcement, fisheries laws and regulations can do little to manage, conserve and ensure the sustainable use of marine resources. This research revealed an overwhelming negative response from both commercial and recreational fishers regarding the lack of enforcement throughout the Bermuda fishery. Fishers openly revealed their dissatisfaction with other resource users' deliberate disrespect of fisheries laws and regulations. An obvious solution to this problem would be increased enforcement at all levels. This would mean an increased presence of fisheries wardens throughout inshore and offshore fishing sites and at local fishing docks. In addition, fisheries wardens would also have to have more of a presence at restaurants

known to buy local catch as well as street side fish stalls. Increasing fisheries warden presence can be seen as a strategy to deter any illegal activity from occurring. However, with only five fisheries wardens, the entire area fished by the local population can not be covered. With over 300 commercial fishers and approximately 16,000 recreational fishers (Pitt & Trott, 2013) increased manpower is needed in the Bermuda fishery. In addition, a more sophisticated method of issuing tickets or fines is also recommended. Currently, there is no simple method of penalization for offences, all offences require court proceedings and a significant amount of administrative labour.

With the difficulties surrounding increased enforcement another option for the adaptive management of Bermuda's fishing sector is increasing compliance. This would allow resources users to govern themselves. There are four ways in which compliance an be increased in the Bermuda Fishery:

- ✓ **Partnering with NGOs and research institutes to increase political will to develop compliance.** NGOs can complement government departments by leading campaigns that will raise public awareness and discourage illegal fishing activities.

- ✓ **Encourage compliance with increased education and public participation.** Increasing public participation increases compliance through raising awareness, creating pressure groups and increasing transparency, accountability

and monitoring. Public participation can aid in demonstrating to stakeholders the impacts of coastal degradation and compel stakeholders to take steps toward conserving marine resources (Bruch & Mengerink, 2008). Education initiatives should target children by incorporating marine resource education into school curricula. This will aid in ensuring that the next generation is more aware and more compliant with fisheries management regulations thus, creating in-house compliance officers in every family.

- ✓ **Enhance compliance through integrated control measures.** Integrated control measures work by integrating various environmental sectors' resources to use financial, personnel, and technical resources more effectively. Integrated control measures are effective in scenarios with limited resources (Bruch & Mengerink, 2008). The government, Bermuda Institute of Ocean Science (BIOS) and the Bermuda Zoological Society (BZS) can combine resources and man power to achieve compliance in the Bermuda Fishery. This can be effective in a situation where the government can set regulations based on the scientific advice of BIOS, BIOS can assist with scientific monitoring,

and the three organizations can combine personnel to make sure regulations are upheld and to put pressure on judicial systems to ensure that law breakers are appropriately punished.

- ✓ **Foster compliance by increasing penalties to better reflect potential long-term damages to the resource and deter continued offences.** Penalties and the threat of enforcement can aid in fostering compliance. Severe penalties must be sufficient enough to deter potential violators and exceed the nominal amount that could be considered 'the cost of doing business' (Bruch & Mengerink, 2008).

❖ Shallow- water Snapper Fishery Recommendations

Table 6: Management Recommendations for the Shallow -Water Snapper Fishery

Current Fishing Issues	**Management Recommendations**
Recreational fishers catching more than their allotted 30 fish per day bag limit	➢ Increased penalties and enforcement ➢ Compliance and enforcement measures ➢ Ticketing Scheme
Lack of data for recreational fishery	➢ Recreational fishing license requiring catch statistics reporting
Recreational fishers illegally selling fish	➢ Fisheries wardens' presence and enforcement ➢ Increased penalties for fishers

	➢ Increased penalties for buyers and vendors like restaurants
Inaccurate reporting of commercial fisher statistics	➢ Compliance and enforcement measures ➢ Introduce logbooks, eLogs, and Vessel monitoring systems (VMS)
Multiple fishers on a single commercial license	➢ Limit commercial licences to a single primary fisher
Fishers landing undersized fish	➢ Size limits for Grey Snappers ➢ NGO partnerships and increased education ➢ Ticketing Scheme ➢ Seasonal area closures ➢ Increased penalties
Illegal use of fish pots	➢ Compliance and enforcement measures ➢ Increased penalties
Lack of knowledge of current fisheries regulations	➢ Education programs ➢ Public Participation ➢ NGO partnerships
Fishers knowledge and opinions are being ignored	➢ Increased public participation ➢ Co-management
Restaurants buying fish from unlicensed fishers	➢ Compliance and enforcement measures ➢ Increased penalties
Fisheries wardens having limited powers	➢ Ticketing scheme ➢ Partner fisheries wardens with other government enforcement bodies such as Marine Police and Bermuda Regiment
Habitat destruction	➢ Monitoring and conservation programs ➢ Adaptive Management ➢ NGO partnerships
Invasive species (Lionfish)	➢ Monitoring and conservation programs ➢ Adaptive Management

Chapter 9: Conclusions

Fisheries scientists have identified various avenues for incorporating adaptive management into fisheries management schemes throughout the world. This research revealed that the FISHE framework is a suitable management option for the adaptive management of the shallow-water snapper fishery in Bermuda. This framework acknowledges the importance fishers' knowledge within a data-limited context. In addition, this research revealed that a data-limited adaptive management framework could help to ensure a more sustainable shallow water fishery. To supplement adaptive management approaches, fisheries managers can incorporate a more holistic approach to managing marine resources through the use of ecosystem-based management. Commercial and recreational fishers in Bermuda have a lot of experience and possess knowledge that is crucial in the management of shallow water snapper species. This knowledge includes: biology and life history information, information on fishing quality and seasonality, and knowledge of snapper aggregation sites. Results from the interviews with commercial and recreational fishers displayed a progressive way of thinking for many fishers; advocating for change to ensure a sustainable fishery for future generations. Fishers were eager to engage in conversation about their experiences fishing and were very aware of the issues surrounding the shallow water snapper fishery, often presenting various solutions to mitigate conflicts between resource users. Bermuda has a long way to go to achieve a fully sustainable fishery, by incorporating adaptive management and data limited methodologies into fisheries management, Bermuda could make its fist step towards a sustainable shallow water reef fishery.

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Appendix

A. Dalhousie Ethics Approval

DALHOUSIE UNIVERSITY
Research Services

Social Sciences & Humanities Research Ethics Board
Letter of Approval

July 16, 2015

Ms Kascia White
Science\Marine Affairs Program (Science)

Dear Kascia,

REB #: 2015-3544
Project Title: Applying Adaptive Management Approaches to Data Limited Fisheries: A Look into Bermuda's Shallow Water Snapper Species

Effective Date: July 16, 2015
Expiry Date: July 16, 2016

The Social Sciences & Humanities Research Ethics Board has reviewed your application for research involving humans and found the proposed research to be in accordance with the Tri-Council Policy Statement on *Ethical Conduct for Research Involving Humans.* This approval will be in effect for 12 months as indicated above. This approval is subject to the conditions listed below which constitute your on-going responsibilities with respect to the ethical conduct of this research.

Sincerely,

Dr. Karen Beazley, Chair

B. Appendix Interview Questions

DALHOUSIE UNIVERSITY
Inspiring Minds

How fishers' knowledge can aid in understanding the state of the shallow-water snapper fishery in Bermuda

1. How many years have you been in the fishing industry as a primary operator?

2. Do you specifically target the following snapper species?

White Water Snapper	Yes/No
Grey Snapper	Yes/No
Yellow Tail Snapper	Yes/No

3. During what parts of the year do you usually fish for these species (e.g. May-July, September- December etc.)?

Month of the Year	**Quality of Fishing**			
	Good	**Satisfactory**	**Poor**	**None**
January				
February				
March				
April				
May				
June				
July				
August				
September				
October				
November				
December				

4. During the best fishing season, how much time per day do you spend fishing snapper species? Does this ever include overnight trips?

5. On average, how many 'units of catch' (in lbs or kg) do you land of each species per day?

Snapper Species	**Units of Catch (lbs/kg)**
White Water Snapper	
Grey Snapper	
Yellow Tail Snapper	

6. Given that there are size limits for whitewaters and yellowtails, how often do you catch undersized fish that have to be released? (leave open, but if asked for guidance suggest rarely, sometimes, frequently, almost every trip?)

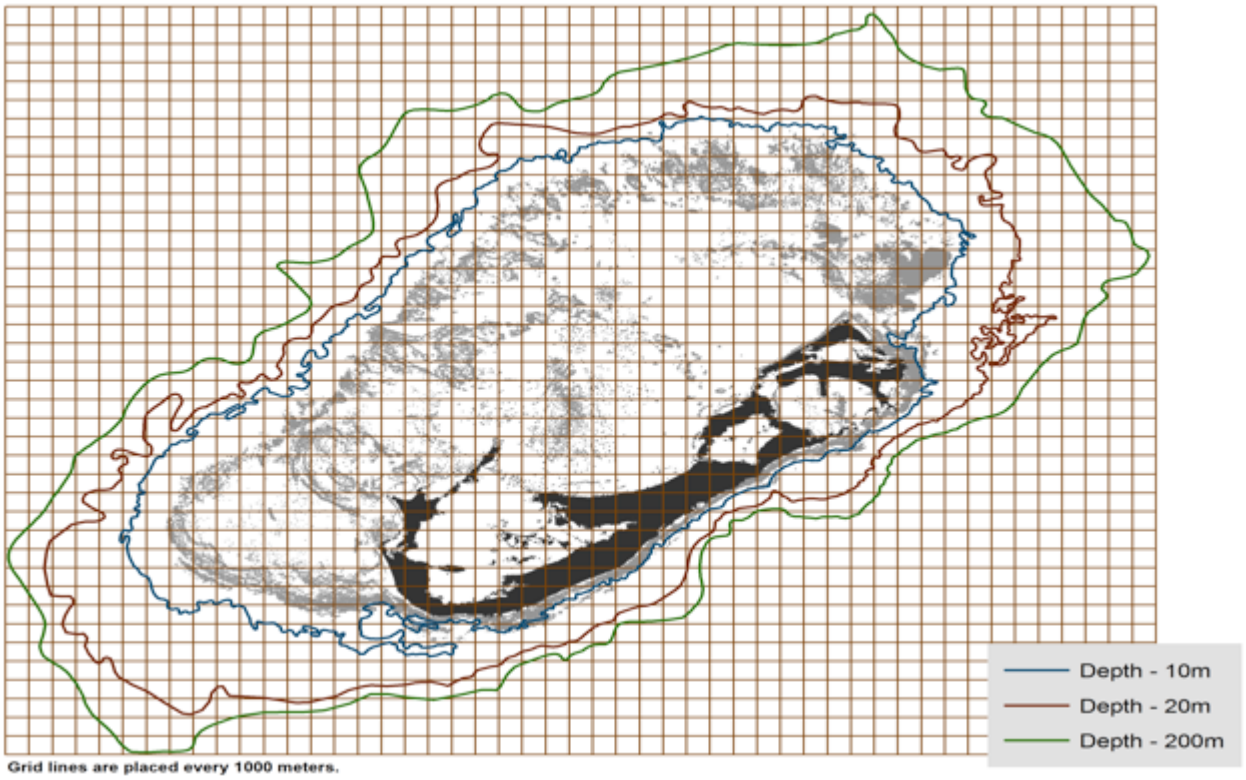
7. Do you think that snapper populations have changed over the time you have been fishing? If so, please explain more…

8. Have you observed any possible aggregation sites for any of the shallow water snapper species? During what month(s) is this most prominent?

Month of the Year	**Quality of Fishing**			
	Species	**Location**	**Approximate Depth**	**Behavior**
January				
February				
March				
April				
May				
June				
July				
August				
September				
October				
November				
December				

Legend			
Species	White Water = WW	Grey = G	Yellow Tail = YT

9. If you were to catch approximately 100 grey, yellowtail, or whitewater snappers where would you likely find them? Please indicate on the map.



10. What do you know about the current management of snappers? Do you think this management is effective?

11. Do you have any suggestions for management measures that would help ensure a sustainable snapper fishery?

C. Management Plan Template

2015

Bermuda Shallow Water Reef Fisheries Management Plan: 2016-2020

STRATEGIES FOR THE MANAGEMENT AND PROTECTION OF BERMUDA'S SHALLOW WATER REEF SPECIES

MARINE RESOURCES SECTION

GOVERNMENT OF BERMUDA
MINISTRY OF HEALTH & ENVIRONMENT

Table of Contents

Executive Summary

1. Country Profile

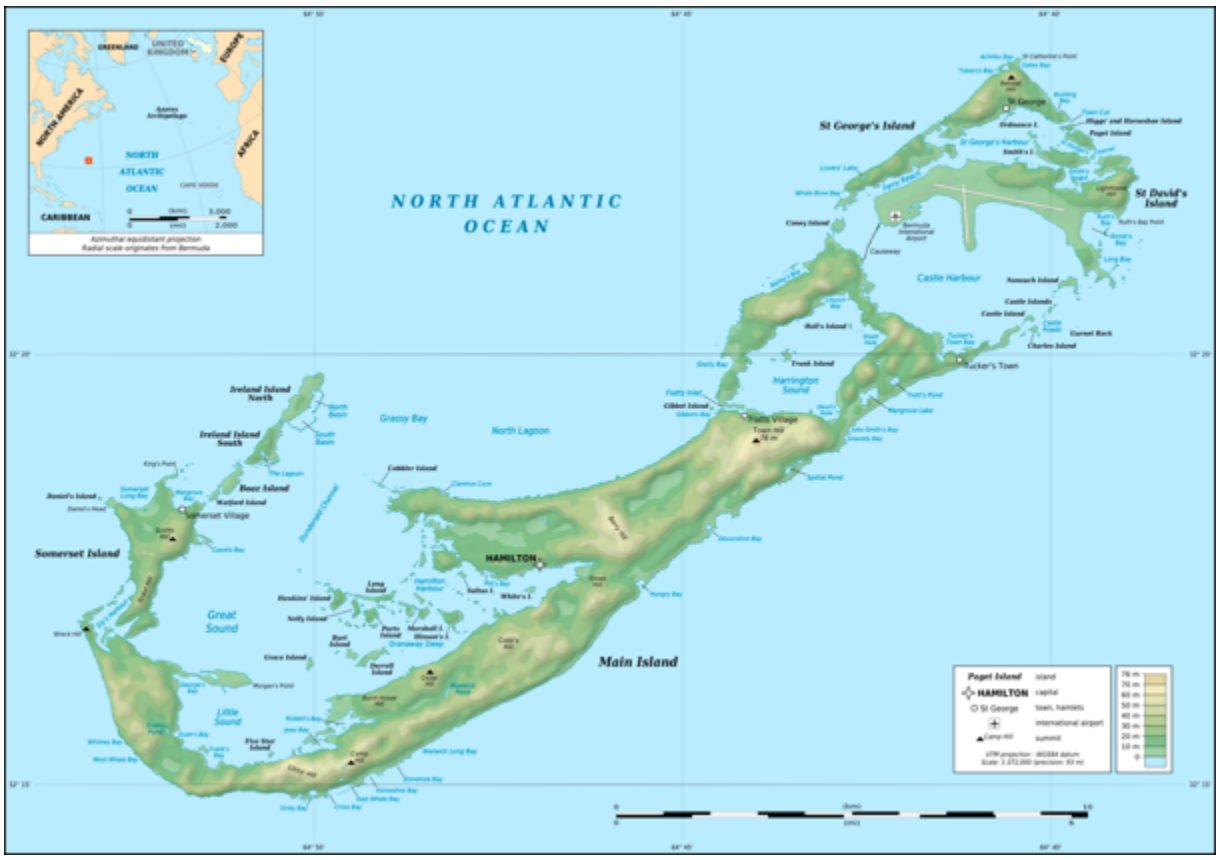


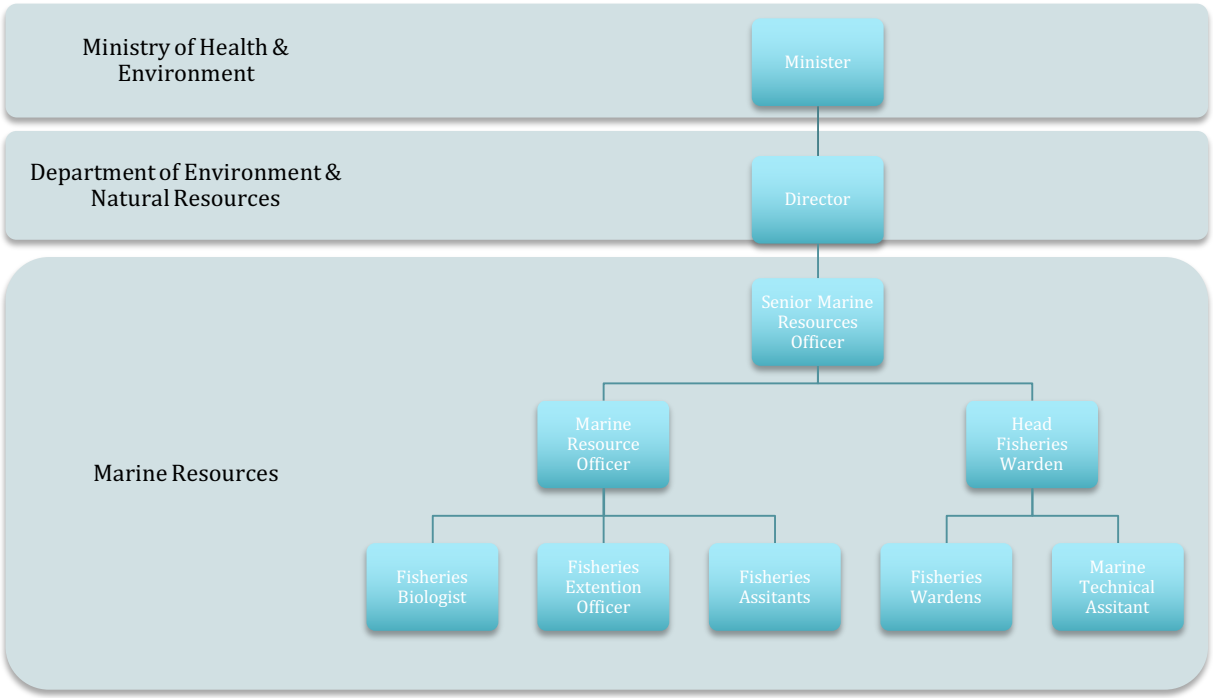
Figure 1: Topographic Map of Bermuda ©Eric Gaba (commons.wikimedia.org)

Table 1: Characteristics of the people and economy of Bermuda. Source:

GEOGRAPHY	
Location	
Land Area	
Coastal Areas	
Maritime Claims	
Climate	
Terrain	
Marine natural resources	
GOVERNMENT	
Type	
Capital	

Administrative divisions	
Constitution	
Legal System	
Suffrage	
Elections	
Executive branch	
Legislative branch	
Judicial branch	
Chief of State	
Head of Government	
PEOPLE	
Population	
Population growth rate	
Infant Mortality	
Ethnicity	
Language	
Literacy	
Labor Force	
Unemployment rate	
Fish consumed	
ECONOMY	
GDP	
GDP by sector	
Per capita GDP	
Inflation rate	
Exports	
Imports	
Main Industries	
Agriculture	
Exchange rates	

2. Fisheries Profile



2.1 Fisheries Resources

2.2 Fishing Vessels

2.3 Fishing Gear

2.4 Stakeholders

3. Management Plan for Shallow Water Reef Fishes

Target Fishes	
Life History	
Fishing Methods	
Management Unit	
Resources Status	
Catch History	
Current Regulations	
Management Objectives	
Management Options	

Issues	Actions	Implementation Strategy	Resources Required
Habitat Degradation and Destruction			
Inadequate Fishery Information Statistics			
Lack of Control over the Recreational Fishery			
Inadequate Management Regulations to Protect all Species			

History of Poor Compliance and Enforcement of Fisheries Regulations			
Insufficient Resources Allocated to Fisheries Managers			
Fishers Engaging in Irresponsible Fishing Practices			
Useful Fishery Resource and Sustainable Management Information is not Readily Available to Fisheries Stakeholders			