The Consumption of Lionfish as a Control of an Invasive Species in Bermuda

By
Alaire Davis
University of Colorado at Boulder

A Thesis submitted to the
University of Colorado at Boulder
in partial fulfillment
of the requirements to receive
an Honors designation in
Environmental Studies
May 2016

Thesis Advisors:

Heidi Souder, Baker RAP, Committee Chair
Randolf DiDomenico, Baker RAP
Dale Miller, Environmental Studies

ABSTRACT

This research focuses on how lionfish are affecting the waters of the Caribbean Sea and western Atlantic Ocean, and the practices in place to control the lionfish invasion. The presence of lionfish in these areas is a significant problem because of the detrimental effect they have on coral reef ecosystems. Countries in the Atlantic that are directly dependent on underwater ecosystems for their economy, and the global underwater environment in general, are at risk. My research aimed to determine if consuming lionfish can be a viable way of reducing lionfish in Bermuda. I approached this question by surveying three categories of people in Bermuda: commercial fishermen, professional chefs, and members of the general public. There is a significant group of the population able to catch lionfish as well as a signification portion of chefs willing to learn how to prepare and serve lionfish. In order to establish a sustainable lionfish fishery, there needs to be modifications to fishing laws as well as efforts that encourage the sale of lionfish in restaurants.

TABLE OF CONTENTS

PREFACE

I would like to thank the members of my thesis committee: Dr. Heidi Souder, Dr. Dale Miller, and Dr. Randolf Didomenico. I was also able to receive funding to do my research through the Undergraduate Research Opportunities Program at the University of Colorado Boulder. I would also like to thanks Corey Eddy and Tammy Trott for their personal communication with me on issues surrounding the lionfish invasion in Bermuda.

INTRODUCTION

This research focuses on how lionfish are affecting the waters of the Caribbean Sea and western Atlantic Ocean, and the practices in place in to control the lionfish invasion. The presence of lionfish in these areas is a significant problem because of the detrimental effect they have on coral reef ecosystems. Consequently, countries in the Atlantic Ocean that are directly dependent on underwater ecosystems for their economy, and the global underwater environment in general are at risk.

This research seeks to answer the following questions:

1. Can consuming lionfish be a viable way of reducing this invasive species in Bermuda?
2. What are the methods of capturing lionfish that contribute to eventual consumption?
3. How do we implement lionfish consumption into the eating habits of persons in the countries affected by the presence of lionfish?

The tool for acquiring the answers to the questions noted above was a set of questionnaires, tailored specifically for three audiences: chefs, fishermen, and the general public. This research focuses on issues concerning the lionfish problems that are specific to Bermuda. Bermuda as an island is unique since it is not in the Caribbean but has many ecological factors similar to those in the Caribbean islands. What makes Bermuda unique is that, unlike many Caribbean nations, Bermuda is economically and socially successful. The island has one of the

world's highest GDPs per capita (Forbes, 2016). Conducting research on potential solutions to the lionfish invasion on a more prosperous island provides a distinct perspective. Bermuda serves as an economic and political role model for other island nations, and thus this Bermuda-based research and proposed solutions to the lionfish dilemma can provide a template to follow for other islands.

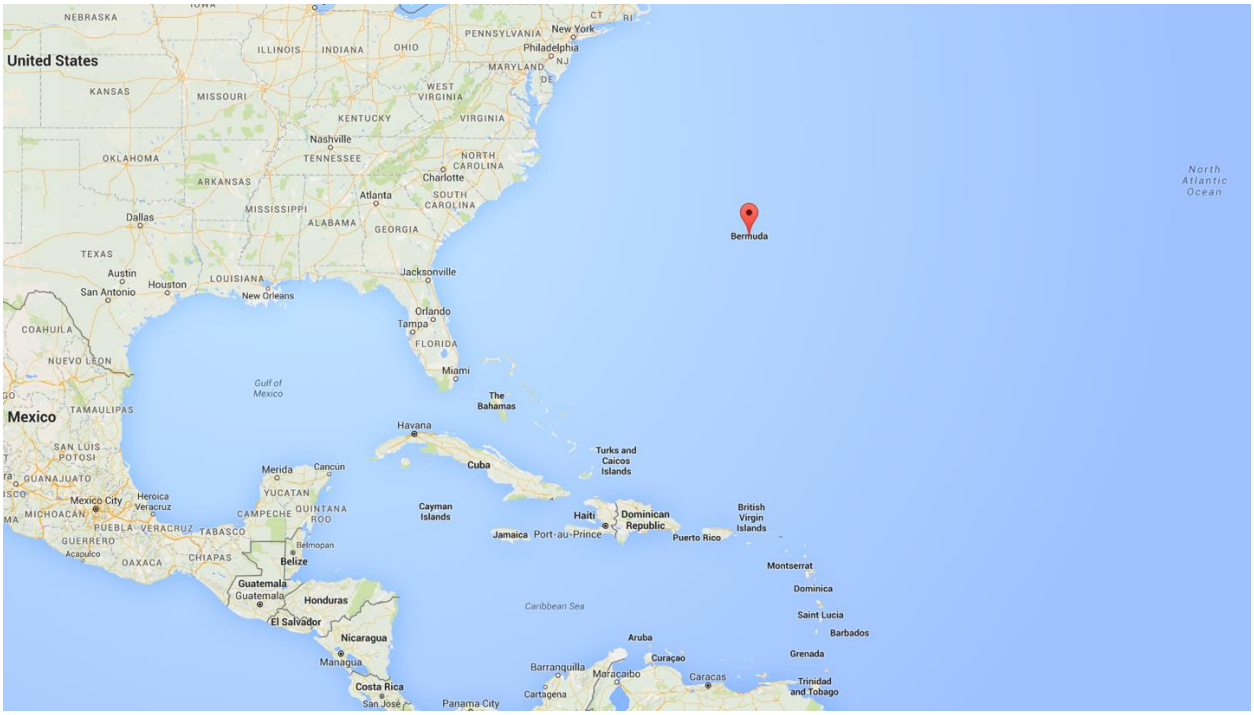

Figure 1: Map of the Caribbean Sea and Western Atlantic Ocean showing the location of Bermuda

BACKGROUND

This section illustrates some background information about lionfish as well as their introduction into the Atlantic Ocean and Caribbean Sea. Lionfish are a unique species with special characteristics, and their presence is increasingly growing in the Caribbean Sea and western Atlantic Oceans.

Basics about Lionfish

The lionfish is a creature with a unique set of adaptive traits that not only make it fascinating to look at but also dangerous to potential predators. There are two species of lionfish, *Pterois volitans* and *Pterois miles* which visually appear almost identical. The genus and species of the red lionfish is *Pterois volitans*, the word "Pterois" comes from the Greek word for "feathered" or "winged," while the word "volitans" comes from the Greek word for "flying" (Robins, 2016). The genus and species of the common lionfish or devil firefish is *Pterois miles*, the word "Pterois" comes from the Greek word for "feathered" or "winged," while the word "miles" comes from the latin word for "soldier". The native range of the *Pterois miles* is primarily the Indian Ocean and Red Sea, while the native range of the *Pterois volitans* is in the Pacific throughout most of Oceania (Schofield et al. 2016). Both species have been found in the Atlantic, with the majority of the invasive population composing of *P. volitans* with a small

Figure 2: Lionfish

number of *P. miles* (Schofield et al. 2016). Both kinds of lionfish are Invasive Alien Species (IAS) in the Caribbean Sea and Atlantic Ocean (Gleason & Gullick, 2014). Lionfish are generalist predators of fishes and invertebrates; the lionfish's diet essentially consists of any small fish that they can fit into their mouth (Ruttenberg et al. 2012). The average life span of a lionfish in the wild is up to 15 years, they are generally found in sizes between 11.8 and 15 inches and can weigh up to 2.6 pounds (National Geographic, 2015). Lionfish are quite dangerous since each lionfish has 18 venomous spines (Bermuda Lionfish Task Force, 2015). The lionfish stores venom in the tips of its needle-like dorsal fins and, if attacked, it delivers this venom to its attacker via their dorsal fins (Wood, 2001). These adaptive traits are necessary in the lionfish's native region to keep the ecosystem in balance, but when the lionfish is present in the non-indigenous waters of the Atlantic Ocean it threatens the health of the coral reef ecosystems.

Lionfish Expansion and Arrival into the Atlantic

Lionfish are native to the Indo-Pacific Oceans, but are now found in large numbers in the Caribbean Sea, Atlantic Ocean, and specifically off the east coast of the United States. According to certain presumptions, lionfish were originally released into the Atlantic near south Florida in the early 1990s by people who no longer wanted them as aquarium pets (Morris & Akins, 2009). Lionfish are present in waters from the Caribbean Sea all the way up to the northern east coast of the United States (González, 2009). Lionfish have been able to populate about a million square miles of ocean in 10 years (REEF, 2016). Record densities of lionfish off the coast of the Bahamas have been reported in a scientific journal published by Simon Fraser

University as of 2008. At three sites in the Bahamas it was discovered that lionfish exist in densities which far exceeds their densities in their native Pacific Ocean (Green & Cote, 2008). Lionfish can reach densities of over 200 adults per acre (REEF, 2011). The number of invasive lionfish has been increasing dramatically and they are now found throughout most of the Caribbean Sea and Atlantic Ocean. Genetic testing has proved that all these lionfish are descended from the approximated 10 original lionfish that were released around south Florida in the early 1990s (NOAA, 2010). Despite Bermuda being located far north and in a remote part of the Atlantic Ocean, lionfish arrived to the island very rapidly with the first lionfish being recorded in 2001 (Bermuda Lionfish Taskforce, 2015). In Bermuda, lionfish are found in very shallow waters and down to depths greater than 250 feet (Bermuda Lionfish Taskforce, 2015). Lionfish have been reported in all sizes, from juveniles 4 inches in length to the world record, nearly 19 inches, that was caught in Bermuda (Bermuda Lionfish Taskforce, 2015). Lionfish are expanding at rapid rates throughout the Caribbean Sea and spreading into new territories.

Figure 3: Map depicting the rapid spread of lionfish in the Caribbean, Gulf, and Atlantic over a 20-year time period: from 1993 to 2013.

SUMMARY OF LITERATURE REVIEW

This research will highlight the specific factors that are causing lionfish to expand so fast in the western Atlantic Ocean and Caribbean Sea. It examines the negative impacts that lionfish are having on communities as well as sustainable ways of attempting to address the problem of over population. There are several approaches that communities are taking to eradicate lionfish, and this report delves into the specific method of hunting and eating lionfish as a way to mitigate the problem in Bermuda.

How Lionfish Are Able to Rapidly Expand Throughout the Western Atlantic Ocean and Caribbean Sea

The lack of controlling mechanisms in the lionfishes' non-native regions, coupled with their advantageous traits have caused the population to expand exponentially around the Caribbean Sea and Atlantic Ocean. In the Atlantic Ocean there are no controlling mechanisms to keep lionfish populations in check like those in their native habitats, enabling them to become a formidable predator. Controlling mechanisms that lionfish experience in their native regions but not in the Caribbean include parasites and competition with other species. Prey in the Atlantic Ocean and Caribbean Sea do not recognize lionfish as predators, making it easier for lionfish to find their prey for food (Albins & Hixon 2011). Lionfish are also able to expand so fast because of unique traits that make them a formidable predator. What makes the lionfish an effective predator is that it is not a selective feeder; it will prey on almost any fish that can fit inside its

large mouth, which often includes juvenile fish. Lionfish consume over 70 species of fish and many invertebrates, they are capable of eating prey up to half their body length (REEF, 2011). At the Bermuda Institute of Oceanic Sciences, scientists placed a lionfish in an enclosed tank with fry and yellow grunts. The lionfish was able to eat all the fry within a few minutes since the fry did not recognized the lionfish as a predator, and the scenario repeated itself with the yellow grunts in the tank (Bermuda Institute of Oceanic Sciences, 2013). In addition to having a wide variety of food options, lionfish are skilled hunters. The lionfish's slow movements, coloration, and long fins render their appearance similar to seaweed and enable them to remain relatively camouflaged. Lionfish then use specialized swim bladder muscles to control their center of gravity and location in the water to better attack their prey (Morris & Akins, 2009). Lionfish can also hunt other fish by flaring their large spine-like pectoral fins and then herding small fish into a corner before consuming them (Albins & Hixon 2011).

In addition to being impressive predators, lionfish are also able to inhabit many areas around the Caribbean Sea and western Atlantic Ocean because they can survive in a wide range of habitats. Lionfish are able to inhabit all marine habitat types and depths, they can be found along the shoreline to over 300 meters deep (REEF, 2011). Being able to withstand such a dramatic range in depths allows the lionfish to conquer various layers of the water column. In an interview I conducted with Corey Eddy, a professional researcher at the National Science Foundation, he advised that, in Bermuda, the lionfish are difficult to track and control because a dense population of them reside in waters over 200 feet deep (Eddy, personal communication, 2014). The wide range in habitats and depths that lionfish are able to withstand is an obstacle that must effectively be addressed in seeking methods to eliminate them (Eddy, personal

communication, 2014). Lionfish are aided in their survival at different depths by their range in temperature tolerance, which is approximately 10-35°C (50-95°F) (REEF, 2011). In addition to being able to adapt to various temperatures and depths, lionfish can also be found in various habitat types. Although mostly found in coral reefs, lionfish are also found in sea grass beds, mangroves, and as well around artificial reefs such as those built on shipwrecks (Albins & Hixon 2011). Since lionfish are fairly indiscriminate about where the inhabit, they have been able to occupy waters from the top of South America all the way up to the Northeast Coast of the United States.

The last factor that makes lionfish so difficult to eliminate is their breeding habits. Lionfish reproduce very rapidly and in large numbers; the average male lionfish can fertilize 30,000 eggs at a time and the female can produce 30-40,000 eggs every four days (REEF, 2016). These breeding traits have allowed the population to grow at an extremely fast rate. Lionfish have many factors in their favor, both innate and due to being in a non-native region, that have enabled them to rapidly expand their population and territory in the western Atlantic Ocean. These unique factors pose threats to communities' abilities to successfully diminish the presence of lionfish.

Negative Implications of Lionfish in Their Non-Native Regions

The expansion of lionfish is a concern for humans because there are economic impacts associated with the lionfish's destructive invasion. Lionfish are diminishing populations of many juvenile fish on coral reefs, while driving away larger fish in competition for the same

prey. Research by Albins and Hixon in the Bahamas demonstrated the first evidence of negative impacts of lionfish on non-native Atlantic coral reef fish (Schofield et al. 2016). Small patch reefs, some with lionfish present and others without any lionfish present, were studied over a five-week period (Schofield et al. 2016). The study focused on the net recruitment (accumulation of new juvenile fish via settlement of larva) on these small patch reefs (Schofield et al. 2016). This research found that the net recruitment of Bahamian native fish was reduced by 79 percent on small experimental reefs with a single lionfish compared to reefs without lionfish (Albins & Hixon, 2008). The lionfish's eating habits cause a dramatic decrease in biodiversity on the coral reefs, which causes concern for island nations, such as Bermuda, as many of them rely on their coral reefs to contribute to their economies. Lionfish damage corals by over-feeding on herbivorous fish that keep seaweed growth on coral in check; without these herbivores, seaweed would overgrow and damage the reef corals (Albins & Hixon, 2011). There has also been additional research in the Bahamas documenting an increase in lionfish populations that corresponded with a 65 percent decline in the biomass of lionfish prey over a two-year time period (Green et al. 2012). Other studies in the Bahamas have indicated that, "lionfish have a stronger ecological effect on native prey fishes than equivalent native predators, and may pose a substantial threat to native coral-reef fish communities" (Schofield et al. 2016). Bermuda is surrounded by coral reefs like those in the Bahamas. Because the marine habitats in Bermuda and the Bahamas are so similar, it can be inferred from the studies done in the Bahamas that lionfish are negatively impacting the underwater ecosystem in Bermuda's waters. While the long-term effects of lionfish are unknown, their feeding patterns disrupt food webs on the reef and can cause a cascade effect of environmental degradation (Gleason & Gullick, 2014).

According to the National Oceanic and Atmospheric Administration, coral reefs around the globe provide goods and services estimated to be worth $375 billion annually (NOAA, 2008). Coral reefs play a large role in tourism, since many tourists want to visit places with beautiful coral reefs. In addition to affecting the tourism industry, the lionfish expansion is a threat to economies based on fishing. In an article published in The Bahamas Weekly, the Conservancy believes that the lionfish destruction of coral reefs will have a direct impact on tourism, fishing, and related industries (Thurston, 2010). The Conservancy stated in that article, "tourists come here to see the turquoise waters, they come to fish and dive and enjoy the beautiful reefs, if these things go, there will be no reason for tourists to come anymore" (Thurston, 2010). Coral reefs provide economic benefits to Bermuda by protecting the coast from storms and hurricanes, aiding the tourism industry, and supporting fisheries (Sarkis, van Beukering, McKenzie, 2010). Bermuda's marine ecosystem is considered to be the island's greatest natural resource, with a grand 280 square miles (725 square km) of reef area (Gleason & Gullick, 2014).

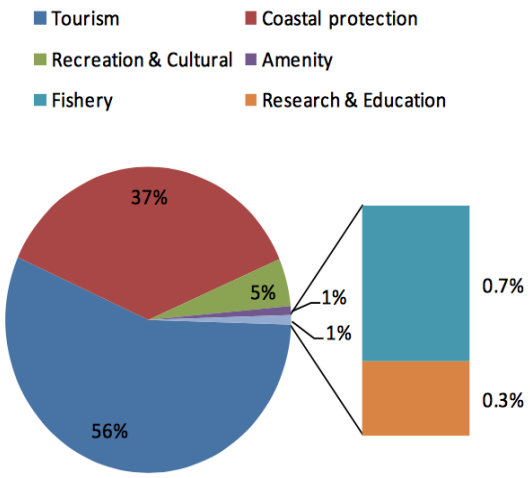

Figure 4: Composition of ecosystem services valued for Bermuda's coral reefs (Living Reefs Foundation, 2013).

In Bermuda, coral reefs earn the island an average of $722 million per year, making the Total Economic Value (TEV) of Bermuda's reefs approximately 10 to 17 percent of the island's GDP (Living Reefs Foundation, 2013). The reefs produce this amount of revenue mainly through tourism and coastal protection but other ecosystem services include recreational and cultural, fisheries, amenities, and research and education (Living Reefs Foundation, 2013).

Residents of Bermuda are very concerned about the lionfish invasion. Graham Maddocks, the President of the Ocean Support Foundation, which works with the government and research agencies to help reduce Bermuda's lionfish population, stated, "the lionfish invasion is probably the worst environmental disaster the Atlantic will ever face." (Linendoll, 2013). The lionfish expansion into Bermuda has been rapid, and various sources have reported increasing numbers of lionfish through sightings and captures (The Ocean Support Foundation, 2016). The Ocean Support Foundation is a Bermudian foundation whose primary goal is to reduce lionfish populations around the island (The Ocean Support Foundation, 2016). Their collection of lionfish sightings and captures shows the dramatic increase in lionfish sightings and captures around Bermuda from 2013 to 2015. Because of the economic value that coral reefs hold, any potential threat to their health, such as lionfish, poses a threat to economies reliant upon the health of corals. Lionfish are expanding in population size and undoubtedly are posing serious threats to Bermuda's economy and causing people to seek measures of eradicating them.

Figure 5: 2013 Lionfish sightings & captures around Bermuda

Figure 6: 2015 Lionfish sightings & captures around Bermuda

Current and Potential Methods of Addressing the Lionfish Epidemic

The lionfish invasion into the Western Atlantic Ocean and Caribbean Sea has caused scientists, conservation organizations, and local governments to seek methods of addressing the lionfish epidemic. REEF, an organization dedicated to ocean conservation, cites Bermuda's government as one of the major collaborators and supporters of REEFS efforts to combat the lionfish invasion (REEF, 2012). There are a variety of current and potential methods to address the lionfish epidemic in the Western Atlantic Ocean and Caribbean Sea.

One current strategy to address the lionfish invasion is to work with aspects of the ecosystem to try to eradicate lionfish in a more natural and sustainable way. The appealing aspect of utilizing the ecosystem is that it would require little future human involvement. Some predators such as sharks and groupers have begun to recognize lionfish as potential prey, and scientists believe that there is hope that these predators will help move lionfish down the food chain (Albins & Hixon, 2011). Fishermen in the Bahamas have claimed that native groupers were preying on lionfish with some regularity, of five Nassau groupers caught off Eleuthera Island, two contained lionfish in their stomachs (Maljkovic et al. 2008). Some divers in the Cayman Islands are using this naturally occurring feeding pattern as a method for eradicating lionfish, and they have done so by training Nassau groupers to eat lionfish (Albins & Hixon, 2011). An issue with this approach to controlling the lionfish population is that studies of Nassau groupers and small lionfish in captivity have shown that the large and hungry groupers will not eat small lionfish (Albins & Hixon, 2011). Accordingly, it may be unlikely that relying on groupers to eat large lionfish will effectively be able to curb lionfish populations since the

lionfish have already matured and most likely would have already. Another proposed method of using nature to eliminate lionfish is to enhance the native biotic resistance through marine reserves that could allow potential natural enemies of the lionfish to prosper (Albins & Hixon, 2011). Mark Albins and Mark Hixon (2011) of the Department of Zoology at Oregon State University think that the lionfish invasion will be controlled by either the starvation of lionfish or by a combination of "native pathogen, parasites, predators, and competitors controlling the abundance of lionfish". Introducing natural elements to curb an invasive species is referred to as a biological control. Biological control, "is the reliance upon natural enemies to attack pest organisms that damage human interests" (Secord, 2003). These methods of incorporating feeding patterns of the underwater ecosystem are a way to attack the lionfish problem and establish a sustainable approach to the issue of their expansion that does not require potentially harmful human intervention. While the method of biological control has successfully regulated pest populations in terrestrial ecosystems, it also has the potential to cause negative unintended consequences for native species (Secord, 20013). Because of the potential negative implications on native species that biological controls have, other methods of eradication need to be examined.

One of the most popular methods of eradication is to hunt and eat lionfish. Fishing as a sport appeals to a large portion of the public in the island communities and that accordingly people could be motivated to help eradicate the lionfish by fishing for them. Stemming from fears about fishing and the impact on restaurants, communities have incorporated industries, such as fisheries and the restaurants, in efforts to kill lionfish. In Bermuda and in other Caribbean islands, a current popular solution is to have divers catch lionfish. Divers harvesting lionfish can

provide a significant amount of control over local populations, especially if they are easily accessible by shore or boat (Morris & Whitfield, 2009). Lionfish residing in the shallow water can easily be hunted by spearfishing, Mark Outerbridge, a champion lionfish hunter, describes lionfish hunting as something anyone could enjoy doing at a low cost with minimal equipment – a basic snorkel gear and a regulation spear (Lagan, 2015). In Bermuda, lionfish reside in deep waters in addition to shallow waters. Katie Linendoll, a writer for CNN, described joining a team of divers in Bermuda to reach the lionfish at deeper depths in order to access these deep residing predators. In this case, she noted that divers have to endure large depths and complicated gear (Linendoll, 2013). Linendoll recounts that the dives are complicated by bottom time, meaning that "at deeper dives of 200 feet, these highly trained divers can only stay down for about 25 minutes before they run out of air and decompress their bodies" (Linendoll, 2013).

Developing seafood initiatives could compliment fishing efforts and make lionfish hunting more profitable. Communities are encouraged to conduct workshops and provide educational materials on how to properly clean and prepare lionfish. Outreach initiatives, such as conducting workshops and providing educational materials on how to clean and prepare lionfish, are important to getting restaurants and consumers interested in eating lionfish as a "green" alternative to eating overfished species of fish (Morris & Whitfield, 2009). By getting restaurants on board with the idea of serving lionfish, lionfish have the potential to increase in demand with fishermen and divers starting to the revenues associated with hunting them (Eddy, personal communication, 2014). As many island economies depend on tourism as a main industry, it is becoming more appealing to incorporate tourism with lionfish removal. Snorkeling and scuba diving are among the most popular activities for tourists travelling to

tropical and subtropical regions (Tabata, 1990). As these recreational activities are becoming increasingly popular, they provide a gateway for lionfish hunting to become a part of ecotourism. In Bermuda, any visitor can receive training and then will be permitted to hunt lionfish off of any tour boat. A great initiative that brings together the fishing, restaurant, and tourism industries is the emergence of lionfish tournaments; these tournaments encourage communities and tourists to participate in killing and/or eating lionfish. In the Caribbean and western Atlantic lionfish derbies have been held by conservation agencies, members of the private sector, and local governments where divers killed hundreds of lionfish and were used in a community cookout (Albins & Hixon, 2011). The Reef Environmental Education Foundation (REEF) promotes efforts such as the annual 'Eat 'em to Beat 'em' Lionfish Tournament in Bermuda, and there are many other lionfish derbies in Florida and all over the Caribbean (REEF, 2016). In my interview with Corey Eddy, he spoke of how the annual lionfish tournament in Bermuda has made a huge impact on eliminating lionfish as more people are starting to catch lionfish (Eddy, personal communication, 2014). Efforts that incorporate tourism, fishing, and restaurant industries are a potential method of eradicating lionfish by involving communities and making lionfish removal economically profitable.

METHODS

For this research on Bermuda's consumption of lionfish, interviews were the primary research method. I interviewed Bermudians and Bermudian residents about their interactions with lionfish. My three subgroups were professional chefs, commercial fishermen, and the general public. The interview approach to the research I needed for this Thesis was the most productive as I was able to speak directly with members of a community affected by lionfish overpopulation and learn from their direct knowledge as to how to prepare lionfish and how lionfish are included in commercial fishing. Moreover, I was able to gain insight on the island's general viewpoint towards the consumption of lionfish as a potential solution to eliminating them. First, I researched my topic generally and obtained background knowledge on the lionfish invasion in the Atlantic Ocean, specifically in Bermuda. The knowledge that I obtained from this research is primarily from scholarly sources, peer-reviewed journals, articles, and other data. After obtaining the necessary background research, I gathered materials needed for the project, such as identifying restaurants whose chefs I could interview about lionfish, and identifying commercial fishermen who had experience with lionfish. I made a spreadsheet containing this information to use in organizing my progress in interviewing individuals.

Next, I began the process of interviewing my first subgroup of people: the chefs. I first gave my survey to a chef who was a family friend to gain feedback on the questions in the survey and adjusted my survey accordingly. I found that chefs are very busy throughout their workday with unpredictable breaks or down time. Because of their hectic schedules, I found that the best way to encourage chefs to participate was to drop off the surveys at their restaurants for

them to complete at their convenience. When going to each restaurant, I explained my project and goals for my research to the chefs, and as well briefed them about the types of questions on the survey. I also reassured them that their identities would remain anonymous in my presentation of the data. After dropping off the surveys, I scheduled a time to return and retrieve the surveys, making it as convenient as possible for the chefs to participate in the survey. At the completion of my distribution and collection of surveys, I organized and filed them for future analysis.

In addition to surveying chefs, I undertook the task of interviewing commercial fishermen, which was fairly similar to my interview methods for the chefs. I first revised my interview questions based on feedback from close friends who are commercial fishermen. I then contacted fishermen in Bermuda and explained the goals of the project, as well as outlined the types of questions in the survey. In addition to reaching out to fishermen and arranging interviews, I also found it helpful to go to known locations where they kept their boats. I was able to confer with some more fishermen and distribute my questionnaires. When I was finished collecting responses, I organized my notes and filed them for later review. Copies of the original survey questions can be found in appendixes D, E, and F.

The next step was to round out my interviews with interviews of the general public. I first revised the survey questions and created an online version of the survey that I distributed online via email and social media. I collected responses from the general public by direct interviews, through random street polling, through door-to-door surveys, and through distribution via social media and email.

In order to streamline my data into electronic form, I input my hardcopy surveys into a survey-organizing website. I then collected and organized all my data by producing graphs and figures of my statistics through SurveyMonkey. For each survey question asked, SurveyMonkey produced a graph illustrating the distribution of answers to that question.

RESULTS

Residents of Bermuda Questionnaires

When surveying the general public in Bermuda, I sought out a wide range of participants to question about the lionfish invasion. Through finding people of varying backgrounds, careers, and ages, I hoped to have surveyed an accurate and diverse representation of Bermuda's population. The lionfish invasion into Bermuda appears to be well known by residents, with 96.30 percent of my interviewed population stating that they were aware of the problem. Of those who were aware of the lionfish presence in Bermuda, the majority (56.96 percent) learned via word of mouth, with social media and news sources being close second and third sources of information. For those who answered 'other', references included scholarly sources such as Ted Talks and educational institutions, as well as seeing lionfish while participating in ocean-related activities such as scuba diving or snorkeling. Bermudians have encountered lionfish in a variety of ways. The majority of Bermudians have encountered lionfish by seeing one in a public aquarium tank. The fact that 70.59 percent of lionfish encounters were through seeing a lionfish at a public

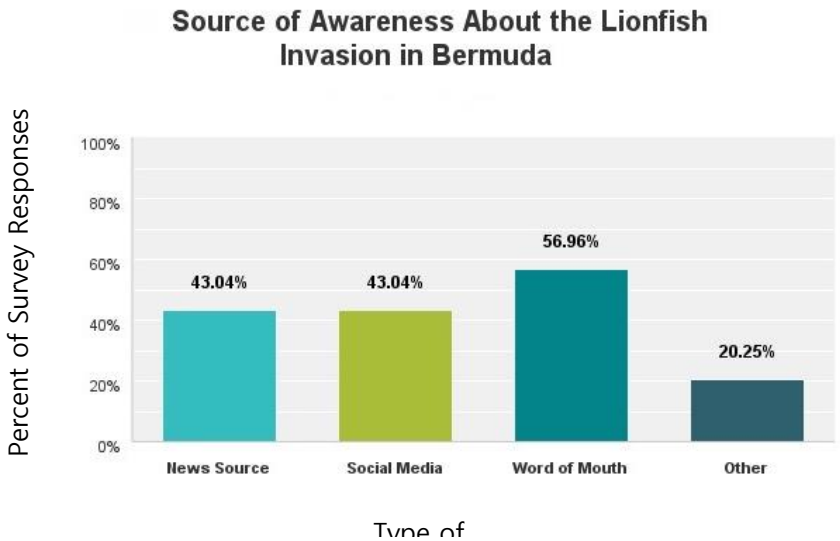

Figure 7: Results for types of awareness that residents of Bermuda have regarding lionfish invasion.

aquarium shows how important educational efforts are in adressing this issue. What is surprising is that of the people interviewed that have encountered lionfish in Bermuda, 41.18 percent have encountered lionfish by catching them. These people belong to the category of general residents of Bermuda that do not hold commercial fishing liscenses. This demonstartes that there are a lot of people catching lionfish who are not doing so to make money commercially. Almost half of these reported lionfish encounters have occurred by people seeing them in the water. Not many people in Bermuda have encountered a lionfish on a menu. Of the people that I surveyed, only 16.18 percent of those that encountered lionfish did so by seeing one on a menu in Bermuda. This low number of sightings on a menu suggests that lionfish in Bermuda are not present in restaurants.

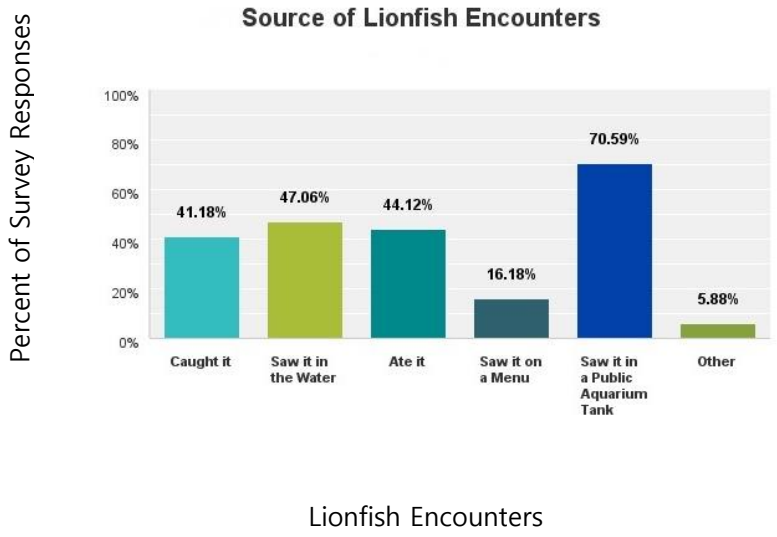

Figure 8: Results for the types of lionfish encounters that residents of Bermuda have had.

For non-commercial fishermen (those not making their primary income from fishing), the majority of them catch lionfish by spearfishing. Specifically, 65.29 percent of non-commercial fishermen catch lionfish by spearfishing while scuba diving. The second most popular method for catching lionfish by non-commercial fishermen is spearfishing while free diving. Only 10.71

percent of my surveyed people reported catching a lionfish with a hand line. For the people who answered that they have caught a lionfish in the past, the majority (46.43 percent) obtained that skill in a class or workshop. A close second method of learning how to catch lionfish was learning from a friend or a colleague.

Professional Chefs Questionnaires

My goal with interviewing chefs in Bermuda was to gauge the level of involvement that chefs in Bermuda have with lionfish. I wanted to see how many chefs know how to prepare lionfish and what their interest is in preparing and serving the fish in their restaurants. From my questionnaires, I learned that only 35 percent of the chefs I met with know how to prepare lionfish, while 65 percent do not. For the chefs who know how to prepare lionfish, the vast majority (85.71 percent) learned how to prepare lionfish verbally from a friend or colleague. Only one chef

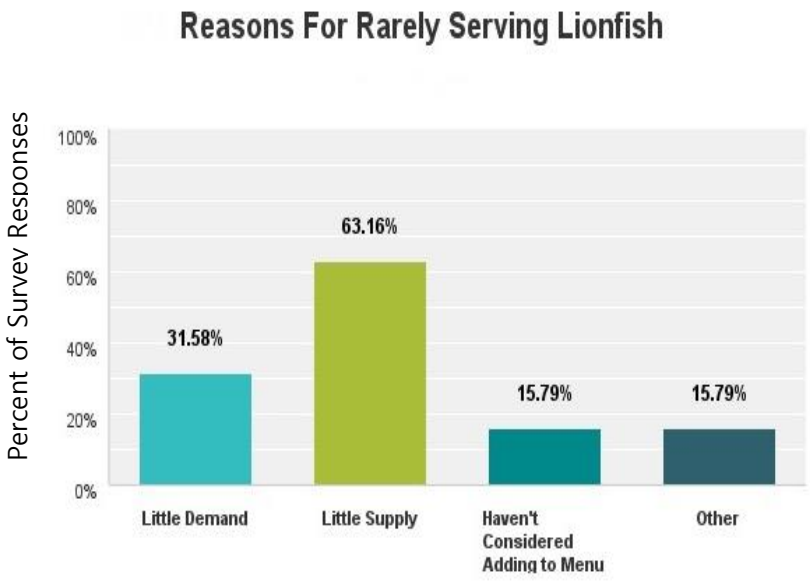

Figure 9: Results of reasoning for rarely serving lionfish at restaurants in Bermuda.

learned how to prepare lionfish from a class. Of the chefs that do not know how to prepare lionfish, 76.92 percent answered that they would like to learn, 15.38 percent answered they would not like to learn, and 7.69 percent were indifferent. None of the chefs I interviewed said that the restaurants they work at serve lionfish all the time or on a regular basis; 75 percent of the restaurants surveyed never serve lionfish, and only 25% sometimes serve lionfish. The majority of chefs claim that they do not serve lionfish because there is little supply. Another reason for not serving lionfish is that 31.58 percent of the chefs felt there was little demand for them and 15.79 percent simply had not considered adding lionfish to the menu. Among the reasons for choosing other, several chefs said they do not serve lionfish because they do not know how to prepare it.

Commercial Fishermen Questionnaires

Of the commercial fishermen that I interviewed, 75 percent said that they have caught a lionfish and 25 percent have not. For those that have never caught a lionfish, only two people said they were interested in learning how to catch lionfish and two said they were not interested in learning. The remaining 55.56 percent felt indifferent about learning how to catch lionfish. The most common way of catching lionfish is by hand line, with 66.67 percent of lionfish caught by commercial fishermen that way. Another popular way that commercial fishermen in Bermuda are catching lionfish is as bycatch, which means that the lionfish are caught unintentionally while catching certain target species of marine life - 40 percent of commercial fishermen who reported catching lionfish in Bermuda have done so by catching them unintentionally in lobster pots when trying to catch Bermuda Spiny lobster. Of the commercial

fishermen who have reported to have caught lionfish, 33.33 percent have caught them by spearfishing while free diving and only 6.67 percent have used lionfish pots. Lionfish have venomous spines that need to be cut off but 94.44 percent of the fishermen surveyed felt confident that they would know how to handle a lionfish if they were to catch one. The majority of commercial fishermen (66.67 percent) who have caught lionfish have used them for personal consumption. The second most common thing to do with captured lionfish is to release them, as 46.67 percent of commercial fishermen reported releasing the lionfish they have caught. Of the commercial fishermen who have caught lionfish, 20 percent have given their lionfish to friends to eat. The fishermen are not commonly selling the lionfish commercially, only 6.67 percent of the fishermen who have caught lionfish have sold them commercially. The annual lionfish tournament in Bermuda occurs every year in July, where people can go out and join teams to capture lionfish. None of the commercial fishermen that I surveyed has given lionfish to the annual lionfish tournaments.

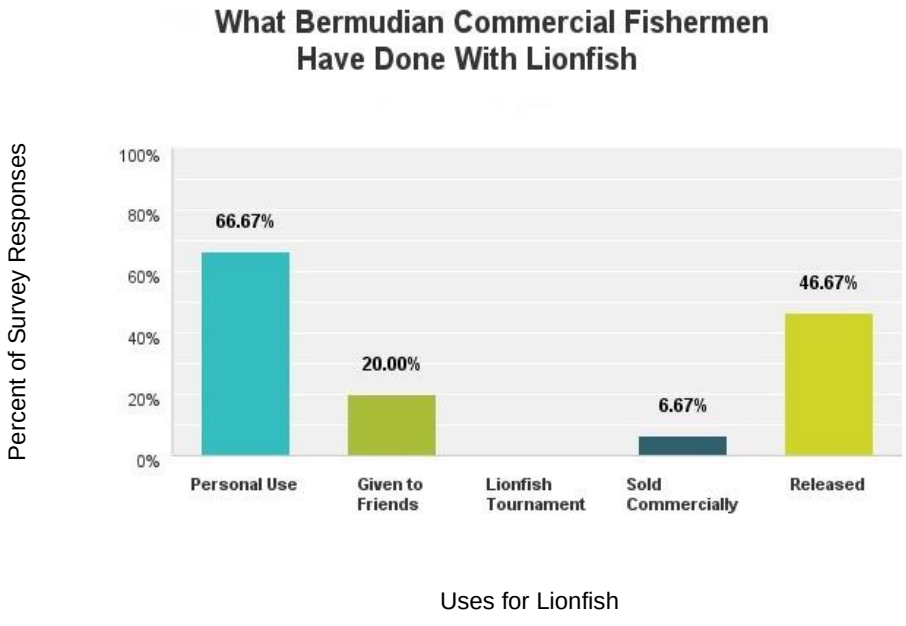

Figure 10: Results for what Bermudian commercial fishermen have done with the lionfish they have caught.

DISCUSSION

How Data Connect to Bermuda Fishing Laws

Spearfishing is an ancient method of fishing that utilizes elastic-powered spearguns, slings, or compressed gas pneumatic-powered spearguns. Spearfishing may be done utilizing snorkeling, freediving, or SCUBA diving techniques. In Bermuda, a license is required for spearfishing, which is a regulation that has been in place since 2011 (Marine Resources and Fisheries Enforcement, 2016). The use of spearguns is outlawed in Bermuda, enabling people to only use manually operated pole spears (Marine Resources and Fisheries Enforcement, 2016). In Bermuda, spearfishing can only occur while freediving, and the use of SCUBA or any other breathing apparatus cannot be used when spearfishing. The sale of speared fish is illegal in Bermuda, even by commercial fishermen. Modifications, regarding lionfish, to these strict laws are frequently proposed, and some modifications have been enacted. These modified lionfish laws are less stringent than the original, prohibitive laws. For spearing all other fish, SCUBA tanks, spearguns, and spearing within one nautical mile offshore is outlawed, but lionfish are exempt from these rules (Marine Resources and Fisheries Enforcement, 2016). Lionfish are the only species of fish that do not have these strict laws imposed on them because they are an invasive species and thus hunting them is encouraged.

Throughout the questionnaires, results demonstrated that spearfishing is a popular activity for both commercial fishermen and recreational fishermen (those who do not have a commercial fishing license). It is surprising that, of the people interviewed who have encountered lionfish in Bermuda, 41.18 percent have encountered lionfish by catching them. These people belong to the

category of general residents of Bermuda who do not hold commercial fishing liscenses and are catching lionfish recreationally. The majority of non-commercial fishermen catch lionfish by spearfishing. Specifically, 65.29 percent of non-commercial fishermen catch lionfish by spearfishing while SCUBA diving. The second most popular method for catching lionfish by non-commercial fishermen is spearfishing while freediving, 35.71 percent of recreational fishermen have caught lionfish using this method. Of the commercial fishermen who have reportedly caught lionfish, 33.33 percent have caught them by spearfishing while freediving. Spearing lionfish has been demonstrated to be a popular way to catch lionfish around Bermuda's waters and results from the surveys show that fishermen (recreational and commercial) are utilizing the less-stringent spearfishing laws regarding lionfish.

Bermuda Environmental Policy Regarding Lionfish

Bermuda has recognized that the lionfish invasion is a severe problem threatening the island's coral reef ecosystems and the economy. In October 2012, members from various organizations met to conduct the Bermuda Lionfish Control Plan Workshop, which was comprised of 31 participants, representing more than 15 organizations from around the island (Gleason & Gullick, 2014). At the end of the meeting, the Bermuda Lionfish Control Plan was formed, and the Bermuda Lionfish Task Force was established to begin work on the plan (Gleason & Gullick, 2014). The Bermuda Lionfish Task Force is comprised of government members, scientific research and education organizations, divers, fishermen, National Government Organizations and the corporate private sector (Gleason & Gullick, 2014). The mission of the Bermuda Lionfish Task Force is "to raise public awareness of the lionfish

invasion in Bermuda and to coordinate and support all activities to control lionfish population growth, thus reducing any negative impacts of the lionfish on our coral reefs, for the benefit of all Bermudians" (Bermuda Lionfish Task Force, 2015). The purpose of the Lionfish Control Plan is to guide the Bermuda Lionfish Task Force partners, general public, and other stakeholders in addressing the long-term effects of lionfish in Bermuda's waters (Gleason & Gullick, 2014). There are five priorities outlined by the Lionfish Control Plan: education, outreach, and training; research and assessment; detection and removal; monitoring and data gathering; and data management (Gleason & Gullick, 2014).

Members of the coalition were able to implement a lionfish sighting and capture reporting program. As highlighted earlier, lionfish sightings and captures can be reported to the Ocean Support Foundation in order to keep track of the lionfish population size. The Ocean Support Foundation is a Bermudian foundation whose primary goal is to reduce lionfish populations around the island (The Ocean Support Foundation, 2016). Their collection of lionfish sightings and captures shows a dramatic increase in lionfish sightings and captures around Bermuda in recent years. The members of the Lionfish Taskforce, in collaboration with the Ocean Support Foundation, were able to establish an online database to collect reports for use by researchers (Gleason & Gullick, 2014).

A main priority of the Bermuda Lionfish Taskforce is implementing education and outreach programs for students and other audiences. Educating the public about the lionfish invasion and the detrimental effects it has on the reefs and economy is a necessary starting point for increasing community involvement. The Lionfish Control Plan aims to reduce the lionfish

population in Bermuda by increasing awareness of sighting and spearing procedures in order to gain support. Implementing lionfish education in local school districts is important. The Bermuda Lionfish Control Plan also targets education efforts at members of the government and the private sector (Gleason & Gullick, 2014).

The Lionfish Control Plan also aims to minimize potential health risks to the general public from contact with their venomous spines. The Lionfish Control Plan aims to minimize these potential health risks by teaching the general public how to properly handle and collect lionfish through demonstrations and other media. The overarching message that the Taskforce wants to deliver to the public is that lionfish have venomous spines but are not poisonous, and that "lionfish are edible and do not have venom within their meat" (Gleason & Gullick, 2014). These efforts to minimize health risks also aim to reduce public concern about handling or consuming lionfish (Gleason & Gullick, 2014). Informing the public about how to handle lionfish is crucial in fostering an interest in catching and/or preparing lionfish as a seafood alternative. Likely a result of these outreach initiatives, 33.33 percent of the residents whom I interviewed already knew how to prepare and cook lionfish. Among Bermudians, there is a high amount of interest in learning how to prepare and cook lionfish. Specifically, 44.44 percent of Bermuda's residents expressed that they would be interested in learning how to prepare lionfish. Because interest is high, these education initiatives are important for increasing involvement. The Bermuda Lionfish Taskforce collaborated with local organizations, such as the Bermuda Institute of Oceanic Sciences, the Ocean Support Foundation, Bermuda Aquarium Museum and Zoo, and the Bermuda Underwater Exploration Institute, to implement education and outreach programs (Gleason & Gullick, 2014). Initiatives have included hosting a Lionfish Exhibit and Invasive

Species Lecture Series at the Bermuda Underwater Exploration Institute as well as hosting the annual Groundswell Lionfish Tournament (Gleason & Gullick, 2014). There is also now a permanent Lionfish Exhibit at the Bermuda Aquarium Museum and Zoo. The Bermuda Lionfish Task Force has also used "website and social media materials" to aid in distributing information about lionfish to residents of Bermuda. These initiatives have proven to be extremely significant in educating the public about the lionfish invasion in Bermuda. Of the members of the residents whom I surveyed in Bermuda, 96.3 percent were aware of the lionfish invasion. 43.04 percent of those who were aware of the lionfish invasion reported having learned about it from social media. The majority of lionfish encounters that residents of Bermuda experienced occurred by seeing a lionfish in a public aquarium. Specifically, 70.59 percent of residents who have encountered a lionfish have done so by seeing one in a public aquarium. The high number of exposure to lionfish occurring at aquariums demonstrates how important and influential these educational institutions are in informing the public about lionfish.

Bermuda's Lionfish Culling Program

The Lionfish Control Plan outlines plans and programs to detect and remove lionfish in Bermuda's waters by culling them. Culling involves reducing the population of a specific species by selectively killing members of that species. The initial lionfish culling program was established in 2008 and focuses efforts on spearfishing for lionfish. The lionfish culling program allows for some spearfishing restrictions to be lifted for capturing lionfish. For shallow-water culling, "interested local volunteers will be trained to cull lionfish at depths accessible to snorkelers and recreational divers" (Gleason & Gullick, 2014). Cullers can choose to be trained

on how to properly spear and handle lionfish, and the Ocean Support Foundation provides volunteers with information on permit requirements. The $20, two-hour-long course allows SCUBA divers, snorkelers, and freedivers to obtain a permit to spear lionfish anywhere in Bermuda (Wilson, 2013). The course covers information about lionfish, safe handling, and spearing practices (Wilson, 2013). These courses are conducted on behalf of the Bermuda Government and are advertised on the Bermuda Lionfish Culling Program Facebook page and other forms of media (Trott, personal communication, 2016). Once volunteers complete the training, cullers receive a plastic permit tag and will be re-issued permits on an annual, renewable basis. The Department of Environmental Protection oversees these permits because they fall outside of the normal fisheries' regulations and allow opportunities to circumvent the fisheries' regulations. In the past, spearfishermen could only spearfish while freediving, but new laws allow lionfish to be exempt from this rule, and they can be speared with the use of SCUBA equipment (Gleason & Gullick, 2014). The permit also allows those who normally do not spearfish to cull lionfish without obtaining a spearfishing license. Cullers are required to report their catches to the Ocean Support Foundation database (The Ocean Support Foundation, 2016). Volunteers are encouraged to adopt a reef area and register it with the Lionfish Task Force or the Ocean Support Foundation. When divers adopt a reef, they are encouraged to visit it regularly to seek out and cull any lionfish that are present (Gleason & Gullick, 2014).

In addition to shallow water culling, the Lionfish Control Plan also outlines plans for deep water culling. Because of the presence of lionfish in deeper waters, shallow water culling is not sufficient enough to combat lionfish in Bermuda. The only way to retrieve these deeper lionfish is through deep water culling or catching them in traps. Volunteers interested in deep water

culling are trained in appropriate deep diving techniques and will then conduct deep water culling. Deep water culling should focus on protected marine areas that are normally closed to fishing "where a lionfish trap fishery would not be able to operate" (Gleason & Gullick, 2014). Deep water culling is a viable way of approaching the lionfish problem until a functioning trap fishery is developed.

Bermuda's Lobster Fishery and Lionfish Pots

While spearfishing is a popular method for lionfish removal in Bermuda, many lionfish are concentrated in deeper waters (30-60 meters) that are inaccessible to volunteer cullers (Pitt & Trott, 2013). Since spearfishing and culling can typically only access lionfish in shallower waters, initiatives have been developed to incorporate lionfish into the commercial fishing industry via trapping. The Lionfish Control Plan outlines that, "lionfish have been caught as bycatch in Bermuda's commercial lobster trap fishery since at least 2003, and have been a regular feature since 2008" (Gleason & Gullick, 2014). Bycatch refers to any fish or marine species that is caught unintentionally while targeting a different species. Lionfish are likely being caught in lobster traps because they feed on the same bait as well as juvenile spiny lobsters (Schofield et al. 2016). Lionfish are caught as bycatch quite frequently, 40 percent of the Bermudian commercial fishermen surveyed who have caught lionfish have caught them as bycatch in lobster pots. Lionfish bycatch mainly occurs at water depths of 40 to 80 meters (Pitt & Trott, 2013). In response to the high number of occurrences of lionfish being caught as bycatch, modifications have been made to fishing laws to adjust for these changes. In the past, bycatch from lobster traps could not be sold, but lionfish caught as bycatch by commercial

fishermen in the lobster trap fishing industry can now be sold. In an interview with Corey Eddy, he highlights this as, "an example of adapting regulations to promote the capture and sale of lionfish" (Tripp, 2013). In addition to modifying bycatch laws, new developments have also been formulated to target lionfish specifically in traps. In response to the occurrences of lionfish showing up as bycatch, the Department of Environmental Protection released a 15-year strategic plan, in 2010, to combat the lionfish invasion within the commercial fishing industry. This plan includes developing a commercial fishery for lionfish. The plan for developing a commercial fishery involves creating special lionfish traps. These traps are a modification from the original lobster traps, and are designed to "increase the catch of lionfish, reduce catch of spiny lobster, and maintain low levels of finfish bycatch for which this standardized trap was developed" (Pitt & Trott, 2013). Proposed modifications to the traps include, "shading the traps, varying the funnel opening and varying baiting practices" (Pitt & Trott, 2013). It is anticipated that lionfish trap fishery would operate alongside the offshore spiny lobster fishery during the lobster season, from September through December (Pitt & Trott, 2013).

Figure 11: Varying versions of lionfish pots.

RECOMMENDATIONS

Lionfish Trapping

As highlighted in the Lionfish Control Plan, "until a functioning trap fishery is developed, culling by divers represents the most effective means of removal from aggregated populations at depth, and thus deep water culling by divers should occur across the Bermuda platform and be a main focus for control efforts" (Gleason & Gullick, 2014). While spearing lionfish is a popular means of removal, I would recommend that Bermuda continues to focus efforts on developing a sustainable lionfish trap fishery. Of the commercial fishermen surveyed in Bermuda, only 6.67 percent of those who have caught lionfish have done so with lionfish pots. This demonstrates that lionfish pots are starting to be more prevalent, but they are not high in use. A concern with the lionfish pots is the occurrence of lobster bycatch in the traps. Because of this, the lionfish pots would have to run in accordance with the lobster trapping season from September through December. The lobster industry in Bermuda is highly regulated, and lobsters are protected during the summer months so they can reproduce and sustain a healthy population. Moving forward, I recommend that additional research be done on how to effectively reduce lobster bycatch. "If lobster bycatch can be sufficiently reduced, the lionfish trap fishery could potentially operate during the summer months, but the need to protect brooding female lobsters must take priority over expanding the lionfish trapping season if lobster bycatch remains an insurmountable issue" (Pitt & Trott, 2013). If commercial fishermen can also trap lobsters in the summer months, then there will be more incentive for them to engage in lionfish trapping to supplement their lobster trapping during the winter months.

The Potential Sale of Speared Lionfish

In Bermuda, spearfishing is a fairly common method for removing lionfish, and modifications have been made to current laws to accommodate the lionfish invasion into the sport. Of the commercial fishermen who have caught lionfish, 33.33 percent have done so by spearfishing while free diving. While the amount of commercial fishermen catching lionfish by spearfishing is fairly high, this method for catching lionfish is more popular for recreational fishermen. Of the recreational fishermen who have caught lionfish, all of them have done so, at least once, by spearing them; 35.71 percent of the instances of captures has been accomplished by freediving, and 64.29 percent has been through SCUBA diving. Normally, in Bermuda, spearfishing with any SCUBA diving gear or any other breathing apparatus is illegal, but there is an exception for killing lionfish (Eddy, personal communication, 2014). In order to legally freedive, divers are to required to be able to freedive without any gear and hold their breath for several minutes underwater. Loosening the restrictions on spearfishing, pertaining to lionfish, contributes to making spearfishing lionfish more accessible to divers. Another modification that has been made is allowing spear fishermen to catch lionfish within one nautical mile offshore, which is outlawed for all other species of fish in Bermuda (Tripp, 2013). Commercial or recreational fishermen are not allowed to sell speared fish (Marine Resources and Fisheries Enforcement, 2016). Currently, the sale of speared fish of any kind is prohibited in Fisheries Regulation 22 (6); therefore, a commercial fisherman would have to be issued a special permit to sell lionfish, but no such permits have been issues or requested (Trott, personal communication, 2016). This law is in accordance with Bermuda's strict environmental regulations. Strict fishing laws are crucial in protecting Bermuda's coral reefs and marine ecosystems, but in the instance

of lionfish, these laws must be moderated. I recommend that commercial and recreational fishermen be allowed to sell speared lionfish. Loosening strict fishing laws is not normally beneficial for marine ecosystems, but in the case of lionfish, overfishing should be encouraged. As lionfish expert, Corey Eddy, points out, "typically, we want to limit fishing effort to allow fish populations to grow for the sake of a healthy ecosystem. Here, we want to maximize the effort to minimize the population for the same outcome" (Tripp, 2013). Allowing fishermen to sell speared lionfish will likely provide more of an incentive to actively cull lionfish. The government of Bermuda has launched a pilot program in December 2015 that has allowed five lionfish permit holders to sell speared lionfish to restaurants and markets. The concept behind this idea is to help develop the fishery by increasing the supply (Eddy, personal communication, 2016). Depending on the success of the program, there is potential to expand the amount of spearfishermen allowed to sell any speared lionfish. Currently, incentives to spear lionfish are based on an interest in the sport as well as conservation. Allowing fishermen to sell speared lionfish would provide another incentive for them to actively engage in lionfish removal efforts.

Teaching Chefs to Prepare Lionfish

There is a low presence of chefs in Bermuda that know how to prepare lionfish but there is a high level of interest in learning how. Only 35 percent of the surveyed chefs in Bermuda know how to prepare lionfish. Of those who know how to prepare lionfish, 85.71 percent learned from a verbal explanation from a colleague or friend. The remaining 14.29 percent of the surveyed chefs learned how to prepare lionfish from a class. Although few chefs know how to prepare lionfish, 76.92 percent of those who don't know would like to learn how to prepare

the fish. 80 percent of the chefs believe that knowing how to prepare lionfish is beneficial to their careers. The remaining 20 percent of chefs were indifferent, and none of the chefs surveyed felt that it was not beneficial. Although only a handful of chefs in Bermuda know how to prepare lionfish, there is a high interest in learning how. Since there is a high percentage of chefs interested in learning how to prepare and cook lionfish, an effective solution would be to hold classes or seminars to teach chefs these skills. Classes could follow the model of the existing lionfish culling permit classes and could be held regularly and sponsored by the Bermuda government. It is important to provide these opportunities for chefs interested in knowing how to prepare and cook lionfish. Classes teaching these chefs to prepare lionfish would likely increase interest and enthusiasm regarding serving lionfish in Bermudian restaurants.

CONCLUSION

In order to make progress in combatting the lionfish invasion in the Western Atlantic Ocean and Caribbean Sea, more research is needed to be done and further questions must be investigated. Modifications need to continue to be made on lionfish traps to see if it is possible to improve them to reduce the amount of lobster bycatch. Further research would need to be done on what the success would be of workshops offered to teach chefs to prepare lionfish. Following the implantation of the pilot program allowing a select group of spearfishermen to sell their speared lionfish, research needs to be done to determine if legalizing the sale of speared lionfish can promote a sustainable lionfish fishery.

Bibliography:

Albins, M. A., & Hixon, M. A. (2008). Invasive indo-pacific lionfish pterois volitans reduce recruitment of atlantic coral-reef fishes. *Marine Ecology Progress Series, 367*, 233-238.

Albins, M. A., & Hixon, M. A. (2011). Worst case scenario: Potential long-term effects of invasive predatory lionfish (pterois volitans) on atlantic and caribbean coral-reef communities. *Environmental Biology of Fishes*, , 1-7.

The Bahamas Economy: Population, GDP, inflation, business, trade, FDI, corruption. (2013). Retrieved from http://www.heritage.org/index/country/bahamas

Bahamas: Economy. (2013). Retrieved from http://globaledge.msu.edu/countries/bahamas/economy

Bermuda lionfish task force. (2015). Retrieved from http://www.lionfish.bm

Eddy, C. (2014). Researcher and Grad Student, Lionfish Task Force. Phone Interview.

Eddy, C. (2016). Researcher and Grad Student, Lionfish Task Force. Email Interview.

Forbes, K. A. (2016). Bermuda's economy. Retrieved from http://www.bermuda-online.org/economy.htm

Gleason, J., & Gullick, H. (2014). Bermuda Lionfish Control Plan Version 6. Prepared by the Bermuda Lionfish Taskforce. 60 pages.

González, J., Grijalba-Bendeck, M., Acero, A., & Betancur-R, R. (2009). The invasive red lionfish, pterois volitans (linnaeus 1758), in the southwestern caribbean sea. *Aquatic Invasions, 4*(3), 507-510.

Green, S., & Côté, I. (2009). Record densities of indo-pacific lionfish on bahamian coral reefs. *Coral Reefs, 28*(1), 107-107.

Green, S. J., Akins, J. L., Maljković, A., & Côté, I. M. (2012). Invasive lionfish drive atlantic coral reef fish declines. *PLoS One, 7*(3), e32596.

Importance of coral reefs. (2008). Retrieved from http://oceanservice.noaa.gov/education/kits/corals/coral07_importance.html

The IndoPacific lionfish invasion of the U.S. south atlantic sea coast and caribbean sea. (2010). Retrieved from http://coris.noaa.gov/exchanges/lionfish/

Lagan, S. (2015). Lionfish hunter's tips for successful spearing. *The Royal Gazette*

Linendoll, K. (2013). Lionfish infestation in the Atlantic Ocean now a growing epidemic - CNN.com. Retrieved from http://www.cnn.com/2013/10/18/tech/innovation/lionfish-infestation-atlantic-linendoll/index.html

Lionfish. (2015). Retrieved from http://animals.nationalgeographic.com/animals/fish/lionfish/

Lionfish research program. (2012). Retrieved from http://www.reef.org/lionfish

Living reefs foundations. (2013). Retrieved from http://www.livingreefs.org

Mather, S., & Todd, G. (1993). Tourism in the Caribbean. *Special Report-Economist Intelligence Unit*, (455).

Maljković, A., Van Leeuwen, T., & Cove, S. (2008). Predation on the invasive red lionfish, pterois volitans (pisces: Scorpaenidae), by native groupers in the bahamas. *Coral Reefs*, *27*(3), 501-501.

Marine ecology & conservation at CIEE research station bonaire: Lion fish bonaire. (2008). Retrieved from http://www.cieebonaire.org/News/Lionfish.html

Morris Jr, J. A., & Akins, J. L. (2009). Feeding ecology of invasive lionfish (pterois volitans) in the bahamian archipelago. *Environmental Biology of Fishes*, *86*(3), 389-398.

Morris Jr, J. A., Thomas, A., Rhyne, A. L., Breen, N., Akins, L., & Nash, B. (2011). Nutritional properties of the invasive lionfish: A delicious and nutritious approach for controlling the invasion.

Morris Jr, J. A., & Whitfield, P. E. (2009). Biology, ecology, control and management of the invasive indo-pacific lionfish: An updated integrated assessment.

Pitt, J., Trott, T. (2013). Efforts to Develop a Lionfish-Specific Trap for Use in Bermuda Waters. Prepared by the Department of Environmental Protection, Government of Bermuda.

Ramsaran, R. (1979). Tourism in the economy of the bahamas. *Caribbean Studies*, *19*(1/2), 75-91.

Rosenthal, E. (2011). Answer for invasive species: put it on a plate and eat it. *The New York Times. http://www.nytimes. com/2011/07/10/science/earth/10fish. html*.

Ruttenberg, B. I., Schofield, P. J., Akins, J. L., Acosta, A., Feeley, M. W., Blondeau, J., ... & Ault, J. S. (2012). Rapid invasion of Indo-Pacific lionfishes (Pterois volitans and Pterois miles) in the Florida Keys, USA: evidence from multiple pre-and post-invasion data sets. *Bulletin of Marine Science*, *88*(4), 1051-1059.

Sarkis, S., van Beukering, P. J., McKenzie, E., Hess, S., Brander, L., Roelfsema, M., . . . Bervoets, T. (2010). Total economic value of Bermuda's coral reefs: Valuation of ecosystem services.

Sealey, N. E. (1982). Tourism in the Caribbean. Tourism in the Caribbean.

Secord, D. (2003). Biological control of marine invasive species: cautionary tales and land-based lessons. *Biological Invasions, 5*(1-2), 117-131.

Tabata, R. S. (1990). Dive travel—a case study in educational tourism: Policy implications for resource management and tourism development. *Proceedings (Unedited), the Global Classroom, an International Symposium on Educational Tourism,*

Thurston, G. (2010). Lionfish plague threatens bahamian economy. *The Bahamas Weekly*

Tripp, E. (2013). Q&A with Corey Eddy and BUEI. Retrieved from http://marinesciencetoday.com/2013/05/15/qa-with-corey-eddy-and-buei/

Trott, T. (2016). Senior Marine Resources Officer. Email interview.

U.S. Geological Survey. (2016). Nonindigenous Aquatic Species Database. Gainesville, Florida.

Why are Lionfish a Threat to the Atlantic? (2016). Retrieved from http://oceanservice.noaa.gov/facts/lionfish.html

Wilson, C. (2013). Get a permit to cull lionfish. The Royal Gazette: Bermuda News. Retrieved from http://www.royalgazette.com/article/20130624/NEWS07/706249941

Wood, M. (2001). "Pterois volitans" (On-line), Animal Diversity Web. Retrieved from http://animaldiversity.org/accounts/Pterois_volitans/

Appendix A

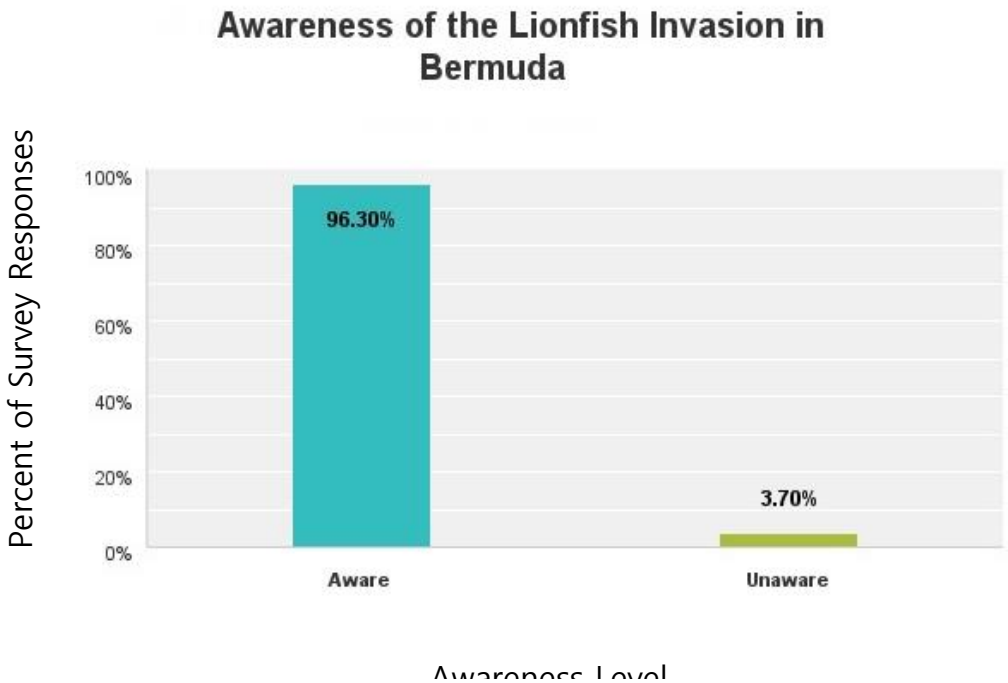

Figure A-1: Results showing Bermudians' awareness of the lionfish invasion.

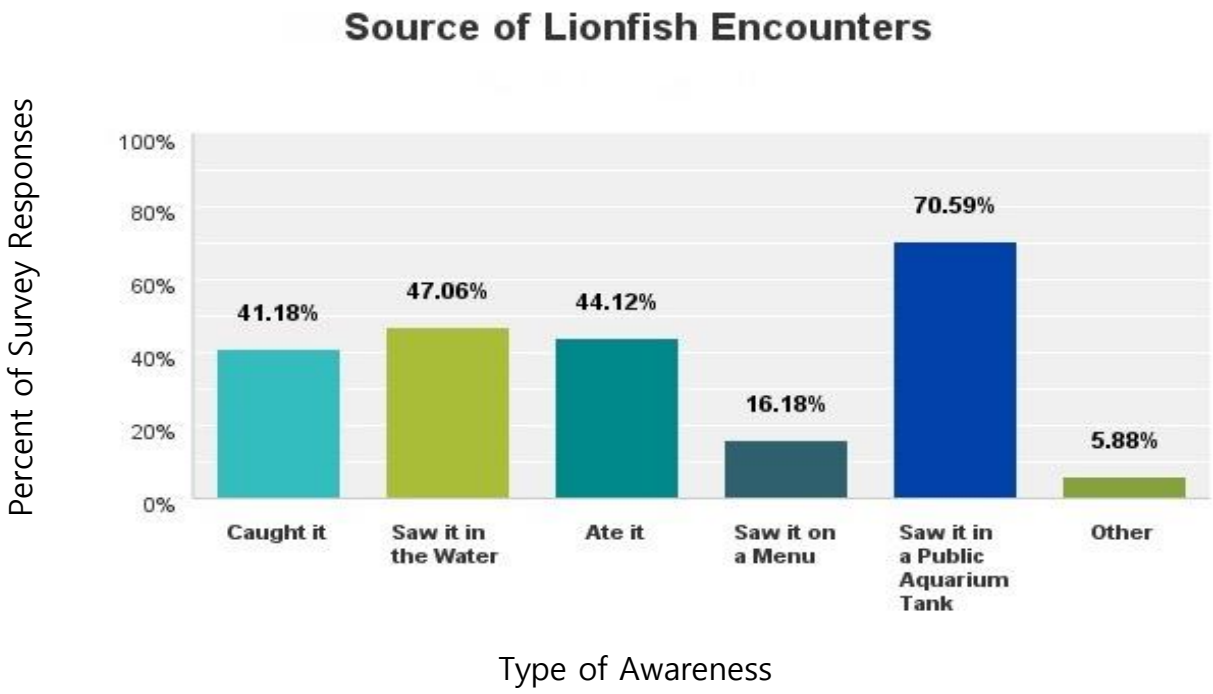

Figure A-2: Results showing the types of awareness about the lionfish invasion in Bermuda.

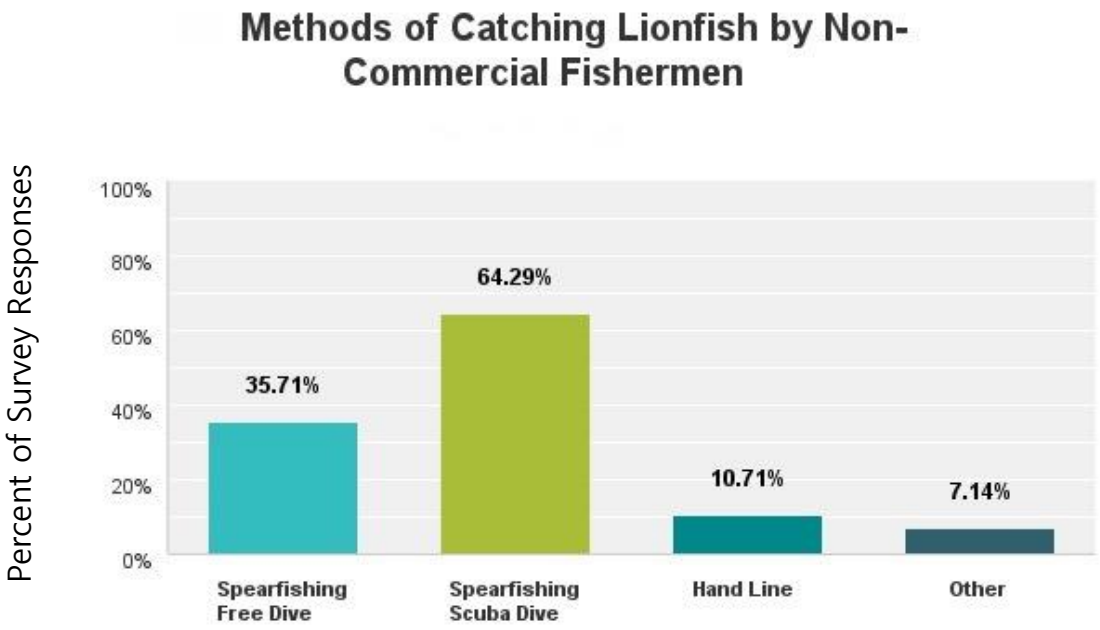

Figure A-3: Results showing methods of catching lionfish by non-commercial fishermen in Bermuda.

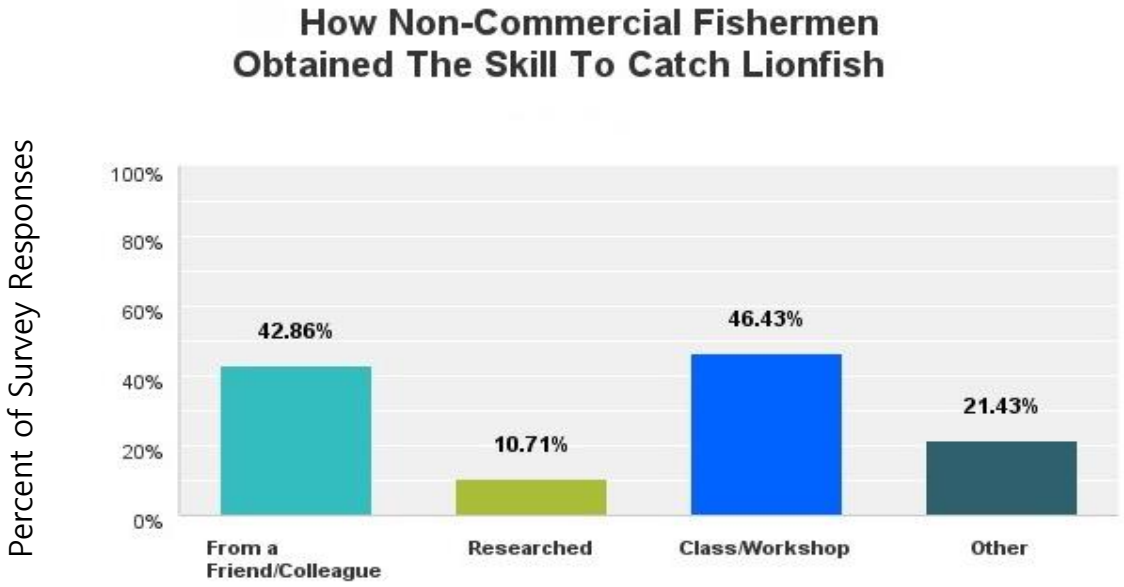

Figure A-4: Results showing how non-commercial fishermen in Bermuda obtained the skill to catch lionfish.

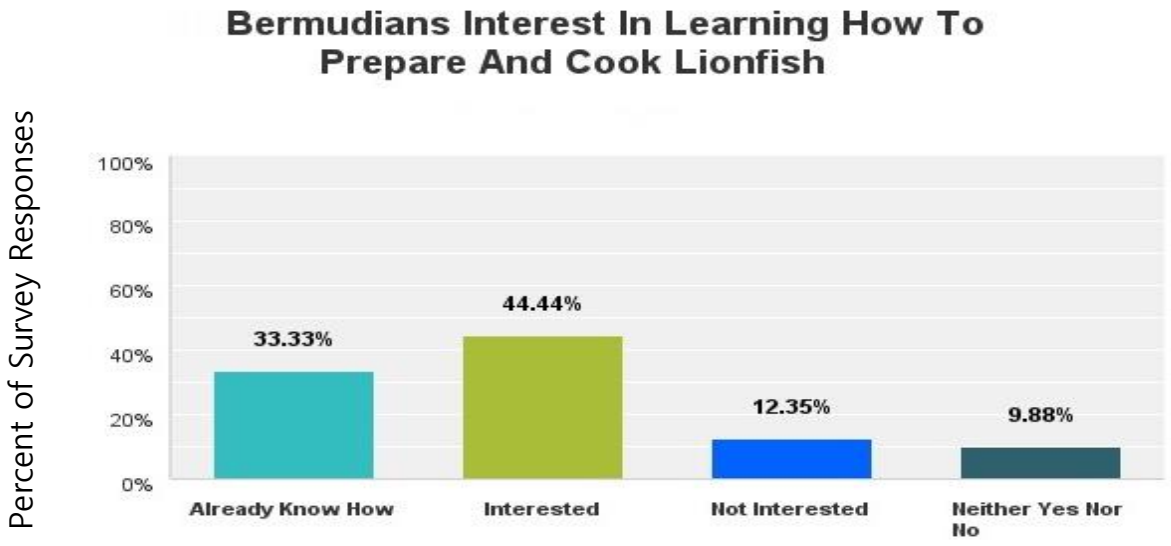

Figure A-5: Results showing the level of interest Bermudians have in learning how to prepare and cook lionfish.

Appendix B

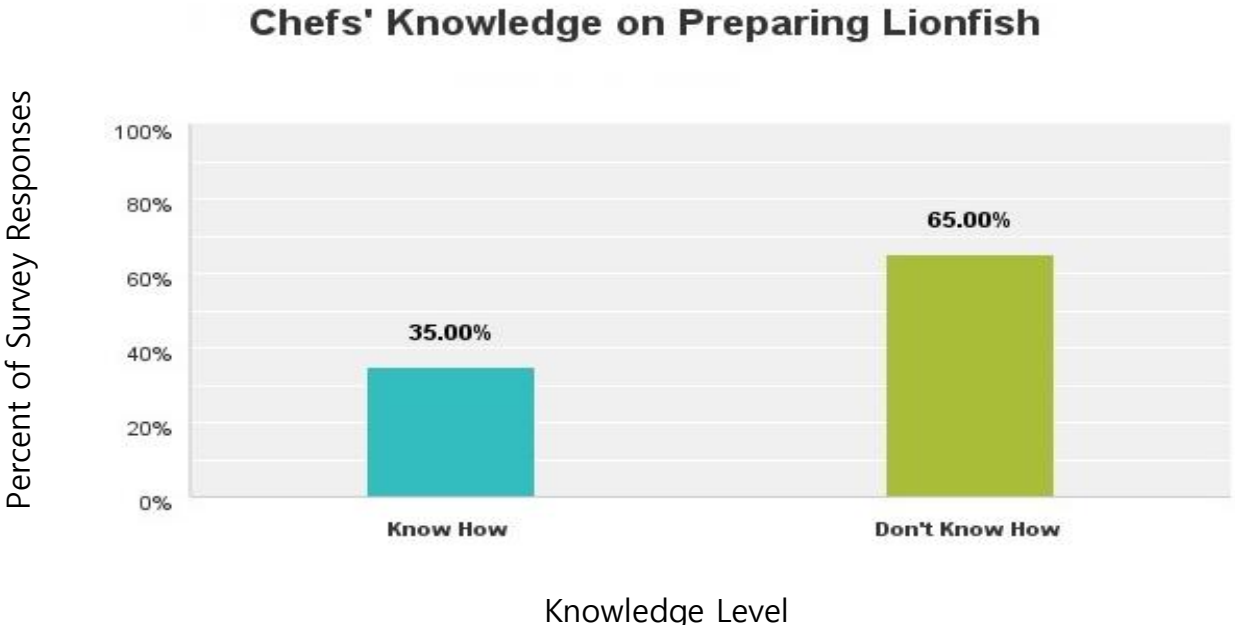

Figure B-1: Results showing the knowledge that chefs in Bermuda have on preparing lionfish.

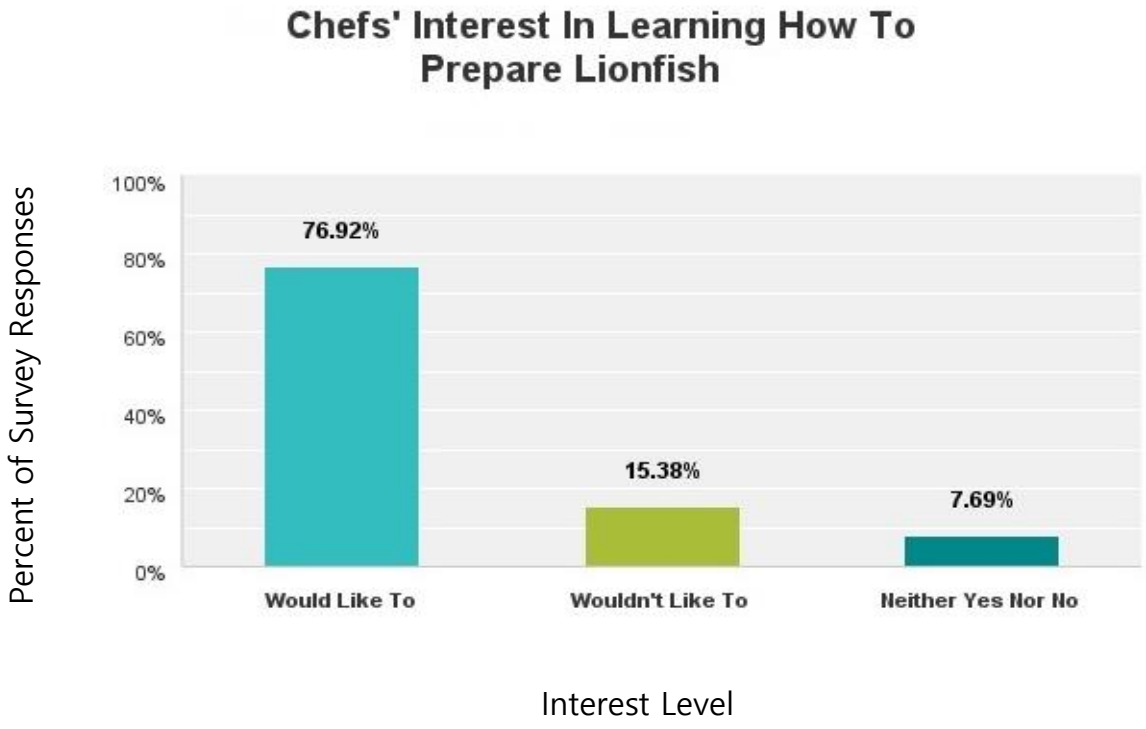

Figure B-2: Results showing the level of interest that chefs in Bermuda have in learning how to prepare lionfish.

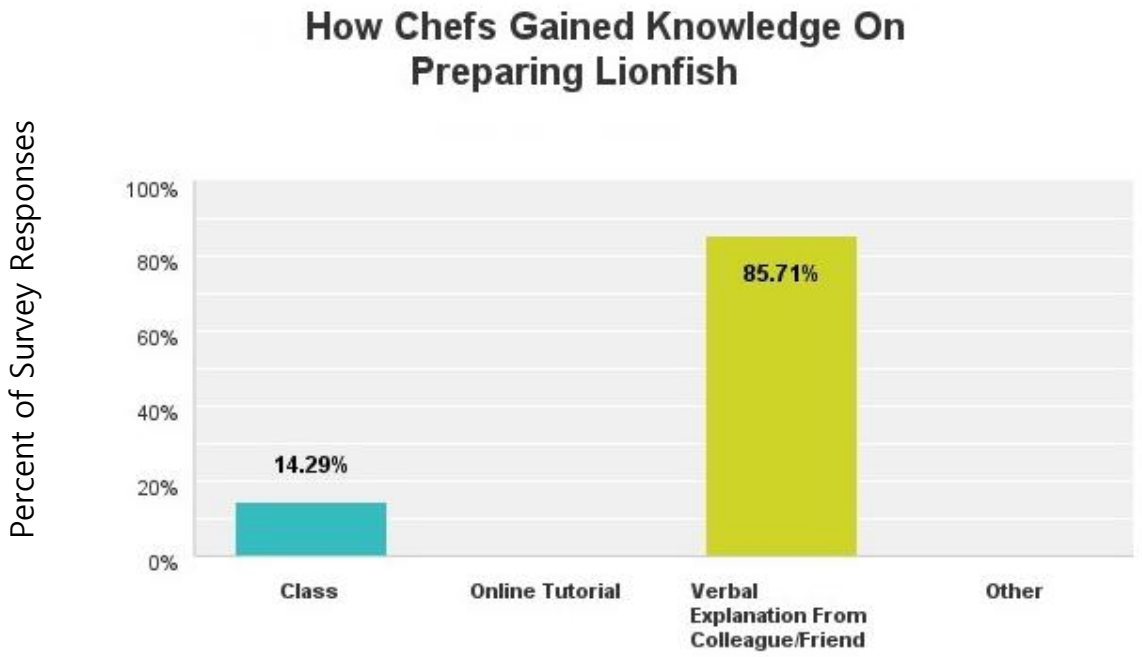

Figure B-3: Results showing how chefs in Bermuda gained knowledge on preparing lionfish.

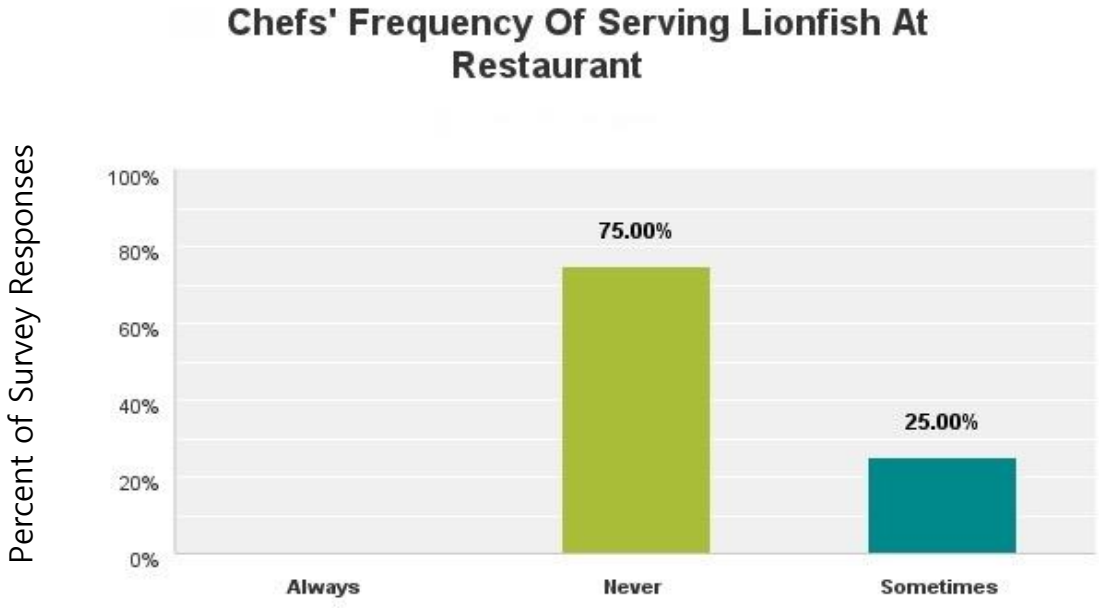

Figure B-4: Results showing the frequency that chefs in Bermuda serve lionfish at their restaurants.

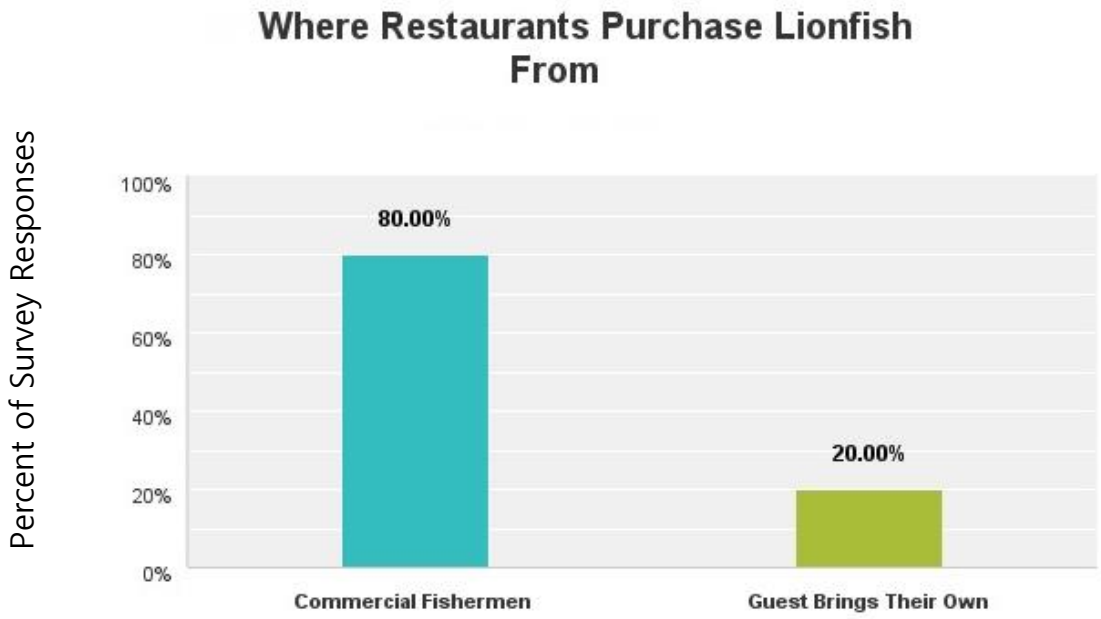

Figure B-5: Results showing where restaurants in Bermuda purchase lionfish from.

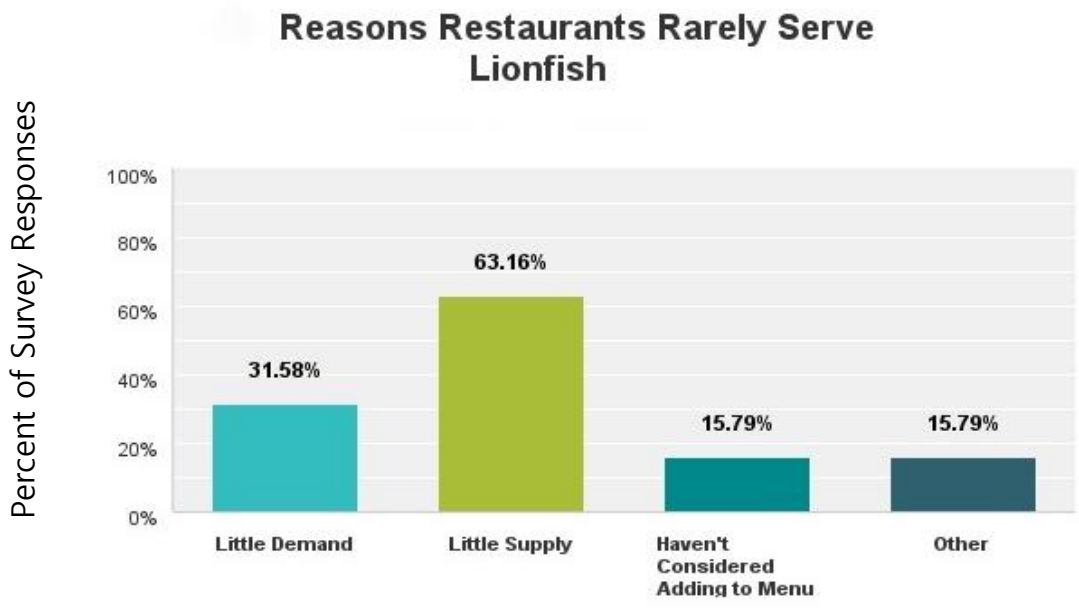

Figure B-6: Results showing the reasons restaurants in Bermuda rarely serve lionfish.

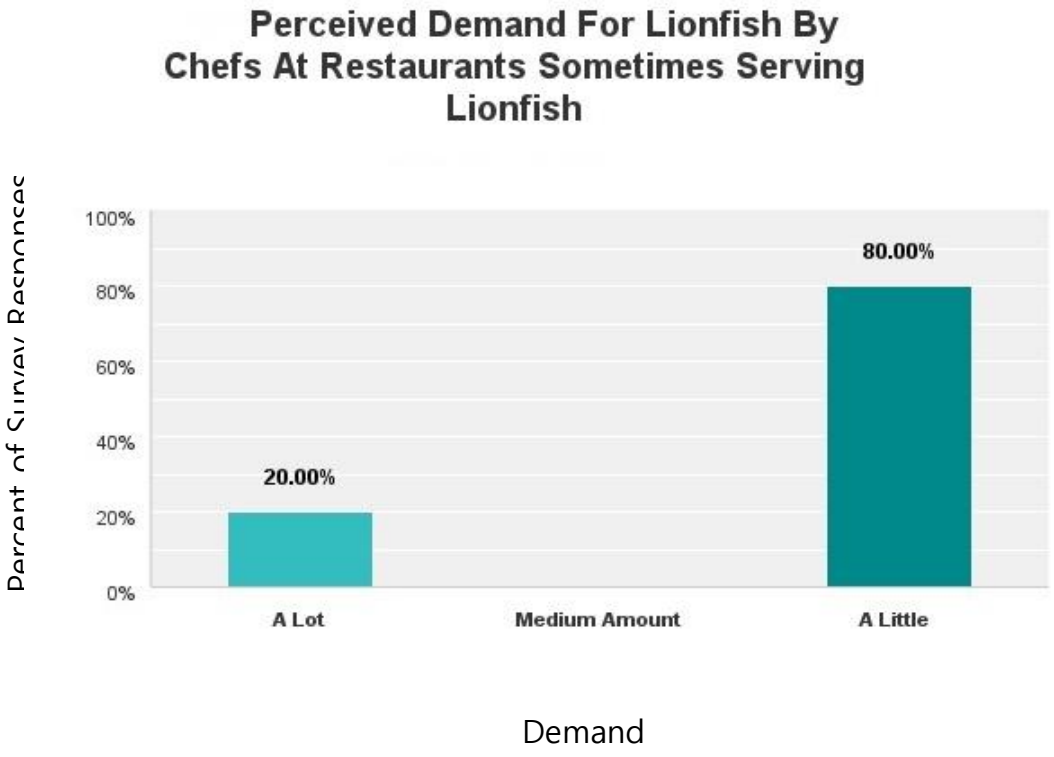

Figure B-7: Results showing the perceived demand for lionfish by chefs at restaurants that sometimes serve lionfish.

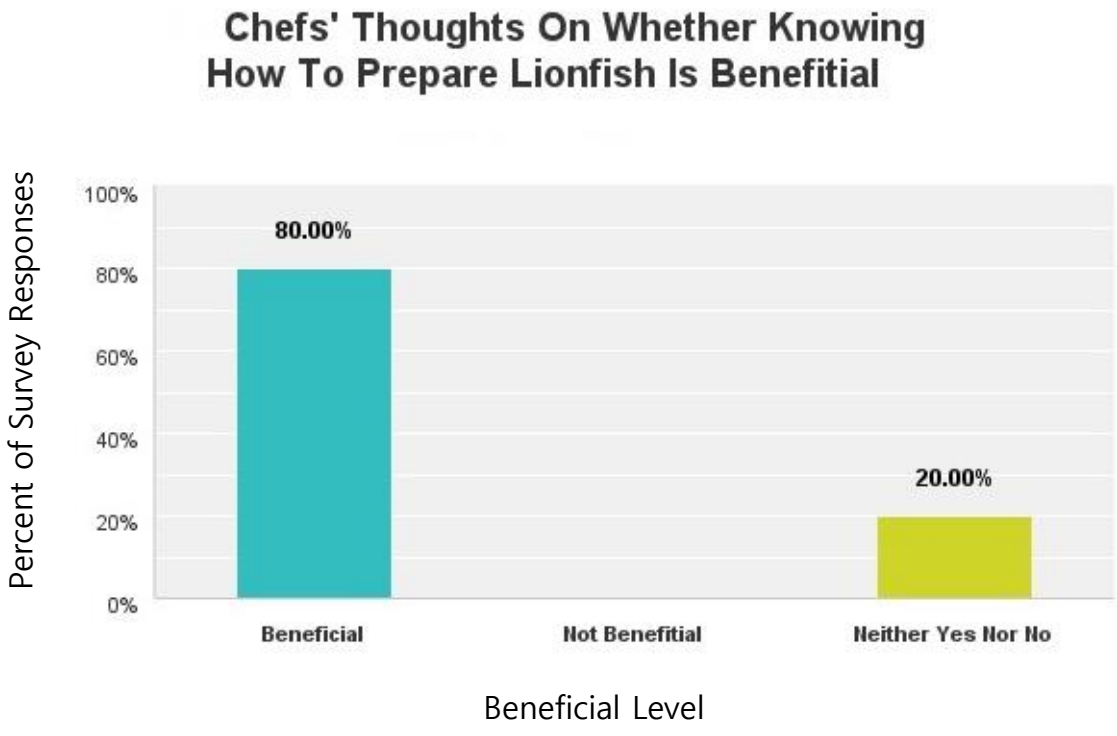

Figure B-8: Results showing chefs' thoughts on whether knowing how to prepare lionfish is beneficial.

Appendix C

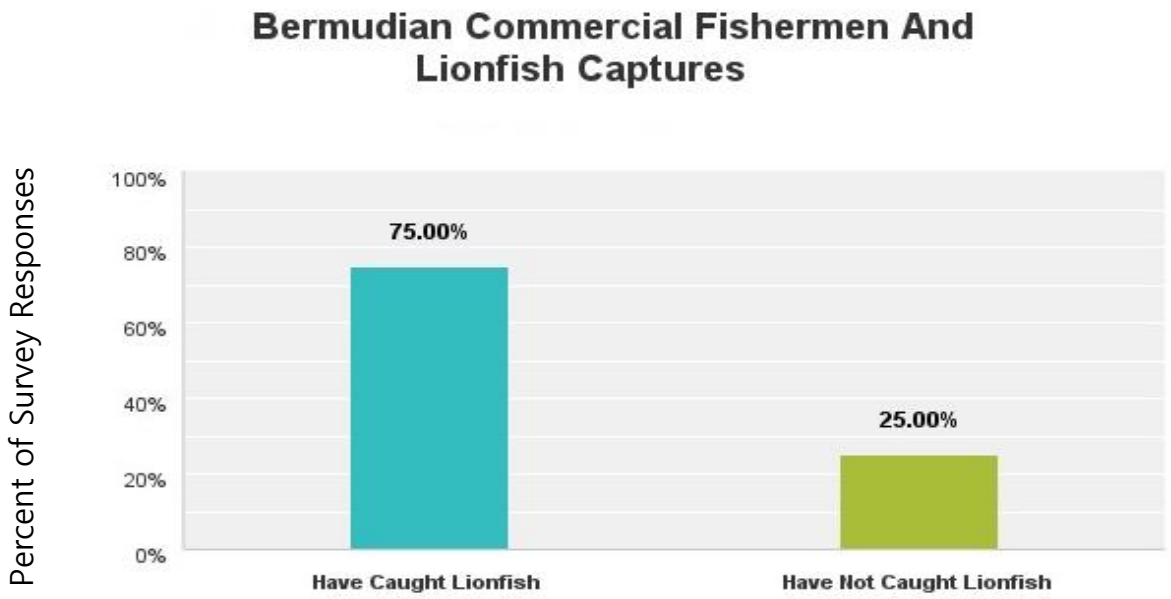

Figure C-1: Results showing Bermudian commercial fishermen and occurrences of lionfish captures.

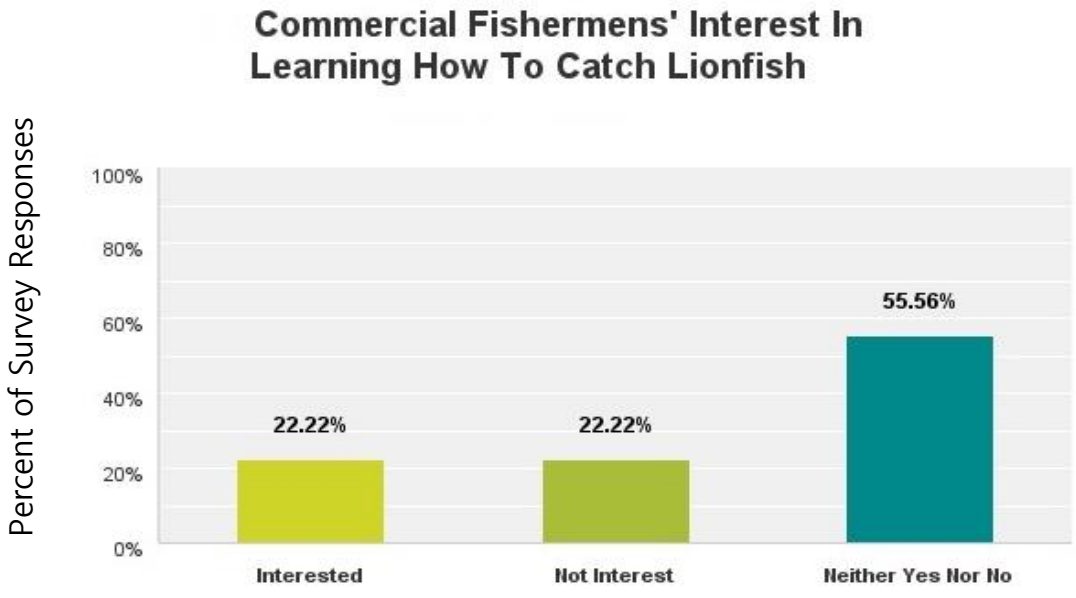

Figure C-2: Results showing Bermudian commercial fishermen's interest in learning how to catch lionfish.

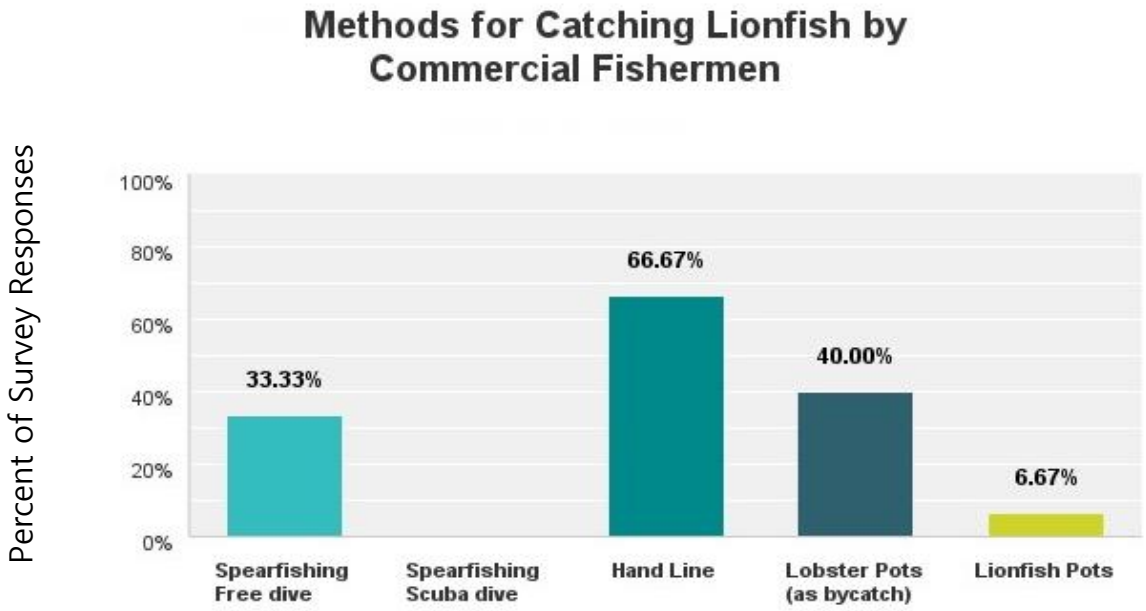

Figure C-3: Results showing the methods that commercial fishermen use to catch lionfish.

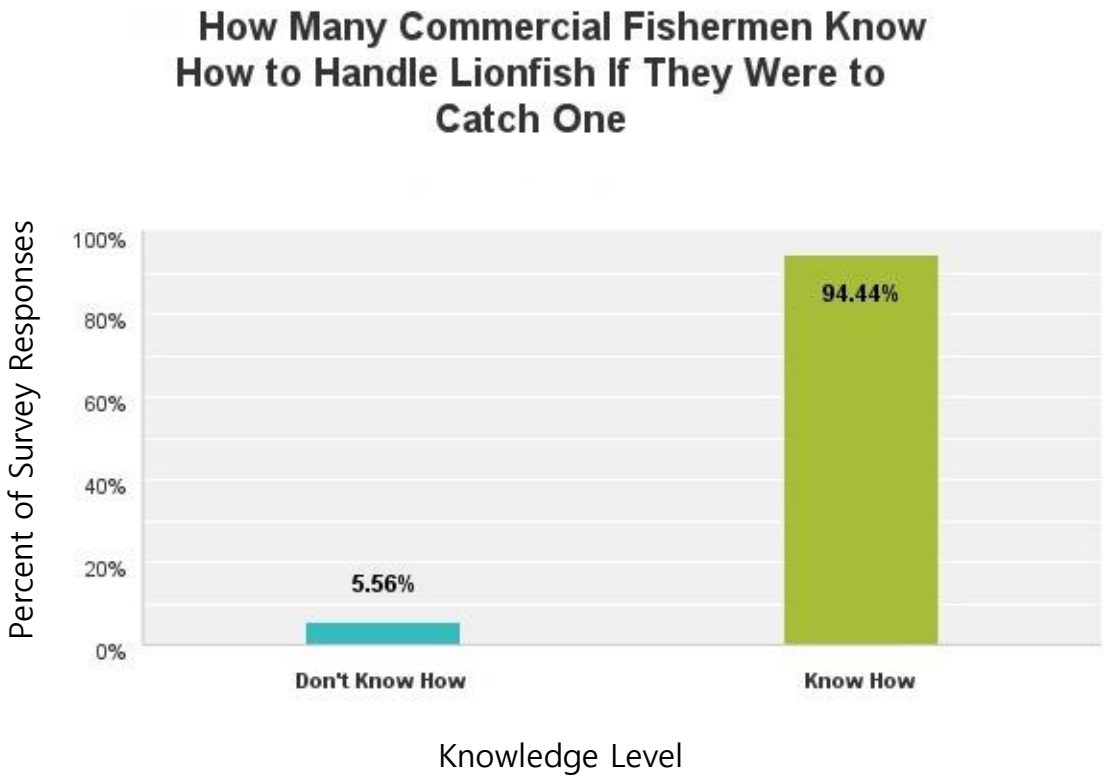

Figure C-4: Results showing how many commercial fishermen feel they would know how to handle a lionfish if they were to catch one.

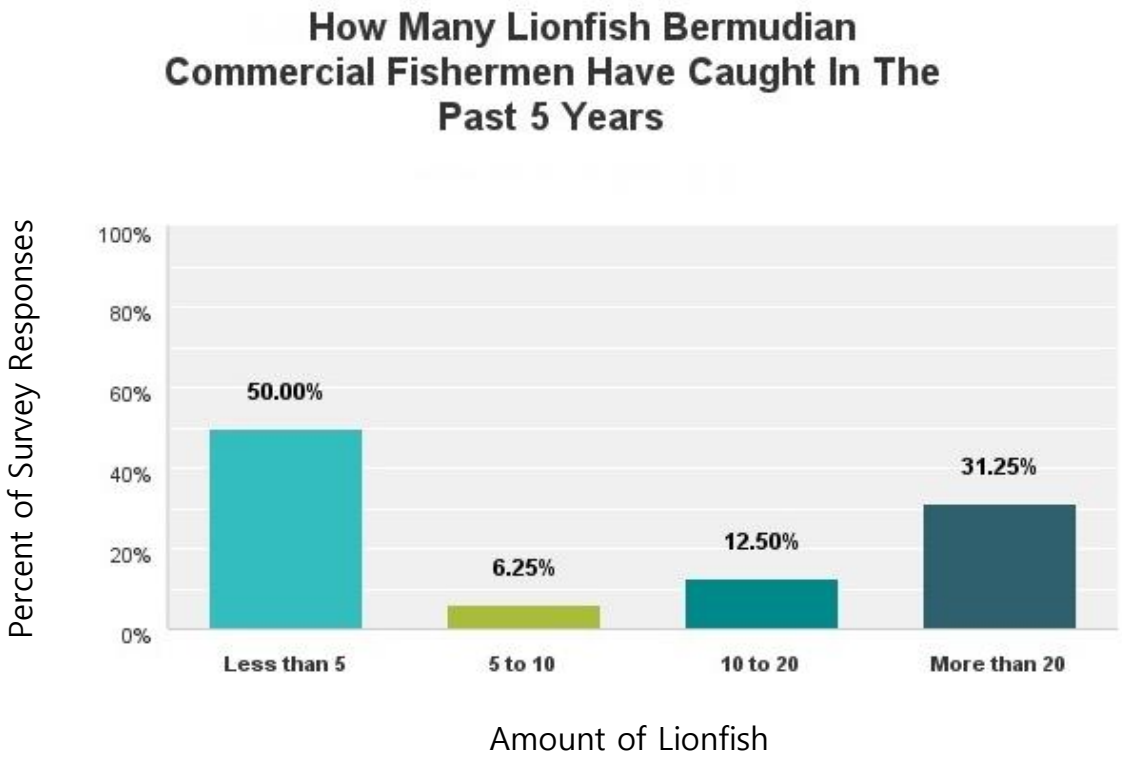

Figure C-5: Results showing how many lionfish Bermudian commercial fishermen have caught in the past five years.

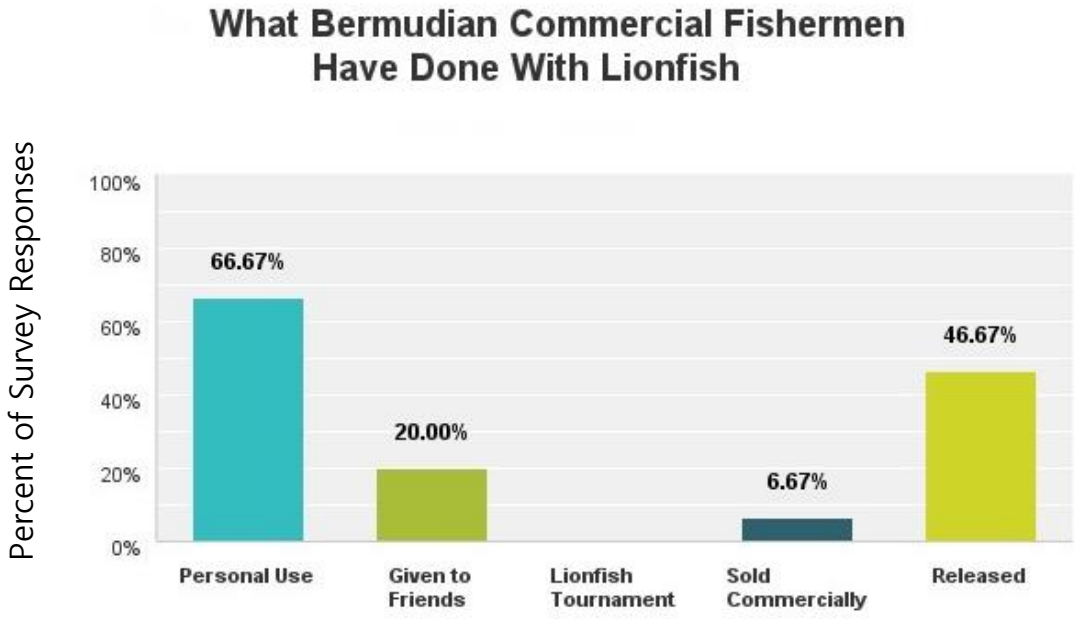

Figure C-6: Results showing what Bermudian commercial fishermen have done with the lionfish they have captured.

Appendix D

Lionfish Questionnaire for Residents of Bermuda

Name:_____

1. Are you aware of the lionfish invasion in Bermuda?
   - ❒ Yes
   - ❒ No

2. If you answered **YES** to Question 1, how did you become aware about the lionfish invasion in Bermuda? (can check more than one)
   - ❒ News source
   - ❒ Social Media
   - ❒ Word of mouth
   - ❒ Other, please specify:_____

3. If you've ever encountered a lionfish, how did you encounter it? (can check more than one)
   - ❒ Caught it
   - ❒ Seen it in the water
   - ❒ Ate it
   - ❒ Seen it on a menu
   - ❒ Seen it in a public aquarium tank (ie. BAMZ or Gorhams)
   - ❒ Other, please specify_____

4. If you answered **CAUGHT IT** to Question 3, how? (can check more than one)
   - ❒ Spearfishing free dive
   - ❒ Spearfishing scuba dive
   - ❒ Hand line
   - ❒ Other, please specify_____

5. If you answered **CAUGHT IT** to Question 3, how did you obtain that skill? (can check more than one)
   - ❒ From a friend/colleague
   - ❒ Researched
   - ❒ Class/workshop
   - ❒ Other, please specify:_____

6. Would you be interested in learning how to prepare and cook lionfish?
   - ❒ Already know how
   - ❒ Yes
   - ❒ No
   - ❒ Neither yes nor no

Appendix E

Lionfish Questionnaire for Chefs in Bermuda
Name of Chef: _____
Name of Restaurant: _____

1. Do you know how to prepare lionfish?
   - ❒ Yes
   - ❒ No

2. If you answered **YES** to Question 1, How did you learn how to prepare lionfish?
   - ❒ Class
   - ❒ Online tutorial
   - ❒ Verbal explanation from colleague/friend
   - ❒ Other, please specify: _____

3. If you answered **NO** to Question 1, would you like to know how to prepare lionfish?
   - ❒ Yes
   - ❒ No
   - ❒ Neither yes nor no

4. Do you think a chef in Bermuda benefits from knowing how to prepare lionfish?
   - ❒ Yes
   - ❒ No
   - ❒ Neither yes nor no

5. Does the restaurant you work at serve lionfish?
   - ❒ Always
   - ❒ Never
   - ❒ Sometimes

6. If you answered **ALWAYS** or **SOMETIMES** to Question 5, from where does your restaurant purchase lionfish? (can check more than one)
   - ❒ Commercial Fishermen
   - ❒ Other source, please specify:_____

7. If you answered **ALWAYS** or **SOMETIMES** to Question 5, how much money do you pay for lionfish?

   $_____per_____lb
   - ❒ Fillet
   - ❒ Whole fish

8. If you answered **ALWAYS** or **SOMETIMES** to Question 5, what is the demand for lionfish?
   - ❒ A lot
   - ❒ Medium amount
   - ❒ A little

9. If you answered **NEVER** or **SOMETIMES** to Question 5, what is the reason?
   - ❒ Little demand
   - ❒ Little supply
   - ❒ Haven't considered adding to menu
   - ❒ Other, please specify:_____

Appendix F

Lionfish Questionnaire for Commercial Bermudian Fishermen
Name:_____

1. Have you ever caught lionfish?
   - ❒ Yes
   - ❒ No

2. If you answered **NO** to Question 1, would you like to know how?
   - ❒ Yes
   - ❒ No
   - ❒ Neither yes nor no

If you answered **YES** to Question 1, please answer the below questions:

3. How do you catch lionfish? (Can choose more than one)

   - ❒ Spearfishing free dive
   - ❒ Spearfishing scuba dive
   - ❒ Hand line
   - ❒ Lobster pots (as bycatch)
   - ❒ Lionfish pots

4. Do you know how to handle a lionfish if you were to catch one? If yes, please explain how.
   - ❒ Yes _____
   - ❒ No

5. How many do you think you've caught in the past 5 years?
   - ❒ Less than 5
   - ❒ 5 to 10
   - ❒ 10 to 20
   - ❒ More than 20

6. What have you done with the lionfish you've caught? (Can choose more than one)
   - ❒ Personal use
   - ❒ Given to friends
   - ❒ Lionfish Tournament
   - ❒ Released. Why? _____
   - ❒ Sold commercially

Appendix G

Conditions: (a) This Permit is valid for one year from 1 September 2015 through 31 August 2016.

(b) The permit holder must have attended the special training course provided by the Ocean Support Foundation on capturing and handling Lionfish or have completed the PADI lionfish specialty course offered by certain local dive shops. Visitors to Bermuda are only permitted to take lionfish in conjunction with local dive shops that offer the PADI lionfish specialty course.

(c) The only type of spear permitted for culling Lionfish under the terms of this permit will be a 3 prong "paralyzer" tip on a pole with a maximum length of 5 ft.

(d) No other species may be targeted in conjunction with permitted Lionfish culling activity.

(e) Permitted spears may be used anywhere on the Bermuda platform (including within 1 nautical mile of the shore) for the purposes of taking Lionfish only. Any person in the water with a spear within 1 nm of the shore and in possession of any fish other than Lionfish, whether in the water or on an attending boat, is in violation of the conditions of this permit.

(f) Permit holders may use permitted spears in conjunction with SCUBA to cull Lionfish only, provided they have a SCUBA certification from a recognized training agency. A person in possession of a SCUBA tank, either on their person or in an attending boat, may not be in possession of any fish other than Lionfish, either on their person or in an attending boat.

(g) A special Lionfish flag, provided with the original permit, must be flown when culling Lionfish.

(h) The permit holder must have the plastic disc issued with this permit and valid photo identification with them on every Lionfish culling trip.

(i) For safety reasons the permit holder should be accompanied by another person, also trained in handling Lionfish.

(j) The permit holder should also file a float plan with Bermuda Radio every time he/she goes on a Lionfish culling trip.

(k) A record of all Lionfish caught must be submitted to the Department through the Ocean Support Foundation.

(l) When spears are not being used, they must be stored in a secure location.