Evaluation of Sea Cucumber Fishing in Puerto Rico

Interactive Qualifying Project Report completed in partial fulfillment of the Bachelor of Science degree at Worcester Polytechnic Institute, Worcester, MA

Sponsoring Agency:

Department of Natural and Environmental Resources (DNER)

Submitted by:

Pedro Miguel, Kelly Morgan, Irma Vlasac, Nathaniel Yuhas

Submitted to:

Sponsor: Dr. Craig Lilyestrom, DNER
Project Advisor: Edward Clancy
Project Advisor: Fabienne Miller

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Abstract

The Department of Natural and Environmental Resources (DNER) required information on the status of sea cucumber fishing in Puerto Rico. The team researched this subject and supplied the DNER with updated material regarding the status of sea cucumber fishing and regulations throughout the Caribbean region. We determined that commercial sea cucumber fishing has ceased in Puerto Rico through the use of interviews with DNER employees and administering questionnaires to sea cucumber fishermen. We recommend the DNER continue the investigation and consider implementing regulations on sea cucumber harvesting in order to prevent from exploitation in the future which could cause significant damage to the oceanic environment.

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Authorship

Vlasac interviewed all fishermen and all Spanish speaking DNER employees
Miguel formatted the report

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Executive Summary

The Department of Natural and Environmental Resources (DNER) had recently become aware of sea cucumber fishing in southwest Puerto Rico. It was brought to their attention two years ago that sea cucumber fishing was occurring when a man requested a sea cucumber fishing permit. Since there are currently no regulations prohibiting sea cucumber fishing, he was granted a commercial fishing license. The DNER knew limited information on sea cucumber fishing, raising a concern as to whether the unmonitored harvesting of sea cucumbers would ultimately impact the environment over time due to unstable fishing practices or harmful fishing methods. The only data known to the DNER regarding sea cucumber fishing in relation to the granted license were monthly landing reports detailing the amounts of sea cucumber being harvested. In order to better assess the state of sea cucumber fishing in Puerto Rico, our team conducted research in different areas such as Lajas/Guanica and Culebra Island.

A sea cucumber is an invertebrate echinoderm in the class Holothurian, related to the sea urchin and sea star. They are most commonly considered the "worm of the sea" because of their role in bioturbation and purification of sediment on ocean floors. Sea cucumbers are generally not consumed in the wild or attacked due to their defense mechanisms and ability to blend into ocean bottoms. However, they are harvested and eaten by humans in the large, mainly Asian, beche-de-mer market, where sea cucumber is considered a delicacy with medicinal and aphrodisiac qualities. According to Chinese medicine, the sea cucumber is known to nourish blood, treat kidney disorders, moisten dryness in the intestines and can be used as a dietary supplement. The majority of sea cucumber are cleaned, gutted, dried, and exported to China and other Asian countries. The market consists of thousands of tonnes, a metric measurement equivalent to 1000 kilograms, grossing tens of millions of U.S dollars per year. Due to their importance in oceanic ecosystems, governments have put regulations in place to ban or limit sea cucumber fishing in different countries.

The project's main research goals were to, first, evaluate the current status of active and past sea cucumber fishing in Puerto Rico; second, examine the sea cucumber fishery in Puerto Rico; and third, to use data gathered through our research to make accurate and adequate regulatory recommendations to the DNER for future sea cucumber harvesting activities. In order to gather the necessary information to accomplish these goals, the team set three methodology objectives. The first objective was to collect data for previously reported sea cucumber fishing sites. The second objective was to determine locations on current and potential sea cucumber harvesting. The third objective was to gather fishermen responses on sea cucumber fishing in Puerto Rico. The final objective was to document habitat and species of sea cucumber at fished and unfished sites. The information gained from these objectives allows the team to discuss the

ecological impacts of overharvested sea cucumbers and if the DNER should implement regulations.

In order to achieve our methodology objectives and provide DNER with information regarding sea cucumber fishing in Puerto Rico, the team received and analyzed sea cucumber landing report catch data, conducted interviews, administered questionnaires, and performed in-water observations of both fished and unfished sea cucumber environments.

Collection of the landing reports provided the team with numerical data to analyze from the 2011 year, such as averages, high and low catch numbers, trends, and an estimation value of harvesting profit. Overall, the team was able to conclude from the landing reports that there was a decrease in fishing hauls over time. Figure 1 below shows this information in graphical form. Notice that from June – August fishing reached a peak and then began to decrease.

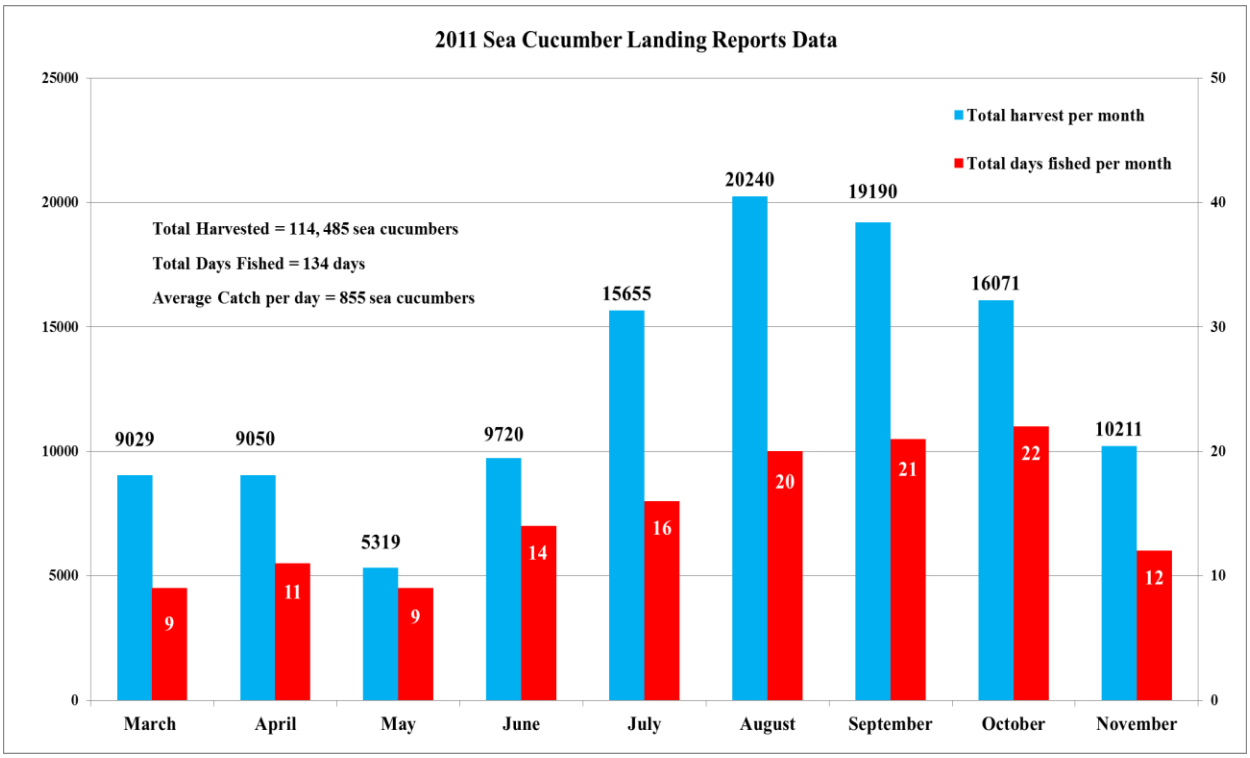


Figure 1: 2011 Sea Cucumber Landing Reports Data

Each structured interview was adapted to the expertise of the interviewee. Interviews were useful in providing information regarding sea cucumber ecology, the status of sea cucumber fishing, or current leads on sea cucumber fishing activity. Table 1 below shows information gained through the interviews that provided the team with information regarding sea cucumber fishing in different areas of Puerto Rico.

Interviewee Name	DNER Position	Location	Interview Summary
Daniel Caraballo	Biologist III, Fishing Statistics	Joyuda	- Name of sea cucumber fishing company manager - Contact information for manager - Species of commercial sea cucumber in Puerto Rico
Angel Dieppa	DNER Marine Biologist	Salinas	-Past observation of Lajas/Guanica area
Carmen Gonzalez	Jobaner Reserve Manager	Salinas	- No sea cucumber fishing activity in Salinas/Jobaner Reserve area
Jesus Fernandez	DNER Fisheries Agent	Fajardo	- Leads in Culebra, no fishing in Fajardo
Ranger Banch	DNER Ranger	Lajas/Guanica	- Observed sea cucumber fishing approximately a year ago - Sea cucumber fishing was managed out of a small house
Misael Feliciano	DNER Ranger	Culebra	- Observed sea cucumber fishing in Culebra - Identified sea cucumber fishermen, only fish for personal consumption

Table 1: Summary of DNER Interviews

The questionnaire was used for fishermen who are currently harvesting sea cucumbers or have harvested sea cucumber in the past. Fishermen responses were useful in that they relayed crucial information regarding the state of sea cucumber fishing, methods employed during sea cucumber fishing, species harvested, and any knowledge of other fishing activity. The most critical information gained through the fisherman questionnaires was related to sea cucumber fishing in Lajas/Guanica, which commercially harvested sea cucumber before ceasing operations in November 2012. The team also gained information on harvesting in Culebra, where harvesting was mainly for personal consumption and not commercial use. The table below summarizes the data found based on fisherman questionnaires administered in Lajas/Guanica and Culebra.

Name	Location	Commercial?	Summarized Findings
Fisherman I & Fisherman II	Lajas/Guanica	Yes	-Fishing ended ~November 2012 -Paid 30 cents per cucumber regardless of species
Fisherman III	Culebra	No	-Fish for sea cucumbers for personal consumption

Table 2: Fishermen Questionnaire Summary

The team visited nine different locations to perform in-water observations, providing a firsthand experience to evaluate the natural habitat of sea cucumbers and species at each location. Critical information gained from these areas was related to dominant species located in either unfished or fished areas. The team determined that H. mexicana was not a primary target by fishermen as compared to I. badionotus or A. multifidus. A ratio of H. Mexicana to I. badionotus was recorded for applicable locations. A summary of in-water results in Lajas/Guanica can be seen in Table 3.

Location	GPS Coordinates	Fished or Unfished	Water Clarity	Current Intensity	Depth (ft)	H. mexicana vs. I. badionotus
Cayo Enrique *(Lajas/Guanica)*	N17°57.307', W67°3.139'	Unfished	Medium	Low	3 to 6	H. mexicana dominant
Cayo Don Luis *(Lajas/Guanica)*	N17°56.713, W66°58.239'	Unfished	Low	Low	2 to 4	2 to 1
Cayo Collado *(Lajas/Guanica)*	N17°57.260', W67°4.738'	Fished	Medium-High	Medium	3 to 6	6 to 1
Cayo Los Hornos *(Lajas/Guanica)*	N17°57.140', W66°68.951'	Fished	Low-Medium	Low	2 to 7	2 to 1

Table 3: Summary of Lajas/Guanica In-Water Observations

After conducting research on sea cucumber fishing in various areas throughout Puerto Rico, the team developed and proposed several recommendations based on our findings that the DNER could consider utilizing in the future. These recommendations include further harvesting investigation, further environmental documentation, transects, and ultimately, sea cucumber fishing regulations.

While harvesting investigations have been conducted by the team in Salinas, Fajardo, Lajas/Guanica, and Culebra, there has been observed sea cucumber harvesting in Belvedere and rumored fishing in Isabela. However, the team was not able to visit these locations due to time constraints. The team recommends for the DNER to interview sea cucumber fishermen at these locations in order to better understand the type of fishing occurring, if it is in great quantities, and whether it is for personal or commercial use. The main challenges associated with conducting investigations involving fishermen are locating them and their reluctance to provide any information.

Documenting more fished and unfished sites at current or possible future fishing locations could provide a baseline for analysis of different sites for use by DNER employees. This documentation is essential in order to observe changes that could have occurred over time with regards to species diversity, species depth, reproductive cycles, or quality of the environment such as water clarity. A continuation of the documentation where sea cucumbers were harvested or are currently being harvested will aid the DNER in learning more about the possible negative effects occurring in the oceanic ecosystem due to a declination in sea cucumber populations.

Transects have been used to count the number of species of marine wildlife in Puerto Rico and are useful for assessing population sizes, and, when done over time, changes in populations. The inclusion of sea cucumbers in transects of the ocean floor surrounding Puerto Rico will aid in accurately determining and recording quantitative amounts and population density of sea cucumbers in specific areas of Puerto Rico.

A final suggestion we propose to the DNER is to consider placing regulations on sea cucumbers, in regards to size limits, temporal closure for reproductive seasons, and a harvesting quota. Through our first-hand observations, sea cucumbers require little gear or effort to catch with the potential to harvest hundreds on a daily basis. The greatest driving force behind harvesting sea cucumbers is the potential value presented by the Asian beche-de-mer market. As can be learned from the harvesting in the Lajas/Guanica area, a small operation can fish and process large quantities of sea cucumber for export in only a few months. Unless regulations are passed in Puerto Rico, sea cucumbers are placed at great risk for exploitation.

Overall, the team was able to reach the set research goals, delivering information on sea cucumber fishing in Puerto Rico to the DNER. This was accomplished through the use of sea cucumber landing reports, interviews with DNER employees, questionnaires with sea cucumber fishermen and in-water observations. The team recommends that the DNER continue our research by conducting sea cucumber harvesting investigations, documenting sea cucumber habitats, performing transect, and ultimately implementing regulations on the harvesting of sea cucumbers in Puerto Rico in order to help protect the sea cucumber population and environment.

1.0 Introduction

The Department of Natural and Environmental Resources (DNER) has a growing interest in sea cucumber fishing in Puerto Rico, where currently there are no sea cucumber specific regulations or policies supporting a sustainable harvest. The project's main research goals were to, first, evaluate the current status of active and past sea cucumber fishing in Puerto Rico; second, examine the sea cucumber fishery in Puerto Rico; and third, to use data gathered through our research to make accurate and adequate regulatory recommendations to the DNER for future sea cucumber harvesting activities.

Sea cucumbers have an important role in the bioturbation of ocean floors and through their intake of detritus, creating a cleaner and healthier benthic environment. Without these creatures, the ocean would gradually become more polluted with bacteria levels and less oxygen in sediment layers. The declination of the sea cucumber population hinders the success of their reproductive process, making it more difficult for repopulation after being harvested.

Currently, there is limited information regarding sea cucumber fishing in Puerto Rico. Research conducted in other areas of the Caribbean regarding sea cucumber fisheries ultimately led to the enforcement of regulations on the harvesting of sea cucumbers. For example, in Cuba, regulations have been put in place restricting sea cucumber fishing locations, harvest quotas, and temporal closures to allow for sea cucumber reproduction (Toral-Granda, Lovatelli, & Vasconcellos, 2008). Having an understanding of the limitations imposed by the regulations in other regions will be helpful in the analysis of sea cucumber fishing in Puerto Rico.

DNER was aware of one small, private corporation known to harvest sea cucumbers in Puerto Rico in the area of Lajas/Guanica. In order to gather the necessary information to accomplish these goals, the team set three methodology objectives. The first objective was to

collect data for previously reported sea cucumber fishing sites. The second objective was to determine locations on current and potential sea cucumber harvesting. The third objective was to gather fishermen responses on sea cucumber fishing in Puerto Rico. The final objective was to document habitat and species of sea cucumber at fished and unfished sites. This information was gained through the use of landing reports, interviews with DNER employees, questionnaires with sea cucumber fishermen, and in-water observations. The results obtained will be utilized by the DNER for an analysis of sea cucumber fishing and whether the environment is at risk.

The following sections consist of background information, methodology, the results collected using our methods, a discussion of the results obtained, and a conclusion to integrate the relationship between all chapters.

2.0 Background

This chapter functions to deliver the background necessary in order to conduct our research to analyze sea cucumber fishing and its impacts on the environment.

First, we discuss the overall biology of a sea cucumber including its anatomy, reproductive cycle, habitat, trophic level, and its medical purposes. Second, we explore harvesting methods, their efficiency, and the impact fishing for sea cucumbers has on the ecosystem. Third, we focus on the general economics and pricing of sea cucumbers in the Caribbean and South America, as well as the countries to which the sea cucumbers are exported. Lastly, we cover the rules and regulations of other countries in order to have a better understanding of how sea cucumber fishing has been regulated and how to relay this information to the DNER in order to decide whether regulatory action is necessary in Puerto Rico.

Holothurians, echinoderms of the biological class Holothuroidea, play an important role as members of the food chain at various trophic levels, and through their natural processes of predation and bioturbation (Conand, 1993). In recent years, fisheries have focused on sea cucumbers as a valuable export to Asian countries as beche-de-mer, the consumer product form of sea cucumber. The high demand for sea cucumbers for the Asian beche-de-mer market has caused overexploitation of sea cucumber species due to overfishing and poorly regulated fisheries. Due to Holothurians' poorly known biology, impacts of Holothurian species loss in marine benthic ecosystems might be underestimated and current marine councils are starting to consider ecological damage as factors in implementing regulations.

2.1 Holothurians

The biology of sea cucumbers, including their habitat, behavior, predation, food source, and reproduction are all essential concepts to take into consideration while conducting research on sea cucumber fishing. The information gathered, in order to provide the DNER with background information involving sea cucumbers, is presented in the sections below.

2.1.1 Anatomy

Sea cucumbers are echinoderms, an invertebrate ocean animal belonging to the class Holothuroidea and relative to the starfish and sea urchin. They have no head, eyes, or brain and breathe through their anus. Shaped like a vegetable cucumber, with longitudinally elongated bodies that are radially symmetric, these creatures have a system of calcareous plates called ossicles that are bony particles buried under their skin making the surface, in some species, very bumpy. Their skin, or epidermis, is also usually soft, leathery, and slimy with common colors being black, brown, green or red. Underneath the epidermis there is a thick layer of connective tissue forming the dermis, which encloses the ossicles. The edible part of the sea cucumber, enjoyed by humans, can be found underneath the dermis section of the animal, within a layer of cylindrical forming muscle. This cylindrical forming muscle is made up of five elongated bands of muscle. (Purcell, Lovatelli, Vasconcellos, & Ye, 2010)

Almost all sea cucumbers have a multitude of tiny suction cup feet called podia, generally organized in five rows and commonly referred to as “tube feet.” These podia provide the animal with limited mobility. More importantly, the podia produce an adhesive secretion that allows the creature to stick to the surface it is traveling on (Purcell, Samyn, & Conand, 2012). The types of sea cucumbers that lack tube feet roam around the ocean floor by way of muscular contractions through their bodies. The echinoderm’s mouths are surrounded by 10-30, often

retractable, tentacles used to gather food for nourishment. Figure 2 shows the exterior anatomy of the sea cucumber, including its tentacles for feeding. Depending on the species of sea cucumber, these tentacles can vary in size and shape, and possess the ability to extend. The anus is located in the rear or posterior end of the creature and, in some species, is surrounded by greatly calcified particles referred to as "anal teeth". (Purcell et al., 2012)

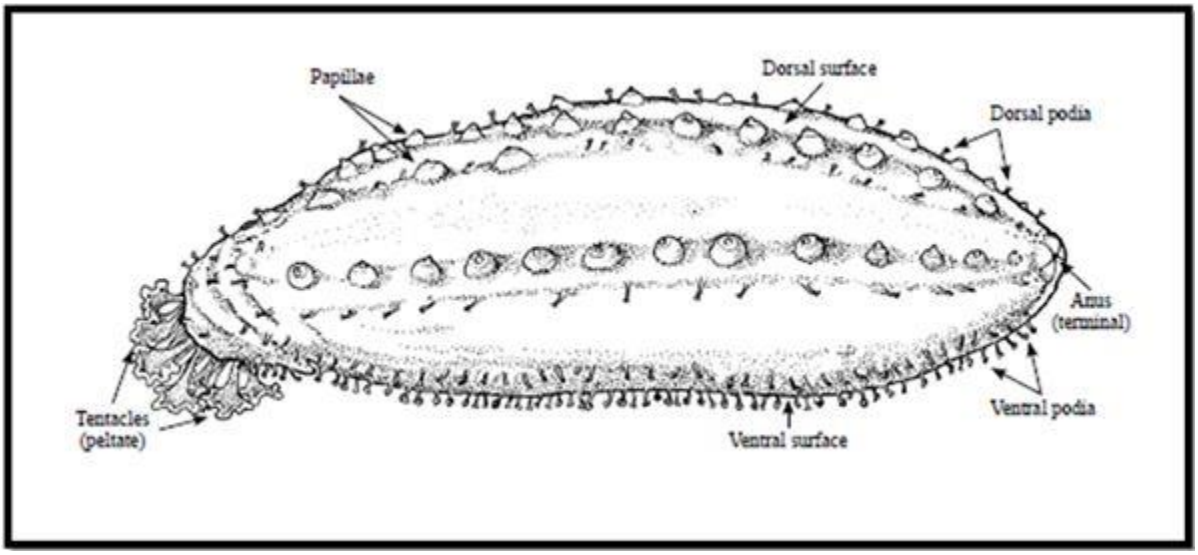


Figure 2: External Anatomy of a Sea Cucumber (Purcell et al., 2012)

The length of these creatures has quite a substantial variance as some sea cucumbers are as small as two centimeters while other species can grow to be as large as six and a half feet (Encyclopedia Britannica, 2013). The typical life span of a sea cucumber can also differ anywhere between five and fifteen years, depending on the species.

2.1.2 Sexual Reproduction

Currently, there are over 1250 known species of sea cucumber worldwide. Reproduction varies amongst species of sea cucumber and can be either sexual or asexual. Commercially exploited sea cucumbers mainly reproduce sexually and populations have both male and female sea cucumbers (King, 2011). The time frame in which sea cucumbers reproduce also depends on

their species, however, they most commonly spawn during the spring and summer seasons. In Panama, H. mexicana and I. badionotus sea cucumbers reach sexual maturity when their un-constricted length is 13 to 20 centimeters (Toral-Granda et al., 2008). Reproduction for both species is at its peaks between the months of July and November. Similarly, off the coast of Venezuela, sexual reproduction occurs predominantly in July and August (Toral-Granda et al., 2008). For reproduction, the sea cucumbers in shallow waters will climb to the highest point they can reach and then rear-up, swaying back and forth to release eggs or sperm through a single gonad gland located on the dorsum of the cucumber (Purcell et al., 2012). The holothurian gametes will continue to float in the water until they encounter egg or sperm and are fertilized, demonstrating importance of density in regards to sea cucumber reproduction. Once eggs are fertilized and hatch into larvae forms, they float in the water with the current for weeks and settle on the seafloor as a juvenile sea cucumber. It is reported that one in every thousand fertilized and hatched egg survives to a juvenile stage, and one in every hundred juvenile sea cucumber reaches adulthood (King, 2011). Figure 3 below shows the different stages of the sea cucumber reproductive cycle.

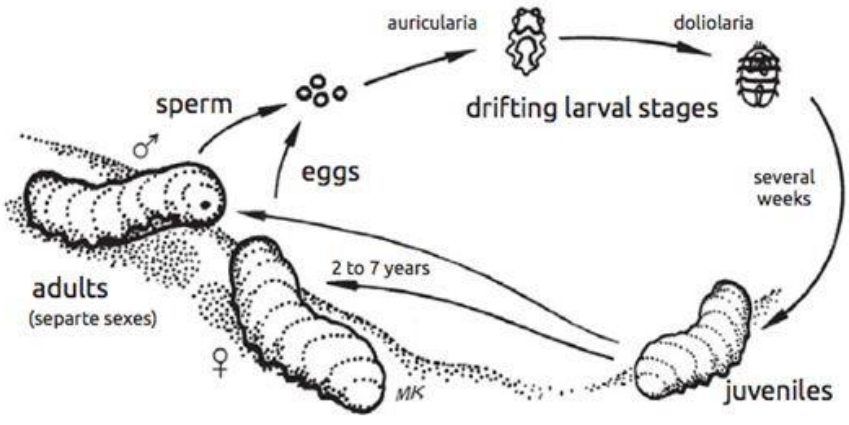


Figure 3: Sea Cucumber Reproduction and Life Cycle (King, 2011)

2.1.3 Defense Mechanisms

A trait unique to the sea cucumber is its defensive mechanism against predators. When attacked, a sea cucumber will expel its internal organs and viscera, through rapid muscular contractions, in order to frighten predators. However, a sea cucumber is able to completely recuperate its missing internal organs, due to remarkable regenerative capabilities, over the course of several months. Furthermore, some species of sea cucumber, when startled, will **eject** a whitish, sticky, filmy, substance in the form of threads that entangle predators. These threads are called Cuvierian tubules, located near the rear of the creature and, in some cases, can contain neurotoxins that can kill ensnared predators. (Atafua, Leiato, Mamea, & Passi, 2008)

2.1.4 Habitat

These creatures are ocean dwellers, living all around the globe and found only in salt waters. Smaller immature sea cucumbers, while still in the larval stage, will live on either plants or other invertebrates (Purcell et al., 2010). Adult sea cucumbers dwell on the bottoms of the ocean floors in either the shallows or the depths of the ocean. They are commonly found to live around coral reefs or in seagrass; however, depending on the species, they may also live on rocks or buried underneath the sediment of the sea bottom. Of the twelve genera of seagrass, only four species are commonly found in the Caribbean and Puerto Rico: Thalassia testudinum, Syringodium filiforme, Halodule wrightii, Halophila baillonii and Halophila englemannii. The first species, Thalassia testudinum (turtle grass), is characterized by a wider and flatter blade. The second species, Syringodium filiforme (manatee grass), is characterized by having a small tubular diameter. The third species, Halodule wrightii (shoal grass), has thin small blades with similar length to the manatee grass.

Lastly, Halophila baillonii (clover grass) is defined by oval shaped blades while Halophila englemannii (star grass) has pedal-shaped leaves; however, both form a pseudo-whorl at the top of their stems. Thalassia testudinum and Syringodium filiforme are the most abundant seagrasses in Puerto Rico (Aguilar-Perera & Appeldoorn, 2007). Figure 4 below shows three species of sea grass in Puerto Rico.

Figure 4: Halodule wrightii (right), Thalassia testudinum (center), Syringodium filiforme (left)

2.1.5 Food Chain

Sea cucumbers are slow moving creatures, moving as fast as a human can walk underwater (Doughton, 2004). Species of sea cucumbers travel at different speeds while feeding and many seasonally migrate to different depths. Referred to as the "vacuum cleaners of the sea," these animals feed off of decaying matter, algae, and microorganisms in the ocean. A single cucumber can process more than 300 pounds of sediment a year, playing an important role in bioturbation of ecosystems. Sea cucumbers are indispensable to the health of the ocean and especially carry an important role in reef recycling and turn over roughly 90% of the ocean bottom (Mathews, Kookesh, & Bosworth, 1990).

Predators of the sea cucumber consist of creatures such as crabs, fish and mollusks. They are also harvested by humans who consume their muscles and eggs. Millions of sea cucumbers are harvested each year for the beche-der-mer market. In Asia, sea cucumber has been served as a delicacy food, beche-de-mer, for approximately 1000 years. Sea cucumber is occasionally used by fishermen for fish bait and is used for medicinal purposes as well (Atafua et al., 2008).

2.1.6 Medical Uses

Generally known to be a source of food for humans, sea cucumbers are also being researched and consumed for their medical capabilities. These creatures have been used as medical treatments for healing wounds, arthritis, tendinitis and joint pain. High in protein at around 55%, sea cucumbers are 10-16% mucopolysaccharide, mostly chondroitin sulfate, which is an element that helps build cartilage and reduce arthritis pain. A mere three grams of dried sea cucumber eaten per day has been reported to greatly reduce joint pain (Dharmananda, 2003). According to Chinese medicine, the sea cucumber is known to nourish the blood, treat kidney disorders, and moisten dryness in the intestines. In modern medicine, sea cucumbers are used as a dietary supplement because sea cucumber extract is easy to encapsulate or put into tablet form. According to Dr. Subhuti Dharmananda of the Institute for Traditional Medicine in Portland, Oregon, a Japanese patent for sea cucumber chondroitin sulfate was issued, which is used in an HIV therapy (Dharmananda, 2003).

Some species of sea cucumber have toxins, which are being used for medical research to combat certain types of bacteria. Fishermen have used the expelled Cuvierian tubules as bandages on bleeding wounds (Kerr, 2000). Unfortunately, some of the extracts of the sea cucumber can cause skin rashes and in some cases, when in contact with the human eye, blindness.

Currently, research is underway to determine if some compounds found in sea cucumbers can help treat cancer. Studies indicate that these creatures have anti-cancer and anti-inflammatory properties, slowing cancer cell growth (American Cancer Society, 2008).

2.2 Harvesting of Sea Cucumbers

Sea cucumbers have been harvested in China for more than 500 years, dating back to the Ming Dynasty (1368-1644), where it was recorded in the *Bencao Gangmu,* a medical report by Li Shizhen, that sea cucumbers were used for medicinal purposes (Chen, 2003). For this reason, China is the top consumer of the sea cucumber (Conand, 2004). Since then, sea cucumbers have been fished and traded all around the world from the South China Sea to the Atlantic Ocean. Of the more than 1250 species known, only about 40 species are harvested.

There are three different methods employed to harvest sea cucumbers: free diving, trawling, or aquaculture. Each is described in more detail in the following sections. Of the three, aquaculture is the least destructive to the ecosystem and produces the largest quantity for harvest. Many environmental concerns have arisen about whether sea cucumbers are being overfished and whether the bottom of the ocean floor is being destroyed in the process of harvesting. To aid in environmental issues and promote sustainable fisheries, in 1995, the Food and Agriculture Organization (FAO) of the United Nations created a code of conduct for responsible fisheries to use and reference when fishing in waters. Some objectives set forth of this code include:

- Establish principles for responsible fishing
- Facilitate and promote technical, financial, and other cooperation in conservation of fisheries resources and fisheries management and development
- Promote the contribution of fisheries to food security and food quality, giving priority to the nutritional needs of local communities

- Promote protection of living aquatic resources and their environments and coastal areas
- Promote research on fisheries as well as on associated ecosystems and relevant environmental factors
- Provide standards of conduct for all persons involved in the fisheries sector (Food and Agriculture Organization of the United Nations, 1995)

2.2.1 Diving for Sea Cucumbers

Free diving is the least efficient sea cucumber harvesting method but is still used today by fishermen. A free diver has few tools to work with when diving and can only carry a limited amount of sea cucumbers back to the surface from the sea bottom. Divers who use SCUBA, Self-Contained Underwater Breathing Apparatus, are able to collect more sea cucumbers from deeper locations because they do not need to rise to the surface for air as free divers do. However, the ability of scuba divers to stay in water for longer periods, as well as go to deeper ocean levels, raises the environmental concern of whether new species are being harvested that generally would not be harvested by free divers due to depth constraints. Over harvesting the sea cucumber from its natural habitat can cause detrimental effects to the ecosystem, for which they play an important role. In 2005, a study in Hurghada, Red Sea, Egypt showed an increase in algae growth on the coral reefs to which the researchers suggested was due to overfishing of sea cucumbers over the last two years (Mohamed & Mohamed, 2005).

2.2.2 Trawling for Sea Cucumbers

Trawling is a method where a net is dragged along the ocean floor, entangling sea cucumbers in the net. For example, in Maine, a typical day's catch ranged between 70 and 200 totes per day, where each tote could hold between 130 and 150 pounds of un-dried sea cucumbers (Chenoweth & McGowan, 1995). Trawling is an easy way to capture a large quantity

of sea cucumbers at once; however, there are many cases of unintentional by-catches of other organisms. Trawling can also damage sea cucumbers due to rough dragging along the sea bottom, reducing the sea cucumbers consumer product worth. Trawling's negative effects on sea bottom environments and unintentional by-catch of other organisms has raised environmental concerns regarding the method. With new breakthroughs in technology and science, more efficient harvesting methods have been implemented.

2.2.3 Aquaculture of Sea Cucumbers

The most advanced method for harvesting sea cucumbers used today is aquaculture. Aquaculture is the farming of aquatic animals, which involves controlled conditions in fresh and salt-water environments. These environments can be man-made or an addition to a natural habitat and aim to resemble the characteristics of the ecosystem the sea cucumbers dwell in. Sea ranching, initiated in 1980 by the Yellow Sea Fisheries Research Institution in China, involves taking the cultured sea cucumbers and putting them into a guarded area of their habitat, protected from predators, disease, and with easy monitoring capabilities until they are of proper commercial size (Chen, 2003). Artificial reefs can be created by using stones or scallop nets then filling the pond with clean salt water as shown in Figure 5 (Cao, 2011). The bottoms of the ponds tend to have sand or mud, for the sea cucumber to bury itself.

Figure 5: Concrete Pond Culture in Vancouver Canada (Cao, 2011)

China and Japan have the most advanced systems for hatcheries, cultivating the sea cucumber until it matures enough to be released into the designated area. The process starts by making sea cucumber zygotes in vitro, placing them into a cultivation area, letting the sea cucumbers mature until they are ready to survive in the pond or designated area. Once the sea cucumbers are settled into their designated area, it is the farmer's job to maintain a healthy environment, including proper salinity, temperature, and other animals that may cohabit the environment in the wild.

2.3 Drying Process

Upon harvesting sea cucumbers, sea cucumber industries implement methods of processing used to preserve the harvest for longer durations and reduce the cost for shipping. Because this creature consists mainly of water, drying the sea cucumber significantly decreases its weight and size. In the Philippines, fishers perform a step by step process in drying the sea cucumber which consists of the following:

1. Washing the fresh caught sea cucumber to remove sand, sea grasses, or other materials
2. Slicing to remove the intestines and other unwanted wastes of the sea cucumber (usually by slicing perpendicular through the ventral side)
3. Washing a second time to remove smaller wastes and clean the freshly sliced sea cucumber
4. Boiling the sea cucumber in order to lightly cook for a maximum of 30 minutes in a big pan or vat
5. Soaking the sea cucumber in salt or brine solution overnight to preserve dried sea cucumber for a longer period of time
6. Drying with smoke for half a day is used to avoid flesh being broken off or into pieces and make the second drying process faster
7. Sun drying to attain the desired dryness of a sea cucumber, lasting for 3-4 days or depending on the sunlight
8. Packaging once the desired dryness or moisture content is met. Usually placed into plastic cellophane and placed into boxes ready for delivery to buyers (Subaldo, 2011)

To use the sea cucumbers, once imported, water is reabsorbed to increase its size and body wall. The best species in the beche-der mer market are large and have thick body walls. Another product from the sea cucumber is the longitudinal muscles, tasting like high quality clam meat. Many years ago, while some countries did not use the entails of the sea cucumber, Indonesia dried the intestine (konowata), the gonad (konoko), and the muscles as well (Tiensongrusmee & PontjoPraWiro, 1988).

2.4 Economics of Sea Cucumbers

Sea cucumbers are generally consumed in Asia, but a significant portion of sea cucumbers are imported from the Caribbean (Toral-Granda et al., 2008). Sea cucumbers are harvested in different amounts, and differ in species depending on each individual country. The locations listed below provide a basis of comparison to Puerto Rico.

2.4.1 Mexico

Hong Kong recorded that 14 tonnes of sea cucumber have been imported from Mexico from 1995 to 2005. The FAO, however, believes that 2,564 tonnes were caught from 1998 to 2005. The average annual catch in this time period was 320.5 ± 86.3 tonnes (Toral-Granda et al., 2008). The species mainly caught are I. fuscus (East coast) and P. parvimensis (West coast). The sea cucumber industry in Mexico is mainly an income supplement during the off season for other sea creatures. (Toral-Granda et al., 2008)

2.4.2 Panama

In 1997, an Asian company was granted a permit by the Panamanian government, harvesting approximately 750,000 sea cucumbers in a mere 30 days of the species A. multifidus, I. badionotus, and H. mexicana. These sea cucumbers were harvested by 25 fishers under the direction of the Asian company. Later in the same year Panama banned all fishing for sea cucumbers (Toral-Granda et al., 2008). The company preferred A. multifidus and I. badionotus over H. mexicana due to its higher quality and therefore higher market value (Guzman & Guevara, 2002). Despite H. mexicana's lowest market value fishermen began to collect the species after the other two species were less common. According to Guzman and Guevara the effects of the 1997 sea cucumber fishery was still evident in 2000 when surveying for the three

species was conducted in Bocas del Toro Panama between May and October (Guzman & Guevara, 2002).

2.4.3 Costa Rica

The general species harvested in Costa Rica are H. inornata and I. fuscus. Costa Rica, even in the early 1990s, had a very advanced licensing system. In 1993 and 1994, there were only ten licenses issued (one per fisher) for sea cucumber harvesting (Toral-Granda et al., 2008). The main method used to harvest the sea cucumbers was by skin diving or a hookah system, long hoses to supply air from the surface to the fishermen. The minimum size permitted was 20 cm and there was a monthly limit of 200 cucumbers per fisher. There were also restrictions on landing ports and areas where harvesting was not permitted. However, sea cucumber fishing was banned soon after to repopulate the area. Hong Kong reported that from 1999 – 2005, 1.3 tonnes had been imported, from Costa Rica, suggesting there was illegal fishing occurring despite the ban (Toral-Granda et al., 2008).

2.4.4 Nicaragua

During 2008 in Nicaragua, there were about 45 year-round sea cucumber fishermen, with about 150 fishermen using periodic sea cucumber fishing to supplement their income. Nicaraguans do not consume any of their catch and all sea cucumbers are exported to Taiwan and China. Before 2005, no statistics were recorded on sea cucumber catch, however, from 2005-2007, approximately 425 tonnes in total were exported. During this time period, there were no sea cucumber fishing regulations in Nicaragua. (Toral-Granda et al., 2008)

2.4.5 Venezuela

The primary sea cucumbers harvested in Venezuela are I. badionotus and H. mexicana. In 1994, approximately 2 tonnes were exported; however, sea cucumber fishing in Venezuela was

banned in 1995 due to overharvesting. In 1995, 0.93 tonnes of sea cucumber was confiscated by the government. Again, in 1996, 0.5 tonnes of H. mexicana were discovered en route to Asia. The sea cucumbers from 1996 were valued at 150,000 USD. Lastly, Hong Kong reported 0.5 tonnes of sea cucumber originated in Venezuela in 2005. (Toral-Granda et al., 2008)

2.4.6 Cuba

Commercial fishing for sea cucumber, predominately I. badionotus, in Cuba was approved in 1997, but did not begin until 1999. A Korean company claimed the first license and was restricted to 320 tonnes (dry) per year. Three million sea cucumbers were caught from 1999-2000. From 1999-2005, there were periods where boats would average between 350 and 1,153 sea cucumbers per day. Throughout 1999-2005, the price of grade "A" sea cucumbers ranged from 13.50 USD to 22 USD per dry kilogram while grade "B" sea cucumber pricing ranged from 6 USD to 10 USD. Cuba has a variety of restrictions in place. Most importantly, there is no fishing from June – October to allow for the reproductive season. This season can change from region to region and is also dependent on water temperature, water conditions, and the availability of food. In 2005, 28 licensed fishers would fish for 20 days and then come back to port. The collection process for Cuban fishers consists of hookah systems at depths between three and fifteen meters. The government also provided processors with a standardized procedure to increase the percentage of high quality product. (Toral-Granda et al., 2008)

2.5 Illegal Trade in Latin America

According to Hong Kong Census and Statistics Department, there are 14 countries from Latin America that export sea cucumbers. However, Hong Kong records that these countries represent less than 1% of the total percentage of imports. This information leads the FAO to

believe that the vast majority of sea cucumbers exported from the region are illegal, unreported, or unregulated (IUU).

Due to the fact that no skills or expensive equipment is required to harvest sea cucumbers, harvesting may be somewhat of a "gold rush" phenomenon to fishermen in different countries. For example, the ease of access has pushed more fishermen to harvest sea cucumbers in Latin America, where the industry has continued to expand since the 1980s. It is noteworthy that the sea cucumbers are not domestically eaten and there is no cultural history in Latin America connected to the sea cucumber harvesting as there is in Asia. The FAO does not have concrete statistics on how dependent fishermen are on the sea cucumber industry and believe fishermen may be willing to break the law in order to engage in harvesting where decent profit can be made. On the whole, even countries that have regulations do not enforce them strictly, which results in illegal fishing activities (Toral-Granda et al., 2008). This has resulted in the many regulations passed in Caribbean countries (Toral-Granda et al., 2008).

2.6 Puerto Rican Fishing Regulations

In Puerto Rico, there are no length requirements or seasonal closures for sea cucumbers. There are no fee based permits or daily maximums as for other similar species, such as the queen conch. The lack of any regulations can cause sea cucumbers to be more susceptible to exploitation. The only requirements to harvest sea cucumbers is possession of either a full time or part time commercial fishing license which simply requires Internal Service Revenue (IRS) documents proving at least twenty percent of one's income (part time license) and at least fifty percent for a full time license is derived from fishing, after an initial period. Lastly, Law 278 passed in 1998 required all fishermen to send landing reports to the DNER. This law applies to

all species in Puerto Rican waters, but not a single species of sea cucumber can be found on the landing report form. (Matos-Caraballo & Agar, 2008)

On March 12, 2004, Regulation 6768, commonly called "Puerto Rico Fishing Regulations" created a fee based permit system for a variety of species including lobster, queen conch, and land crab. The regulation created length requirements, seasonal closures, and individual and boat based quotas. Lastly, the regulation required that fishermen submit IRS documents in order to obtain a commercial fishing license. These regulations are followed closely through the use of DNER rangers, who monitor fishermen and enforce the regulations in different areas throughout the island (Matos-Caraballo & Agar, 2008).

It is also noteworthy that the 2008 Comprehensive Census of the Marine Commercial Fishery of Puerto Rico suggests that many fishermen never applied for a commercial fishing license due to the fact it would force them to pay taxes on ten percent of their income. Many fishermen refuse to comply with regulations due to distrust of the DNER. (Matos-Caraballo, 2009)

2.7 Regulations in Other Countries

Although there are no regulations for sea cucumber harvesting in Puerto Rico, regulations in other countries have been specified with regards to licenses, permits, size limits, gear limitations, and moratoria in order to protect holothurian species and fishers alike. For example, in Alaska, sea cucumber fishing is restricted to hand picking and regulations in many countries have been put into effect prohibiting the use of scuba (Alaska Department of Fish and Game, 2008). It is important to understand the biological, socio-economic, and managerial impacts of regulations on sea cucumber fishing in different countries in order to better understand how

regulation implementation can benefit industry while benefitting fisherman and the sea cucumber population. In recent years, trawling has been banned in certain countries due to its negative impacts on the environment. Many countries including Costa Rica, Venezuela, India, and Egypt have completely banned sea cucumber harvesting due to exploitation. Some locations have closed seasons, where fishermen are prohibited from harvesting until the closure is removed, while others enforced regulations pertaining to boat size, fishing times, and species quota, protecting species with great exportation value. Appendix A covers regulations, their success in managing fisheries and their limitations by region or country.

3.0 Methodology

The project's main research goals were to, first, evaluate the current status of active and past sea cucumber fishing in Puerto Rico; second, examine the sea cucumber fishery in Puerto Rico; third, to use data gathered through our research to make accurate and adequate regulatory recommendations to the DNER for future sea cucumber harvesting activities. The DNER had little to no information on those who harvest sea cucumbers and their methods, thus it was crucial to provide DNER with as much information as possible to determine whether more research is necessary to assess sea cucumber fishing for regulatory action. In order to accomplish these goals, we identified the following methodology objectives to serve as the basis for our research and selected instruments:

1. Collect any past data on sea cucumber fishing in Puerto Rico.
2. Determine locations of current and potential sea cucumber harvesting.
3. Gather fishermen responses on sea cucumber fishing in Puerto Rico.
4. Document habitat and species of sea cucumber at fished and unfished sites.

To help us achieve these objectives, we employed a variety of research methods. This chapter explains our methods, processes and reasoning behind our selected methods as well as the challenges and limitations encountered. The table in Appendix B is a planned outline of our timeline and Appendix C contains our methodology flow chart, for reference.

3.1 Collect Past Data on Sea Cucumber Fishing in Puerto Rico

The team sought information on the number of sea cucumbers harvested per day, per month to provide a perspective of the magnitude of sea cucumber fishing in Puerto Rico. In order to properly investigate sea cucumber fishing in Puerto Rico, we established that, prior to our

arrival, any form of past DNER quantitative information on sea cucumber fishing would be useful as a starting point for analysis in our research investigation. The analyses performed on the landing reports would be useful in comparing catch numbers with actual sea cucumber fishermen responses collected later-on in our research.

Prior to our arrival in Puerto Rico, we contacted our sponsor, Dr. Craig Lilyestrom, Director of DNER Marine Resources Division, who provided ten months of sea cucumber landing reports from the Fisheries Research Lab in Joyuda, Puerto Rico. However, privacy concerns withheld access to the remaining landing reports of 2012, limiting the data to March 2011-November 2011 and March 2012. These landing reports are hand-written reports filed by the DNER that commercial fishermen are required to fill out every month with information regarding years, months and dates fished as well as quantity harvested per day, per month, and name and address of the company.

The data was analyzed to estimate daily and monthly averages, the market size, differences and similarities between months, and highest and lowest catch periods. Calculations were used in comparison with one another in order to determine any trends or fluctuations on a day-to-day or month-to-month basis. All data was organized and compiled into a Microsoft Excel spreadsheet in order to create a graphical representation of the number of sea cucumbers harvested over time.

3.2 Determine Locations for Current and Potential Sea Cucumber Harvesting

After receiving quantitative information on sea cucumber fishing in Puerto Rico from the landing reports, the team worked towards identifying locations of past, current or potential sea cucumber harvesting activity. Determining the locations of sea cucumber harvesting would aid

the team in receiving firsthand responses from sea cucumber fishermen and DNER employees who had observed harvesting. In order to accomplish this, we constructed and administered interviews to a variety of DNER employees, including biologists, managers, fishing agents and rangers. Following our sponsor's advice and with the consideration that the duration of the project was only two months, the team focused on specific areas to determine the status of sea cucumber fishing. These locations included Salinas, Fajardo, Lajas/Guanica, and Culebra.

Our team interviewed various DNER employees, conducting each interview in the same manner. Every interview was in-person, formal and consisted of structured questions that were reviewed by our sponsor and designed specifically dependent on the position of the interviewee and the information we wished to gain from him/her. All four members of the team were present, with a personal notepad and a copy of the interview questions to record the responses of the interviewee. With the permission of the interviewee, interviews were recorded visually with a camera. Once all interviews were complete, we stored all responses in Microsoft Word where we compared and contrasted answers in order to identify potential sea cucumber fishing sites and sea cucumber harvesting specifics. After responses were stored, video recordings of all interviews were erased.

The team conducted an interview with Daniel Caraballo in order to provide us with possible locations of sea cucumber fishing in Lajas/Guanica and general information regarding sea cucumber fishing. Caraballo is a DNER Biologist III who has worked the last 24 years in commercial fishing statistics at the Fisheries Research Lab. He is responsible for filing fishery landing reports and has conducted previous research on sea cucumbers in 2011-2012, which has not been published yet. Our questions for Caraballo specifically focused on number of

fishermen, status of fishing, fishing locations, methods employed, and processing/ exporting of sea cucumbers.

The team sought information regarding sea cucumber fishing in Salinas and the Jobaner Reserve, therefore, the team interviewed Angel Dieppa, a DNER marine biologist, and Carmen Gonzalez, the DNER manager of the Jobaner Reserve facility. Questions for both DNER employees primarily focused on whether they had heard of sea cucumber fishing in Salinas or in other locations.

To determine whether sea cucumber fishing was occurring in Fajardo or other locations, the team interviewed Jesus Fernandez, a DNER fishing agent who monitors commercial fishing in Fajardo. Questions for Fernandez primarily focused on sea cucumber fishing in the area or in other locations. Jesus Fernandez made many phone calls during the interview in order to give the team information from different DNER rangers throughout Puerto Rico, who exercise their responsibility as guardians and custodians of natural resources, and from fellow DNER employees he believed could aid us in our research.

To discover whether sea cucumber fishing was still occurring in Lajas/Guanica, the team interviewed Ranger Banch, a DNER ranger who had previously worked in the Lajas/Guanica area. Banch was an important resource to the team's research based on his knowledge of sea cucumber fisherman contacts, locations, and first hand observations of sea cucumber fishing activity. Questions asked primarily focused on number of fishermen, status of fishing, fishing locations, methods employed, and processing/ exporting of sea cucumbers.

To identify whether sea cucumber fishing was occurring in Culebra, the team interviewed Misael Feliciano, a DNER ranger who worked on the island and had observed firsthand sea cucumber fishing activity in the Culebra area. Our questions for Feliciano were primarily

concentrated on sea cucumber fishing activity and information regarding number of fishermen, status of fishing, fishing locations, methods employed, and processing/ exporting of sea cucumbers.

To continue the search for sea cucumber fishing in Culebra, we interviewed Ana Roman, a Deputy Project Leader for the US Fish and Wildlife Service on Culebra Island who had knowledge of sea cucumber fishing activity in Culebra. Questions for Ana Roman focused around reports of sea cucumber fishing in the Culebra area as well as reserved waters around the island.

Main challenges encountered during interviews included interviewee limited knowledge of sea cucumber fishing and an occasional language barrier between three of four team members and the interviewee. To overcome the language barrier, one team member led the interview in Spanish, translating information to the remaining team members upon completion of the interview.

3.3 Gather Fishermen Responses on Sea Cucumber Fishing in Puerto Rico

In order to gather fishermen responses in the areas of Salinas, Fajardo, Lajas/Guanica and Culebra, the team administered informal and unconstructed interviews to non-sea cucumber fishermen as well as structured questionnaires to only sea cucumber fishermen. This allowed for us to acquire data for our research to aid us in making an evaluation of sea cucumber fishing in Puerto Rico.

The questionnaire, found in Appendix D, contained a series of multiple choice and open-ended questions about sea cucumber fishing, harvesting data and fishing locations in Puerto Rico. The questionnaire also included identification images of the most common sea cucumbers

in the Caribbean area in order to provide a visual identification for the species harvested, should they be unfamiliar with the names of the species. The questionnaire was constructed in a manner for the fisherman to complete the questionnaire with minimal assistance; however, the team members were available to avoid confusion with any questions.

Once responses for both the unstructured interviews and questionnaires were gathered, they were entered into Microsoft Word documents and organized according to question and location. After entering the data, we compared answers from different fisherman within the same location as well as different locations. We were able to determine most common species harvested, methods employed, fishing locations, price received per sea cucumber, amount harvested per day, processing/exporting, and estimated economics. The information gained from these interviews and questionnaires aided our results by comparing these responses to data we had previously collected and analyzed in the sea cucumber landing reports and interviews with DNER employees. Through this comparative method, the team identified consistent answers and found the most useful information to be presented to the DNER.

The team sought out to acquire fishermen knowledge of sea cucumber fishing in the Salinas and Fajardo area. The information gained from three unstructured interviews helped to determine the status of sea cucumber fishing in these two locations. In both locations, questions involved sea cucumber fishing activity or harvesting in general.

To gather sea cucumber fishermen responses in Lajas/Guanica, the team interviewed and administered questionnaires to two sea cucumber fishermen. Reponses were crucial to our research, as it allowed the team to receive information on the only company to report sea cucumber harvesting. Interview questions outside the questionnaire for these fishermen

specifically focused around motives to harvest sea cucumbers, their manager's name and company history, and additional comments which may aid in our research.

In order to gather sea cucumber fishermen responses in Culebra, the team interviewed and administered a questionnaire to one sea cucumber fisherman. Receiving responses to the questionnaire would aid the assessment of sea cucumber fishing in Culebra, whether for commercial or personal use. Interview questions outside the questionnaire included the processing of sea cucumbers and locations for exportation.

The main challenges our team encountered during the process of contacting and interviewing fishermen included their overall hesitancy and unwillingness to offer information, especially due to our association with DNER. Based on the fishermen's behavior and discrepancy between answers, the team also questioned the accuracy of answers received. Another challenge the team encountered involved all fishermen speaking in Spanish while only one member of the team speaks Spanish. For this challenge, the team member administered all the interviews alone, relaying the information to the rest of the team once the interview was complete. This challenge limited the amount of questions, to what one member ask rather than allow the collaboration of the team as a whole. Another challenge our team encountered was the overall difficulty in finding sea cucumber fishermen to interview. In order to be able to find the fishermen, a contact chain occurred where different DNER employees contacted each other, and through their acquaintances, were able to reach the fishermen. The Figure 6 below shows the contact chain and process we followed to reach each fisherman.

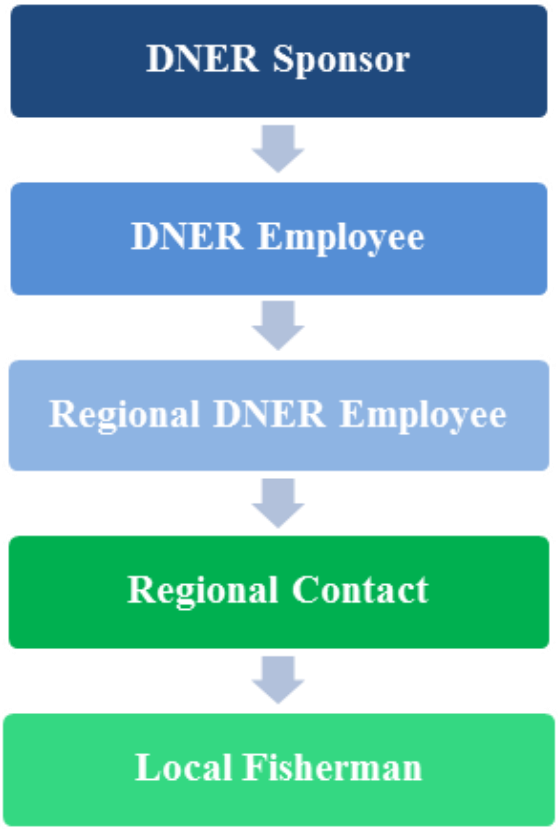


Figure 6: Contact Chain

3.4 Document Habitat and Species of Sea Cucumber at Fished and Unfished Sites

In order to document habitat and species of sea cucumber at fished and unfished sites, the team performed in-water observations and analysis. The team documented nine DNER ranger verified fished/unfished locations in Lajas/Guanica and Culebra. The DNER rangers provided a boat to allow the team to perform in-water observations at locations shown in our maps in Appendix E and Appendix F. Once at the locations, all members of the team snorkeled and one member took underwater photographs using a GoPro High Definition Camera. The team documented types of seagrass, water clarity, current intensity, water depth, species of sea cucumbers, ratio H. mexicana to I. badionotus, and sea cucumber sizes.

The ratings used to judge water clarity and current intensity were created by comparing individual locations during in-water observations as well as using the photographs taken of surrounding protective cays, mangroves or sand bars. Water clarity was judged on a five level scale with levels being low, low-medium, medium, medium-high, and high. Current intensity was judged on a three level scale with levels described as low, medium and high. The team approximated depth at each location by a comparison of a snorkeler's height. For depths greater than snorkeler's height, an estimate was obtained by one snorkeler completely submerging one's self while another snorkeler could estimate the remaining distance. Ratios between the species H. mexicana to I. badionotus were estimated by the team's in-water observation notes and underwater photographs. When there were few documented cases of other species, we assigned a "dominant" rating. These observations and documentation allowed us to better assess and analyze the current state of fished ecosystems compared to unfished ecosystems in the same area.

The team faced challenges while conducting in-water observations such as difficulty in accurately defining water clarity, current intensity and water depth as well as accurately identifying species and species ratio. For species identification, the team used Paul Humman and Ned Deloach's Reef Creature Identification, an archival source containing images, variations, and descriptions for few sea cucumbers in the Caribbean area , as well as Aymeric Desurmont's Papua New Guinea sea cucumber and beche-de-mer identification cards (Desurmont, 2003), (Humann & DeLoach, 2002).

4.0 Results

In this chapter, the team presents the data and findings gathered at specific locations from our research of sea cucumber fishing in Puerto Rico. For better interpretation of results, data is presented based on methodology objectives. First, we assess past sea cucumber fishing in Puerto Rico. Second, we present locations with current or potential sea cucumber harvesting. Third, we present fishermen responses on sea cucumber fishing in Lajas/Guanica and Culebra. Lastly, we outline our documentation of habitat and species of sea cucumber at fished and unfished sites.

4.1 Past Data on Sea Cucumber Fishing in Puerto Rico

The 2011 sea cucumber landing reports contain the amounts of sea cucumbers harvested per day for each month by a company named Vermesco Corporation. The team performed data analysis to estimate totals, averages, differences and similarities between months, and highest and lowest catch periods. Vermesco Corporation fished for 134 days collecting a total of 114,485 sea cucumbers. Figure 7 illustrates sea cucumber fishing catch numbers by month with the number of days fished per month. We next utilized this data to calculate the harvest per day to be on average 855 sea cucumbers. The lowest amount harvested in one day was 94 sea cucumbers while the highest amount harvested in one day was 2160. The team noticed a fluctuation in day-to-day harvesting numbers as well as month-to-month. For example, one day the harvest number was 1165 sea cucumbers, the next day was 862, and the third day was 2160.

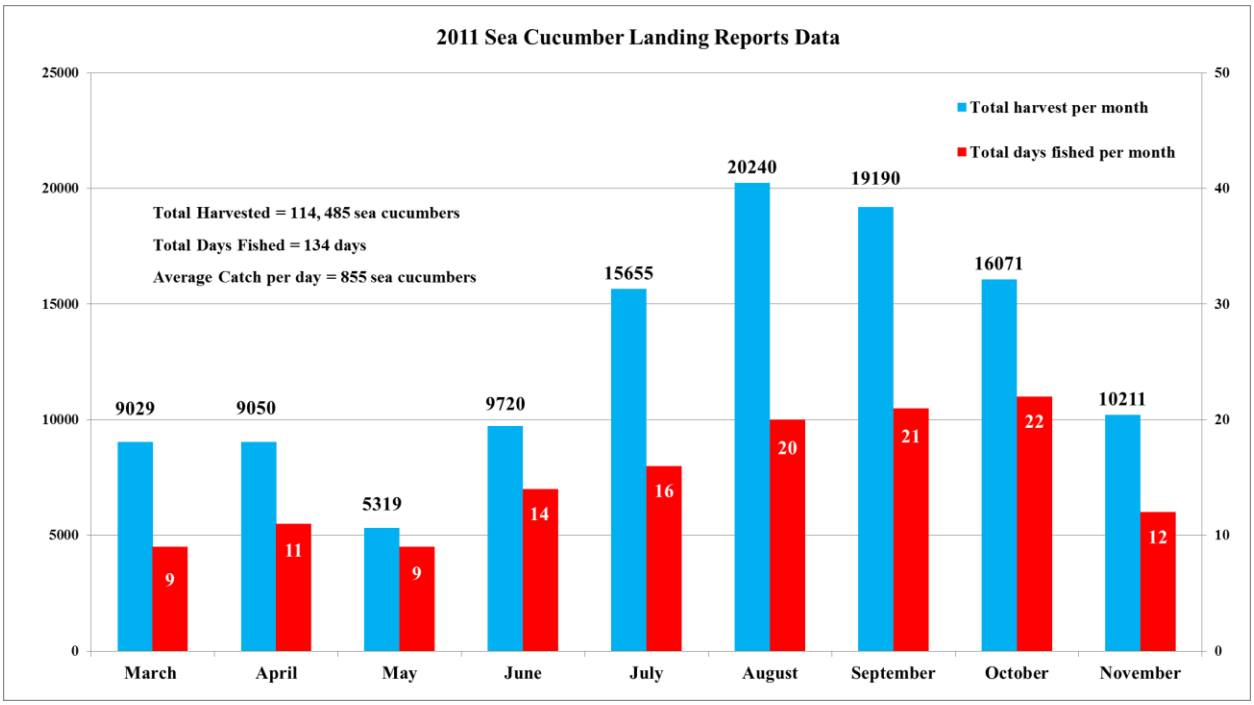


Figure 7: 2011 Sea Cucumber Landing Reports Data

Notice the increased harvesting numbers from June through August where sea cucumber harvesting had reached its peak. As shown above, August had the highest harvesting number, fishing for 20 days of the month; while May had the lowest harvesting number, fishing for nine days of the month and having the lowest single day harvesting number.

Only one month of landing reports for 2012 was received, although more are known to exist, making it difficult to perform an analysis for year-to-year harvesting data; however, it provided a comparison for the month of March. The harvesting number for March 2011, as shown above, was 9,029 while the harvesting number for March 2012 was 4,922. The average harvested sea cucumber per day decreased by more than 700 sea cucumbers, even though the company fished eight more days during March 2012 than in March 2011.

4.2 Locations for Current and Potential Fishing in Puerto Rico

This section presents the results from interviews administered to DNER employees. The following results were obtained from Salinas, Fajardo, Lajas/Guanica, and Culebra. A summary of the interviews can be seen in Appendix G.

Angel Dieppa stated there was no sea cucumber fishing in the Salinas area. Dieppa also stated that fishing for sea cucumbers would be dangerous to the oceanic system as a result of their distinct and unique role in the ecosystem and in the bioturbation of the ocean floors. Carmen Gonzalez also confirmed there was no sea cucumber harvesting occurring in Salinas or surrounding areas; however, she had heard of sea cucumber fishing in the Lajas/Guanica area describing that it was more difficult to find sea cucumbers in the shallow water presently than it was in the past based on her own firsthand observations. The team does not know how recent these observations were and if they were related to the time in which sea cucumber harvesting was occurring.

According to Jesus Fernandez there was no sea cucumber fishing in the Fajardo area; however, there was active sea cucumber fishing in Culebra Island by a family who owns a restaurant. Contact information for a DNER ranger in Culebra who had seen the family fish for sea cucumber was provided to the team.

Daniel Caraballo started a personal study of sea cucumber fishing in the Lajas/Guanica area in 2011- 2012. According to Caraballo, Vermesco Corporation started harvesting sea cucumbers in early 2011 with one manager and an estimated four separate fishermen, each owning their own boat. The fishermen would return their daily haul to the manager's home, which served as a processing center. The fishermen would start their work day around 7 AM and

return with their haul at approximately 12 PM. Methods involved with harvesting included using snorkeling gear for depths ranging from 10 to 15 feet and scuba for depths between 20 and 40 feet. The fishermen harvested three species: Isostichopus badionotus, Astichopus multifidus, and Actinopyga agassizii. Vermesco Corporation was responsible for gutting, cleaning, and drying the harvested sea cucumbers, all of which are processes involved in preparing the sea cucumbers for exportation. The destination for exportation was known to first be Miami, U.S., then to be sold and exported again to an Asian country. No local restaurants were involved with purchasing sea cucumbers for consumption or selling purposes. Caraballo's research lead him to conclude that populations of sea cucumbers have started to decline as sea cucumber harvesting has reached its peak in the area of Lajas/Guanica. Caraballo further suggested that the main issue with fishing in tropical Caribbean waters is that, although there are many species present, these species are found in small populations, making it very easy to overfish.

Ranger Banch informed the team of observed sea cucumber fishing in the area of Lajas/Guanica approximately one to two years ago. According to Banch, there are significantly fewer sea cucumbers in the water currently compared to several years ago. Three sea cucumber fishermen worked for Vermesco Corporation in the Lajas/Guanica area and would haul in boats full of sea cucumbers on a daily basis. They would fish 6am-12pm, handpicking the sea cucumbers. After the sea cucumbers were harvested, a different set of people processed the harvest by cutting the sea cucumbers and leaving them to dry outside of Vermesco Corporation. Fishing for sea cucumber was not the fishermen's only source of income as they would generally fish for other marine creatures such as queen conch. The sea cucumber fishermen had an Asian boss, higher in the work chain than the manager, who would come and take the sea cucumbers after they were processed for exportation. Banch had heard of an

observation that harvesting of sea cucumber might be occurring in Isabela, Puerto Rico, which may be related or unrelated to Vermesco Corporation.

According to Misael Feliciano there was active sea cucumber fishing on Culebra Island by a family that owned a restaurant. The team was provided with the name and general location of the family's restaurant. The family did not fish every day and did not have their own boat, but paid to be taken on a boat to harvest sea cucumbers. They caught 60-70 sea cucumbers per trip, used the sea cucumbers for personal use, and had sent sea cucumber products to family in New York in the past. The restaurant owner had made a comment to Feliciano suggesting that sea cucumber fishing has the potential for much profit. Lastly, Feliciano stated that the loss of sea cucumber in the ocean would cause an imbalance in the ecosystem and, overall, damage the environment. Ana Roman provided the team with information regarding regulations on the island of Culebra as well as permits for fishing in all of Puerto Rico. Roman also knew of the family's activity in sea cucumber fishing on the island and reported that the family had been known around the island for paying children to fish for sea cucumber in shallow waters.

Along with the structured interviews results, the team was informed of sea cucumber harvesting in Belvedere. Although sea cucumber fishing has been confirmed by a DNER employee, the area was not investigated due to time constraints.

4.3 Fishermen Responses on Sea Cucumber Fishing in Puerto Rico

This section presents the results from unstructured interviews with non-sea cucumber fishermen as well as structured questionnaires administered to only sea cucumber fishermen. The sea cucumber fishermen's full responses to every question on the questionnaire can be found in Appendix G. The following results were obtained from Salinas, Lajas/Guanica, and Culebra.

The three fishermen interviewed in Salinas stated sea cucumber harvesting had not occurred and was not occurring in the area. During the interview, it was apparent the fishermen had no knowledge of the use of sea cucumbers. The fishermen claimed to not harvest sea cucumber because they were unaware of its beche-de-mer market value or that sea cucumbers are known to be a delicacy food.

The questionnaires administered to two fishermen separately in the Lajas/Guanica area provided a daily count of harvested sea cucumbers that ranged from 175 to 300 sea cucumbers. Both fishermen used scuba to harvest sea cucumbers under water in a range from 5 - 20 feet, a depth considered shallow for the fishermen when also asked whether sea cucumber harvesting had been moved to deeper waters. Both fishermen were paid 30 cents per sea cucumber by the manager of Vermesco Corporation who sold the harvested sea cucumbers to a foreign company. Of the different species of sea cucumber known, I. badionotus and A. multifidus were harvested by both fishermen. Fisherman II claimed to harvest all species listed on the questionnaire except for A. agassizii, as well as two additional species not listed, the pinto sea cucumber and the green sea cucumber. Both fishermen provided information that they did not process the sea cucumbers themselves; however, there was a garage attached to the house of the manager where five to six workers processed the sea cucumbers separately. They also confirmed that sea cucumber fishing activity had ceased during the month of November 2012, and that the manager of Vermesco Corporation left Lajas/Guanica in December 2012. General comments made by the fishermen outside of the questionnaire included that there was a noticeable but undefined decrease in water quality, such as darkened or yellowed areas in the water, possibly due to either a loss of sea cucumbers from fishing or other occurrences that would degrade water quality. The fishermen also mentioned another man who was the highest person in the work chain, information that

corresponds with the interview with Ranger Banch where he mentioned an Asian man working above the manager of Vermesco Corporation. Lastly, Fishermen II indicated the manager had previously harvested 2500-3000 sea cucumbers per day in Santo Domingo, Dominican Republic. He also mentioned that the manager plans to relocate to Mexico for sea cucumber fishing.

According to a commercial fisherman in the Lajas/Guanica area, the manager of Vermesco Corporation offered him 50 cents a sea cucumber, one to two years ago, for as many sea cucumbers he could harvest. Vermesco Corporation would then sell the sea cucumbers to an outside source. The manager was looking to hire more sea cucumber fishermen; however, the fisherman refused because the 50 cent offer was too low.

The team interviewed one fisherman from Culebra, Fishermen III, who actively fished sea cucumbers with the family previously observed harvesting cucumbers by the DNER rangers. Fisherman III harvested two species, H. mexicana and A. multifidus, using a rental boat occasionally. Lastly, he commented on the low quality of the sea cucumbers in Puerto Rico and mentioned sea cucumber aquaculture in both New York and Hong Kong.

4.4 Habitat and Species of Sea Cucumber for Fished and Unfished Sites

In these following sections the main findings are presented the team believes to be most relevant to our research. A complete detailed account of each fishing location with photographs can be found in Appendix H. Below, in Table 4, a summary of Lajas/Guanica area and Culebra Island in-water observations is shown.

Location	GPS Coordinates	Fished or Unfished	Water Clarity	Current Intensity	Depth (ft)	H. mexicana vs. I. badionotus
Cayo Enrique *(Lajas/Guanica)*	N17°57.307', W67°3.139'	Unfished	Medium	Low	3 to 6	H. mexicana dominant
Cayo Don Luis *(Lajas/Guanica)*	N17°56.713, W66°58.239'	Unfished	Low	Low	2 to 4	2 to 1
Cayo Collado *(Lajas/Guanica)*	N17°57.260', W67°4.738'	Fished	Medium-High	Medium	3 to 6	6 to 1
Cayo Los Hornos *(Lajas/Guanica)*	N17°57.140', W66°68.951'	Fished	Low-Medium	Low	2 to 7	2 to 1
Pelaita *(Culebra)*	N18°17'55.9", W65°15' 10.6".	Unfished	Medium	Low	6 to 9	3 to 1
Punta Cabra *(Culebra)*	N 16°17'43.3", W65°16' 34.1'	Unfished	Low	None	2 to 7	1 to 1
Tamarind Beach *(Culebra)*	N18°19'4.01", W65°19' 8.39"	Unfished	High	Medium	8 to 14	A. multifidus dominant
Daquiti *(Culebra)*	N18°17'09.4", W65°16' 52.6"	Unfished	High	High	4 to 10	3 to 1
Punta Carmelo *(Culebra)*	N18°18'09.1", W65°16' 48.5"	Fished	Medium-High	High	3 to 7	H. mexicana dominant

Table 4: Summary of In-Water Observations

Lajas/Guanica

Fished locations included Cayo Collado and Cayo Los Hornos at points A and C seen in Figure 8. At both fished sites, H. mexicana was the dominant species over I. badionotus. These two species were the only two species present at any site in Lajas/Guanica. Fished sites produced less color variation among the same species in Lajas/Guanica.

Figure 8: Lajas/Guanica In-Water Observation Sites

Unfished locations included West Cayo Enrique and Cayo Don Luis at points B and D in Figure 8. The unfished locations had more intra-species color variation. I. badionotus was found in both a “chocolate chip” color variation and burnt umber variety. H. mexicana was found in a black top gray bottom form as well as a black top rose colored bottom. The variations for I. badionotus can be seen in Figure 9.

Figure 9: Two Color Variations of I. badionotus

As a whole, all four sites had very similar habitats with dense patches of turtle and manatee sea grass. Depths of sea cucumber as a whole tended to be shallower, with a range of 4 to 6 feet in depth.

Figure 10: Culebra Island In-Water Observation Sites

Culebra Island

Only one of the five observed sites near Culebra had reports of sea cucumber fishing. Punta Carmelo, the fishing site at Point C on Figure 10, had many H. mexicana present, but only one documented I. badionotus of the "chocolate chip" variety. The site was exposed to the current off of the open ocean, but still had dense patches of turtle and manatee grass. Water clarity despite the current still received a medium-high rating.

The unfished sites seen in Figure 10 were a diverse grouping of habitats. Tamarindo at point A in Figure 10 was significantly deeper waters than previous sites in Lajas/Guanica and the team documented no specimens of H. mexicana. One case of A. multifidus and one case of I. badionotus were documented. Both specimens were approximately three times longer than average sea cucumber at all sites. These sea cucumbers were also found in more rocky coral habitats.

Pelaita and Daquiti at points D and E were very similar to the fished site Punta Carmelo, with the exception that Daquiti had lower levels of current and wind. However, despite similar habitats, Pelaita and Daquiti had many more documentations of I. badionotus and one of A. multifidus. However, H. mexicana still maintained overall ratio dominance.

Punta Cabra at point B was more similar to the sites near Lajas/Guanica except with lower water clarity and greater shelter due to mangrove protection. At this site H. mexicana, I. badionotus, and H. atra were present, with this site being the first case of H. atra found. I. badionotus was documented at an equal ratio of one to one. In addition to these findings, color varieties were also present in I. badionotus, which had not been found in other locations.

5.0 Discussion

This chapter discusses the results and findings of our research regarding sea cucumber fishing in Puerto Rico based on the team's research goals. First, we evaluate the current status of active and past sea cucumber fishing in Puerto Rico. Second, we examine the sea cucumber fishery in Puerto Rico including the company involved, species harvested, and economics. Lastly, we discuss our proposed recommendations to the DNER in order to help them protect the sea cucumber, aid them in keeping better and updated population and harvesting statistics, and urge them to investigate further into sea cucumber fishing in Puerto Rico.

5.1 Evaluate the current status of sea cucumber fishing in Puerto Rico

The team has determined three main locations where sea cucumber fishing is currently occurring or previously existed in Puerto Rico. Only one company, Vermesco Corporation, has reported the harvesting of sea cucumber. Stationed in Lajas/Guanica, the company ceased all activities in November 2012. Although there is no current fishing in Lajas/Guanica, a family is harvesting sea cucumbers in Culebra, but for personal consumption, not commercial use. DNER rangers have reported harvesting in Belvedere and Isabela; however, the team could not investigate this activity due to time constraints.

The team developed the conclusion of sea cucumber fishing in Lajas/Guanica through interviews with DNER employees including Daniel Caraballo and Ranger Banch, as well as through structured questionnaires administered to two fishermen formerly employed by the company. The conclusion of Culebra was based upon the interview with Ranger Misael Feliciano and the questionnaire administered to one sea cucumber fisherman.

Through our research, the team has endured many challenges, limitations, and discrepancies in evaluating the status of sea cucumber fishing in Puerto Rico. One challenge faced was not being able to contact the manager of Vermesco Corporation. This information was crucial to learning about the company, their motives, and exact exporting locations. A second issued faced was the unwillingness of fishermen to answer questions or determining the truth between fishermen responses. While administering the questionnaire, Fishermen III of Culebra had indicated that fishing was for personal use only; however, Feliciano noted a harvest of 60 – 70 sea cucumbers per trip and that the family had sent sea cucumbers to relatives in New York in the past. An interesting topic introduced was aquaculture in New York and Hong Kong, especially when not one person during our research had mentioned it. This suggests that Fisherman III knows more about sea cucumber harvesting than was presented during the questionnaire.

5.2 Examine the sea cucumber fishery in Puerto Rico

5.2.1 Vermesco Corporation

Vermesco Corporation consisted of one manager, four fishermen, and 5-6 processors for exporting sea cucumbers. Each fisherman had their own boat and harvested approximately 175-300 sea cucumbers per day by using scuba or free diving. Using scuba eliminated the need to rise to the surface intermittently to breathe and is a less harmful method to the environment as compared to trawling. Fishing would continue for an upwards of six hours, starting at 6 or 7 AM and returning at 11:30 or 12 PM. Although many species have different exportation value, each fisherman was paid 30 cents per cucumber, regardless of species. Fishermen harvested a variety of species as well as other organisms such as mollusks and crustaceans. Upon fishing during the day, fishers would return their haul to processors to prepare the sea cucumbers for exportation.

Areas associated with exportation were noted to be Miami, USA and Asia. In total, 114, 485 sea cucumbers were harvested during a ten month span in 2011 as seen in Figure 10. Data from the landing reports yielded an average catch of 855 sea cucumbers per day, which corresponds with the number of fishermen involved in the fishery and their responses for harvest numbers. From June-August, the monthly harvest increased by 4000-5000 each month. This led us to question the reasoning for these fluctuations and whether location, weather, season, number of fishermen, or errors in landing reports were the cause of the differences in sea cucumber harvest numbers. During August, the month of highest harvesting days and catch numbers, Vermesco Corporation harvested 20, 240 sea cucumbers, suggesting that more than four fishermen were involved because fishermen responses yield a range of 175-300 sea cucumbers harvested per day. The months of July, August, September, and October had between 5000-10,000 more harvested sea cucumbers than the other harvested months as seen in Figure 11.

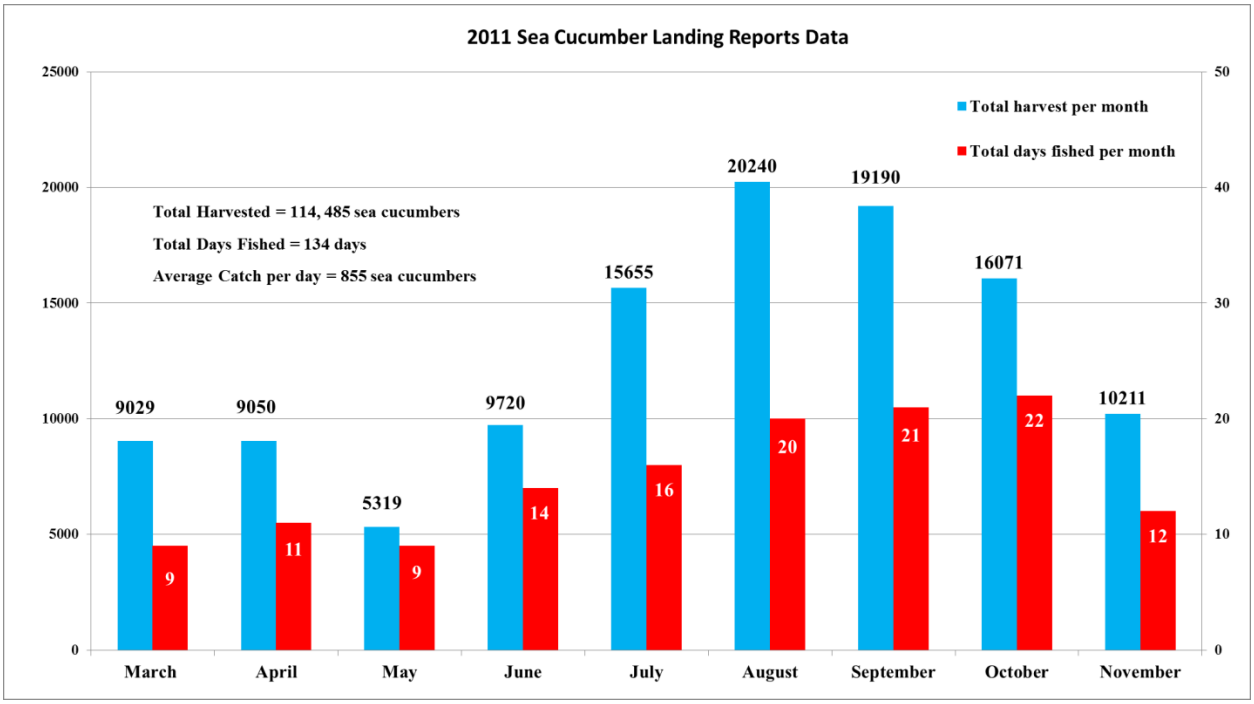


Figure 11: 2011 Sea Cucumber Landing Reports Data

During these months the fishermen also fished more days. These months correspond with sea cucumber reproduction in the countries of Panama (July through November), Cuba (June through October) and Venezuela (July and August). As described in the background, sea cucumbers typically enter shallower water during the reproduction season so this period makes sea cucumber most vulnerable to harvesting. The fact sea cucumbers may be in shallower water could be the reason 5000-10,000 more sea cucumbers were harvested and why the fishers fished more days during the July to October period.

Before Puerto Rico, the manager of the company had previously harvested in Santo Domingo, Dominican Republic, where he would obtain 2500-3000 sea cucumbers per day. After harvesting in Puerto Rico for at least 10 months, the manager was said to have moved to a new location to continue sea cucumber harvesting. This leads the team to believe that the manager harvests locations heavily and then quickly leaves soon afterwards.

Conclusions made upon the sea cucumber fishing of Vermesco Corporation were based upon interview results from Caraballo and Banch, landing report data, and questionnaire responses from fishermen who were formerly employed by the company. General comments from the fishermen regarding the manager of Vermesco Corporation and his past history harvesting sea cucumbers in Santo Domingo, led the team to concerns whether the same operation occurred in Puerto Rico. The team speculates if there could be errors in the reporting of catch data filled out in the landing reports, knowing the manager's past history of sea cucumber harvesting and the fact that regulations do not exist to monitor harvesting in Puerto Rico.

5.2.2 Species Harvested

In Lajas/Guanica, fishermen targeted A. multifidus and I. badionotus, resulting in reduced amounts of those species at fished locations based on in-water observations. In Culebra, targeted species were A. multifidus and H. mexicana, demonstrating that A. multifidus was the most highly sought sea cucumber being harvested in both areas. Based on our observations, the team believes sea cucumber fishing has caused less species diversity and less intra-species color variation at specific fished locations.

Interviews with Fishermen I, II, and III along with the team's in-water observations supports the above conclusions on species harvested. The species H. mexicana was dominant at eight of the nine locations and the ratio of H. mexicana to I. badionotus tended to be greatest at fished locations. Besides H. mexicana dominance, fished locations lacked in intra-species coloration and overall species diversity. All three fishermen harvested A. multifidus, two harvested I. badionotus, and two harvested H. mexicana. In addition, Fishermen II indicated he also harvested the pinto sea cucumber and the green sea cucumber.

The conclusions drawn by the team from the interviews and in-water observations have a variety of limitations and unknowns attached to them. The team's time constraints only allowed for one visit to each site which provides for only a limited amount of in-water observations. Constantly changing conditions could affect sea cucumber locations on a daily basis possibly skewing observations. Changing conditions could also influence different species locations due to certain water characteristics. The team was unable to observe past fifteen feet deep due to a lack of scuba equipment. H. mexicana may have been scarce in deeper waters while other species, such as A. multifidus, may be in abundance. In addition, the team does not have any documentation of the visited locations before they were fished so a pre and post fishing

comparison cannot be analyzed. Documentation before fishing would have also allowed the team to determine the likelihood of the possibility that I. badionotus and A. multifidus are normally not found in similar ratios to H. mexicana.

The fishermen questionnaires do not completely correspond with the team's in-water observations. It is unlikely that H. mexicana was harvested due to its overabundance and its low market value; despite the fact that two fishermen indicated they harvested H. mexicana. However, global demand for I. badionotus suggests that all three fishermen probably harvested the species, but only two of the three indicated they did so. Fishermen may not have completely disclosed information on what species they harvested or may have indicated species they did not actually harvest due to a distrust of the DNER.

5.2.3 Economics

Since the company station in Lajas/Guanica harvested 114, 485 sea cucumbers and paid four fishermen 30 cents per sea cucumber, the company paid the fishermen approximately 34,345 USD all together over the 10-month period from the landing reports. The company also consisted of 5-6 workers for processing the sea cucumbers. If each of these workers were given an estimated 30 cents per sea cucumber processed, same wage as fishermen, this would bring the total cost to more than 68,000 for the 10-month period. According to alibaba.com on April 26, 2013, I. badionotus had a market value between 50-200 USD per dry kilogram, where 90 sea cucumbers is approximately one kilogram. Using the extreme prices per kilogram the range after expenses is between about -4000 USD to +186,000 USD. The median value is therefore about 90,000 USD. It is important to note these estimates are subject to varying market prices. In addition to this, the number of dried A. multifidus to add up to a kilogram in dry weight could not be found. This knowledge would affect the range of profit. However, the current market price

range for A. multifidus is 40-95 USD per dry kilogram. With this information the team believes the fishermen and processors were poorly compensated with the manager of the company taking the vast majority of the income. This is in agreement with the Culebra restaurant owner comments stated by Feliciano that the sea cucumber industry has significant income potential.

5.3 Recommendations

Based on our findings, the team has developed and proposed several recommendations and preventative measures that the DNER can consider utilizing in the future in order to protect the sea cucumber and gain more information about this creature, building upon what is already known and been discovered by our research in regards to its harvesting in Puerto Rico. Figure 12 provides a visual summary of our suggestions, described in further detail below, for future prevention of sea cucumber exploitation and continued research in this field.

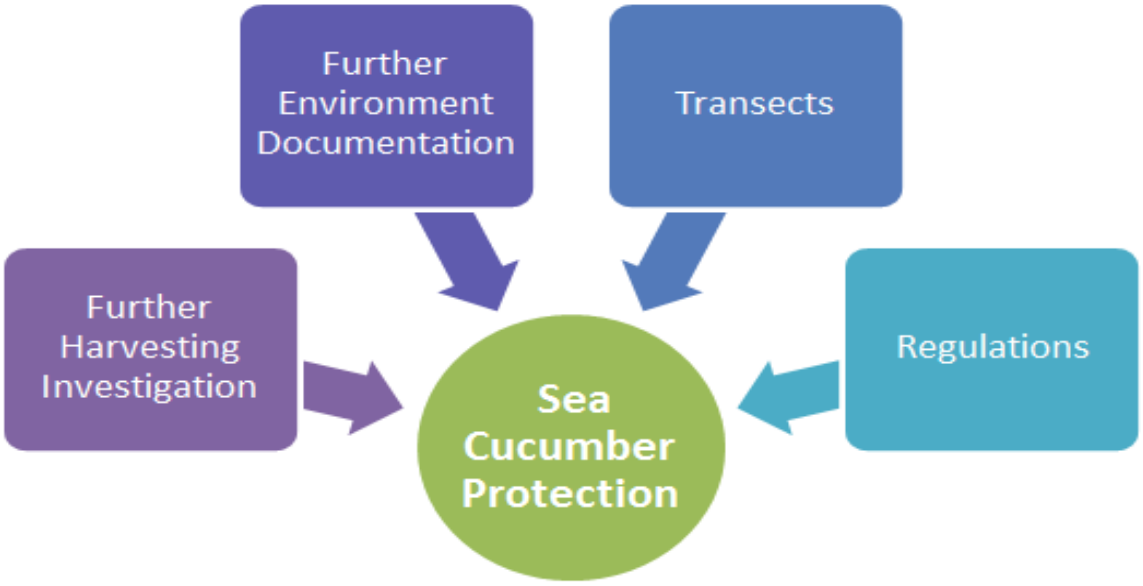


Figure 12: DNER Plan of Attack

5.3.1 Further Harvesting Location Investigation

In order for the DNER to obtain a full and entire representation of sea cucumber fishing throughout all of Puerto Rico, it is crucial for them to continue investigation through observations and interviews at the locations we already have visited as well as other areas where sea cucumber fishing has been reported to occur. We observed and interviewed at Salinas, Fajardo, Lajas/Guanica, and Culebra. However, Culebra still has the potential for more information to be gathered as well as new sites such as Belvedere and Isabela. If continued and further investigations in possible sea cucumber sites are pursued, the DNER should be able to build on the information and investigation we have started, especially since we have determined sea cucumber fishing in Puerto Rico to be an affair that will take longer than two months to fully uncover. While conducting further investigation in these areas, researchers should be prepared to face challenges especially when associated with the DNER, such as fishermen's overall hesitancy and unwillingness to offer information.

5.3.2 Further Sea Cucumber Species and Environment Documentation

Continuing to document and take underwater pictures of areas where sea cucumbers are being harvested or were originally harvested is another important step for the DNER to conduct. The documentation of specific species as well as the characteristics of their environment in certain locations will help the DNER create records and archives to have the opportunity to compare pre and post sea cucumber fishing. This is essential in order to observe changes that could have occurred overtime in regards to species diversity, depths found, reproductive cycles, water clarity, detritus buildup, and the invasion of other creatures or predators. This will be helpful in further determining the reason for such an abundance of H. mexicana compared to any other species in the locations we observed. Such documentation can be used to support the

hypothesis that a reason for H. mexicana dominance, especially in fished areas, is due to its low quality and, therefore, market value. In order to determine areas that should be focused on, the DNER should select based on our previous research of fished and unfished sites as well as any new locations where potential sea cucumber harvesting is reported to occur. This will aid them in learning more about the possible effects occurring on the oceanic ecosystem due to sea cucumber declination over a period of time. A possible challenge to this recommendation is having the correct equipment as well as determining areas to focus on for documentation since resources are limited and a thorough accurate observation takes time to complete.

5.4.3 Transects

Another suggestion for the DNER is to consider proposing that sea cucumbers be included in transects of the ocean floors around Puerto Rico. Having sea cucumbers in transects will aid in accurately determining and recording the quantitative amounts and population density of sea cucumbers and aid in keeping count of species populations now and in the future. The majority of DNER employees, local fishermen, and sea cucumber fishermen we interviewed all agreed in the regions they had observed, that the sea cucumbers were less visible than before and their numbers decreasing. From our research specifically in the Lajas/Guanica area, sea cucumber populations have decreased, potentially due to overharvesting, which may have been why sea cucumber harvesting ceased last year. Thus, it is important for sea cucumbers to be included in ocean transects in order to determine whether their number is decreasing and hence effecting the ocean ecosystem. Challenges in proposing transects include not having the resources to perform or request sea cucumbers to be monitored.

5.4.4 Possible Regulations

A final suggestion we propose to the DNER is to consider placing regulations on sea cucumbers. Through our first-hand observations, it is clear that these creatures are effortless to harvest, with the potential of hundreds being easily captured daily until the population dramatically decreases. Not only is this creature easy and cheap to catch but it is just as easy to process, package and ship. Currently, there are no restrictions enforced from catching, selling, or exporting these creatures or even for personal use. An outsider who is knowledgeable in the beche-de-mer market can easily travel and station themself in order to commercially harvest sea cucumbers with no restrictions and regulations. It is unknown how long it will take before local fishermen start taking an interest in harvesting sea cucumbers in Puerto Rico. It is also unknown how many families are harvesting these creatures for their own personal use and consumption. The team recommends Puerto Rico enforce sea cucumber restrictions similar to those of Cuba's regulatory system. In Cuba, there is a separate license required to harvest sea cucumbers that has a tonnes limit, a temporal closure during the months of June-October, and a length requirement for the southeastern region of 24 centimeters. Research would have to be conducted on sea cucumbers in Puerto Rican to tailor a set of regulations that would create a sustainable sea cucumber fishery for Puerto Rico. Unless potential sea cucumber harvesting reports are verified and regulations, restrictions and enforcement are put in place, Puerto Rico is, and has proven to be in the past based on our research and findings, a potential hotspot for worldwide sea cucumber companies. The greatest challenge in enforcing regulation is to monitor sea cucumber fishing and determine whether fishermen are abiding by the law. Another challenge involved with restrictions, size limits in specific, is the inability to determine total size of sea cucumbers due to muscle contractions making the sea cucumber smaller in length.

6.0 Conclusion

The project's main research goals were to, first, evaluate the current status of active and past sea cucumber fishing in Puerto Rico; second, examine the sea cucumber fishery in Puerto Rico; and third, to use data gathered through our research to make accurate and adequate regulatory recommendations to the DNER for future sea cucumber harvesting activities. In order to gather the necessary information to accomplish these goals, the team set three methodology objectives. The first objective was to collect data for previously reported sea cucumber fishing sites. The second objective was to determine locations on current and potential sea cucumber harvesting. The third objective was to gather fishermen responses on sea cucumber fishing in Puerto Rico. The final objective was to document habitat and species of sea cucumber at fished and unfished sites. The information gained from these objectives allows the team to discuss the ecological impacts of overharvested sea cucumbers and if the DNER should implement regulations.

The team primarily focused on the areas of Lajas/Guanica and Culebra Island conducting interviews, administering questionnaires, and performing in-water observations to understand what types of sea cucumber fishing activities were ongoing in these areas. Based on our research, commercial fishing of sea cucumbers was active in the area of Lajas/Guanica, but ended in November 2012, while fishing in Culebra is not commercial. In-water observations of unfished and fished locations suggested that I. badionotus and A. multifidus were the targeted species of fishermen. Based on quantitative data gained from sea cucumber landing reports from Vermesco Corporation stationed in Lajas/Guanica, the team believes it is in the best interest of the DNER to continue our investigation in order to assess whether implementing regulations is a necessary step to protect sea cucumbers and the environment.

The team's interview results indicate that sea cucumber fishing could be occurring in Belvedere and Isabela. The team, due to time constraints, was unable to investigate these locations. An investigation of these possible fishing sites could provide more valuable information to be analyzed alongside the team's information. In addition to these sites, it is possible there are other sea cucumber fishing locations that the team was unable to uncover due to the time constraint.

The continuation of the documented habitats where sea cucumbers are fished, have been fished, or could be fished will provide data for the DNER to analyze possible future sea cucumber fishing. In order to monitor sea cucumber fishing in Puerto Rico the team recommends documentation of habitat characteristics such as species of sea cucumber present, water clarity, current intensity, and depth. These characteristics should be stored in a database for future DNER reference. Clearly defining a preferred habitat for different species of sea cucumbers would allow for more accurate transects to be performed. From transect data, estimates for total stock of different sea cucumber species could be created. Over time fluctuations and dips due to environmental factors or harvesting could be recorded and analyzed to aid the DNER in creating or changing sea cucumber regulations.

Sea cucumber fishing in the Caribbean is not a completely new phenomenon and based on the team's research it has occurred on a commercial scale for at least two years in Puerto Rico. The risk for exploitation is present throughout Puerto Rico, despite the fact that commercial fishing is said not to be currently active. Many nations including Costa Rica, Venezuela, and Cuba have enacted regulations or complete bans due to overharvesting and, considering Puerto Rico has not been harvested on a wide scale, the team recommends enacting regulations to prevent overharvesting. Possible regulations include a minimum length to ensure

enough mature sea cucumbers to allow for successful reproduction or a seasonal ban to allow for the reproductive season (June-October). A possible drawback of a length minimum is that the length of a sea cucumber decreases when out of the water since it contracts, thus it could be difficult for the fisherman to determine its size. Also, due to the fact that the months sea cucumbers reproduce has not been studied specifically in Puerto Rico, it could be challenging for regulators to determine what months to apply a temporal closure. Another regulation that could be enacted is a permit system with a maximum catch limit per time period or per permit. Any of these regulations however require enforcement or else sea cucumbers will still be at risk for overharvesting which could lead to a lower quality environment for all species indigenous to Puerto Rican waters, not only sea cucumbers.

Appendix A: Regulations, limitations, and common species by country.

Location	Regulations	Limitations	Common Species
Galapagos Islands, Ecuador	• Minimum size limit for fresh/processed sea cucumbers • Only small-scale fishers allowed to fish in Galapagos Marine Reserve (GMR) • Moratorium on number of fishers; only sons or daughters of current fishers allowed to become fishers • In process of eliminating non-active fishers from fishery • Maximum Beam length for boats: 18 m • Fishery Management Program (FMP) where info collected from fishing sites, fishing effort, total catches, fishing methods,	Regulation not very effective amongst fishers and processors, juveniles still taken	I. fuscus
Yap, Federal States of Micronesia	• Weight regulations on "premium" or "standard" cucumbers • Standard group have individual species quota • Premium have more comprehensive quality control • Shipments must have only one species group per package		

Location	Regulations	Limitations	Common Species
New Caledonia, France	• Northern Province: minimum legal size limits for fishing sea cucumbers • Min length (cm) for fresh (live or unprocessed) animals and corresponding measure for dried • Northern and Southern Province: scuba prohibited, fishers only collect through free diving/wading • Torches/Night fishing prohibited • Fisheries are registered through a licensing system, required to be renewed each year for a fee • Fishers must apply for special concession in order to harvest sea cucumbers • Have some marine reserves	Difficult to enforce due to cucumber contractions Difficult for nighttime inspections	
Japan	• Semposhi Fishery Cooperative Association set annual quota of 50 tonnes, divided into seasons, 30 tonnes in spring, 20 tonnes in summer, fishing prohibited for rest of open season as soon as annual quota reached by fishers. • Use dragnets to harvest • Fishing allowed during winter, closed season starting in April; spring considered spawning season in most of Japan archipelago • Semposhi Fishery self-regulated season: March 1-April 30th, June 16-July 20.		A. japonicus

Location	Regulations	Limitations	Common Species
British Columbia, Canada	• Fishing permitted along south coast originally, opened to central and north coast • Fishers must return any by-catch not specified by single species quota and license • Restricts permits to single species • Season open 3 weeks in October		P. californicus
Canada	• "Newfoundland sea cucumber drag"		C. frondosa
Costa Rica	• Currently banned		H. inornata
Venezuela	• Banned since 1995		I. badionotus
Pacific, Melanesia	• Access to shoreline, lagoon reefs controlled by individual communities		
Australia	• Total global TAC for harvesting in GBR; may regulate TAC for certain species • 2004; total TAC was 380 tonnes • species specific limit reference points		H. fuscogilva H. scabra (ban) A. mauritiana (ban) H. whitmaei (ban)
Fiji	• Various market chains • Fishers or community collect sea cucumbers and use middleman for export		
Sagay, The Philippines	• 32,000 hectare MPA • Fishery regulation specific to P. proteus		
Indian Ocean	• Bans on collection, processing, and trade of commercial species e.g. India, Egypt.		

Location	Regulations	Limitations	Common Species
Western Indian Ocean	• Scuba prohibited in Kenya, 2003 (poor compliance) • Seychelles: fishers require scuba training before use • Madagascar: scuba legally prohibited • Seychelles requires fishers submit logbooks monthly • Madagascar considered open access regime without controls • Seychelles have limit of 25 fishing licenses to citizens • Seychelles: fishing season from Oct. 1 -June 30 • Seychelles; Maximum 4 divers w/ life insurance allowed authorized to fish under a sea cucumber fishing license • Seychelles: Real time monitoring at designated landing sites, constant monitoring at processors to ensure illegally caught cucumbers are not traded • Seychelles incurs small fee per kg sea cucumber for better management		I. fuscus H. mexicana
Malaysia	• Many marine reserves, as well as three Fisheries Prohibited Areas. Little poaching occurs, enforcement officers stepped up to prevent poaching.		

Location	Regulations	Limitations	Common Species
Cuba	• Temporal Closure from June-October for reproductive season • Length Restriction; Southeast Region must be 24cm, Southwest region must be 22 cm • Monitors of land, follow-ups, comparisons between what is actually caught and what is exported • All paperwork must match precisely to export in order to leave country • Sanitary registration must be issued to export product, checked by customs		I. badionotus
Solomon Islands	• Ban since 2005 on export of beche-de-mer in response to declines in fisheries		
Great Barrier Reef, Australia	• Sea cucumber fishery broken up into 154 fishing sectors • Sectors divided into three fishing years on a three year cycle • No more than 4 divers allowed in the water at any time from a fishing vessel • During permitted year of fishing, fishing only allowed for 15 days of the year in each sector		

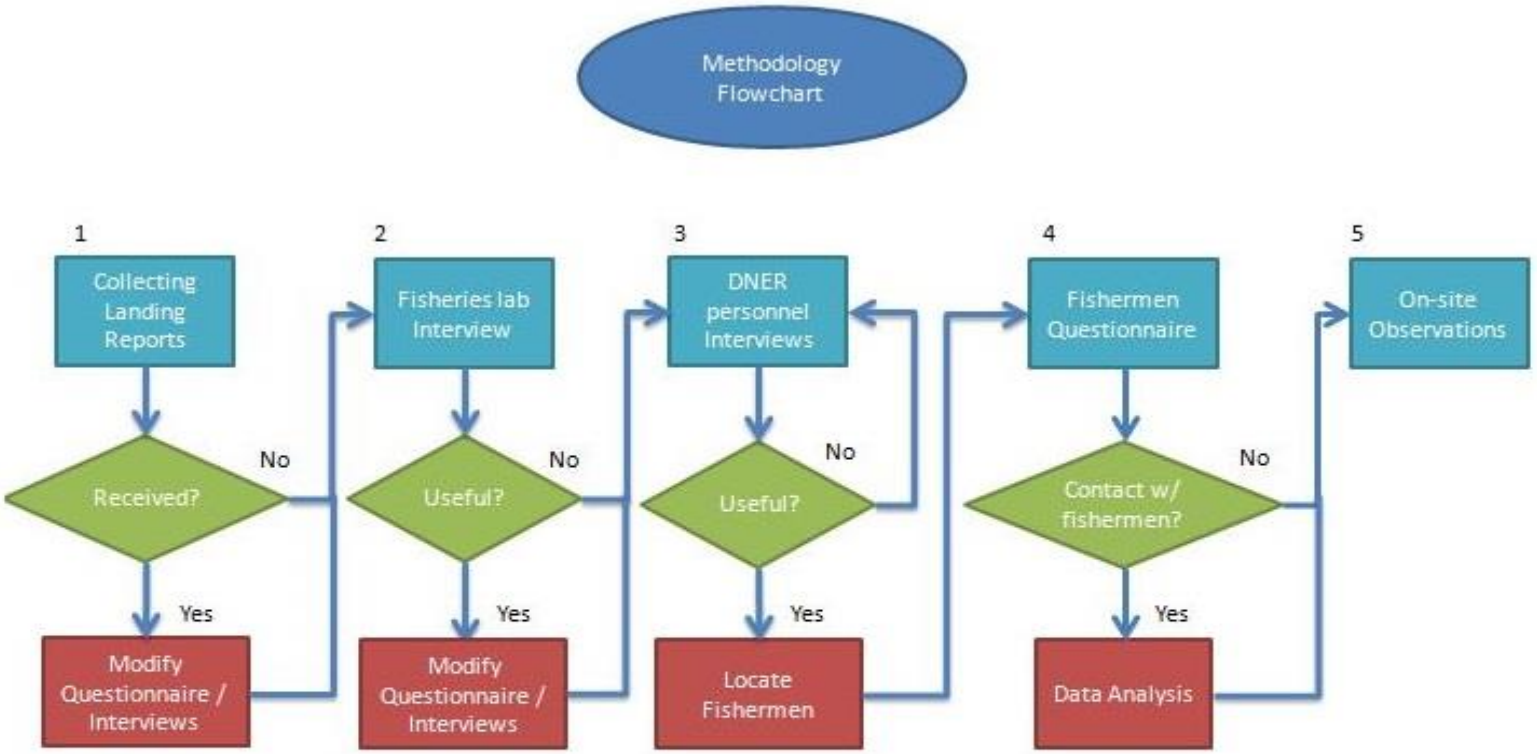
Location	Regulations	Limitations	Common Species
Alaska, USA	• Use rotational harvesting strategies • Each fishing area operates on a three year rotation and harvested at rate of 6% a year • Underwater surveys conducted by Department divers prior to fishing openings. • Restricted to hand picking only		P. californicus
United States	• Dragnet modified for collecting sea cucumber after trawling raised environmental concerns		C. frondosa
Papua New Guinea	• Prohibition of torches and surface lights	Few law enforcers, few inspections, gear still used commonly	

(Purcell et al., 2010)

Appendix B: General Project Timeline

Week 1	Arrive at DNER, Meet Sponsor Craig Lilyestrom, Travel to Joyuda, Interview with Caraballo, Begin recording info/writing, Work on paper at DNER
Week 2	Travel to Salinas, Interview non-specific fishermen, Interview with Dieppe, Interview with Gonzalez , Work on paper at DNER
Week 3	Travel to Fajardo, Interview with Fernandez, Interview non-specific fishermen, Easter weekend – Work on paper from home
Week 4	Travel to Lajas/Guanica for data collection, Interview Ranger Banch, Administer questionnaire to sea cucumber fishermen, Conduct in-water observations, Work on paper during weekend
Week 5	Travel to Culebra, Interview Ranger Feliciano, Interview with Roman , Interview and Administer Questionnaire to sea cucumber fishermen, conduct in-water observations, work on paper
Week 6	Work at DNER, Work from home
Week 7	Finish writing report, Presentations to DNER

Appendix C: Methodology Flowchart



Methodology Objectives:

1.) Collect any past data on sea cucumber fishing in Puerto Rico

2.) Determine locations of current and potential sea cucumber harvesting

3.) Gather fishermen responses on sea cucumber fishing in Puerto Rico

4.) Document habitat and species of sea cucumber at fished and unfished sites

Appendix D: Fishermen Questionnaire

Instructions

This survey is completely anonymous. Data collected through this survey will be used for the sole purpose of research by the Department of Natural and Environmental Resources and Worcester Polytechnic Institute. Participation is voluntary, all questions are optional.

Please check all that apply.

Part I: General

1) What do you generally fish?

- ☐ Sea Cucumbers
- ☐ Sea Urchins
- ☐ Queen Conch
- ☐ Other: _____

2) When do you fish?

- ☐ March – May
- ☐ June – August
- ☐ September – November
- ☐ December – February

3) Do you fish during the day or the night?

- ☐ Day
- ☐ Night

4) Do you fish alone or with other fishermen? If with others, how many?

- ☐ Alone
- ☐ With Others (Specify Amount):

_____

Part II: Fishing Products

5) How many sea cucumbers on average, quantity wise, do you catch after a single fishing trip in one day? In one month?

Day: _____

Month: _____

6) What methods do you typically employ when fishing?

- ☐ Skin Diving
- ☐ Other: _____

7) What gear do you use?

- ☐ SCUBA
- ☐ Nets
- ☐ Hookah Hose
- ☐ Snorkel
- ☐ Other: _____

8) Has fishing moved into deeper waters?

- ☐ Yes
- ☐ No

Part III: Sea Cucumber Specifics

9) What do you generally do with your catch?

- ☐ Personal Use
- ☐ Local Restaurant
- ☐ Local Vendor/Company
- ☐ Foreign Vendor/Company
- ☐ Other: _____

10) How do you process them?

- ☐ I do not
- ☐ I do process them
  - ☐ Dry
  - ☐ Gut
  - ☐ Clean
  - ☐ Package
  - ☐ Other: _____

11) What species of sea cucumber do you typically catch and what is the price per dry pound or per catch? (Please circle the unit)

☐ I. badionotus

Price: _____ (lb / catch)

☐ A. agassizii

Price: _____ (lb / catch)

☐ A. multifidus

Price: _____ (lb / catch)

☐ H. mexicana

Price: _____ (lb / catch)

☐ H. floridana

Price: _____ (lb / catch)

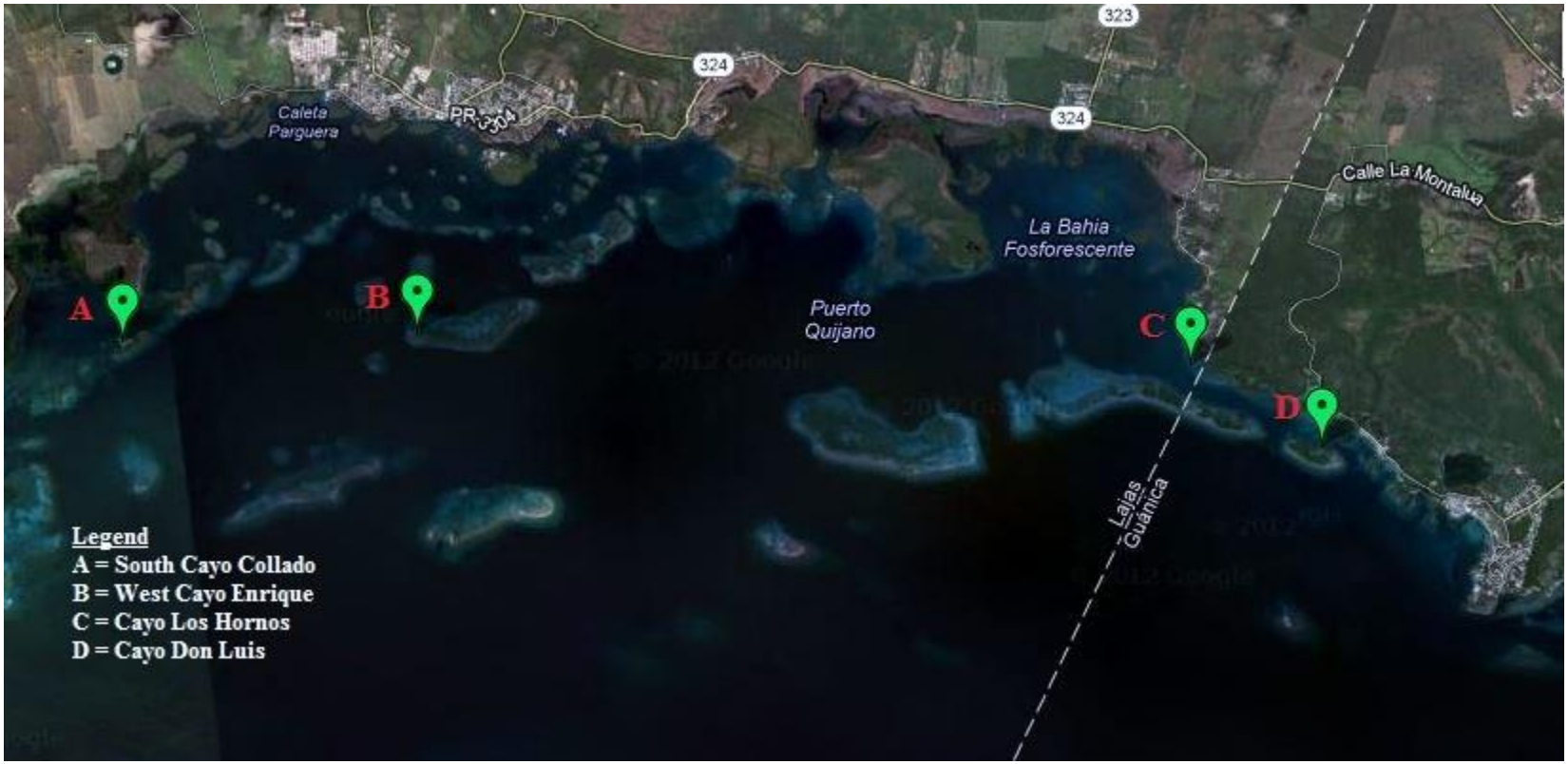
☐ Other: _____

Price: _____

12) Using the maps below for guidance, where do you typically fish? Indicate below with an "X" near the region.

13) Do you know of any popular fishing areas? Indicate below with an "O" near the region.

Appendix E: GPS pinpoint locations of Lajas/Guanica



Appendix F: GPS pinpoint locations of Culebra Island

Appendix G: Questionnaire Responses with General Comments

#	Question	Fisherman I	Fisherman II	Fisherman III
1	**What do you harvest?**	Sea cucumbers, queen conch	Sea cucumbers, queen conch, lobsters	Sea cucumbers
2	**When?**	June - August	March - November	Once in awhile
3	**During day or night? Both?**	Day	Day	
4	**Alone or with others?**	With others	Alone	
5	**How many sea cucumbers?**	175 - 235 per day	200-300 per day	
6	**What methods?**	By hand	By hand	By hand
7	**Gear i.e. SCUBA/Hookah**	SCUBA	SCUBA	
8	**Deeper waters?**	No	No	
9	**What is done with sea cucumbers?**	Foreign Vendor/Company	Foreign Vendor/Company	
10	**Process yourselves?**	Do not process	Do not process	
11	**Species collected?**	A. multifidus, I. badionotus	A. multifidus, I. badionotus, H. mexicana, H. floridana, Pinto, Green	A. multifidus, H. mexicana
11A	**How much compensation?**	0.30 USD	0.30 USD	
	Comments	•Noticed dark and yellow spots in water	• Sea cucumber hide when its colder • Put sea cucumbers in a sack when harvesting, • Manager had 5-6 people for processing • Manager stopped fishing in November. • Manager previously harvested DR, 2500-3000 sea cucumbers per day • Manager mentioned moving fishing to Mexico	• Sea cucumbers are of less quality than accustomed to • New York and Hong Kong have aquaculture

Appendix H: In-Water Observations

Lajas/Guanica

In Lajas/Guanica, the team snorkeled a total of four locations with two unfished sites and two fished sites to gather first-hand in-water results in accordance with the methodology.

Unfished Sites

The location at the west side of Cayo Enrique at the Global Positioning System coordinates N17 57.307', W067 3.139', was a DNER ranger confirmed non-fishing location. Figure 13 presents two of the three species of seagrass that sea cucumbers are often documented in. The species pictured has turtle grass and manatee grass present.

Figure 13: H. mexicana sea cucumber in habitat

Due to some suspended algae and sediment Cayo Enrique received a medium clarity. Water clarity for visited sites can be seen in Table 5. The waters at Cayo Enrique were moderately calm due to the protection the cay provided with a low rating.

Location	Water Clarity	Location	Water Clarity
Cayo Enrique	Medium	Daquiti	High
Cayo Collado	Low-Medium	Pelaita	Medium
Cayo Los Hornos	Low	Punta Cabra	Low
Cayo Don Luis	High	Cayo Carmelo	Medium-High
Tamarindo Beach	High		

Table 5:Water Clarity by Location

Sea cucumbers were found at a depth ranging from three to six feet. The H. mexicana, or "Donkey Dung" sea cucumber, image below was taken after sediment and seagrass had been removed from the outer wall. Figure 14 clearly shows the distinguishing ridges along the body of the species H. mexicana. H. mexicana was the dominant species at this unfished location.

Figure 14: Two H. mexicana sea cucumbers

The location called Cayo Don Luis had the GPS coordinates N17° 56.713, W66° 58.239' and had no reports of fishing according to the DNER Rangers. The water clarity at this location was significantly lower than any of the previous sites due to stagnant sediment-filled water. The sediment at the bottom tended to be finer and easily suspended by any movement of water. The location received a low score on current intensity due to the fact it was completely protected on

one side due to the crescent shape of the cay. The vast majority of sea cucumbers were found in higher density turtle grass in shallow water ranging from two to four feet. H. Mexicana and I. badionotus were both found at this site with an approximate ratio of two to one in favor of H. Mexicana. This site contained multiple intra-species coloration diversity as can be seen in Figure 15. The second sea cucumber from the left, H. Mexicana, is brown while the others are shades of black. The fifth sea cucumber from the left is a color variation of I. badionotus.

Figure 15: Different Variations of H. mexicana and I. badionotus

Fished Sites

The location in Lajas/Guanica at the south side of Cayo Collado was at the GPS coordinates of N17° 57.260', W67° 4.738'. Cayo Collado was confirmed by the DNER to be a sea cucumber fishing site. The water clarity at this location was estimated to be medium-high clarity. Both turtle and manatee grass were present in thin to dense patches. This site had a medium level of current due to a significant amount of open water. Most sea cucumbers were found at a depth ranging from 3-6 feet. At this site the team located I. badionotus and H. mexicana. However, H. mexicana was the dominant species with a ratio of six to one with only a handful of I. badionotus sea cucumbers found. Figure 16 presents the "chocolate chip" variety of

I. badionotus while Figure 17 shows another variation. Figure 17 also shows the three rows of podia that are common to all I. badionotus despite color variation.

Figure 16: I. badionotus in turtle grass

Figure 17: Three Rowed Color Variation (Top & Bottom)

The location at Cayo Los Hornos had the GPS coordinates N17° 57.140', W66° 68.951'. The DNER Rangers reported that sea cucumber fishing had occurred at this location. This location was protected on all sides of the cay allowing mainly turtle sea grass to be found in medium densities around the cay. The complete protection warrants a low current intensity rating. The clarity was affected by high amounts of suspended algae and detritus receiving a low-

medium rating. The depth at this location ranged from two to seven feet with most of the sea cucumbers being found in the four to five foot range. The sea cucumbers at this site had more color variation on the I. badionotus sea cucumber seen in Figures 18 and 19. This site had more color variation on the I. badionotus sea cucumber seen below in Figures 18 and 19. At this site H. mexicana still had a ratio of two to one against all other species.

Figure 18: Two Variations of I. badionotus

Figure 19: Variation of I. badionotus

Culebra Island

Unfished Sites

The location named Tamarind beach was at the GPS coordinates of N18° 19’ 4.0116”, W65° 19’ 8.3964” with no reports of sea cucumber fishing. The habitat of the area included intermittent dense patches of manatee and turtle sea grass in between coral structures. The water clarity was far greater than any site in the Lajas/Guanica area due to a reduced amount of suspended detritus receiving a high rating. At this site the sea cucumbers were not found in heavy sea grass, but in rocky coral locations. There was little protection beyond a point on the left side of the beach and therefore the location received a medium current intensity rating. The team only documented two sea cucumbers, but the specimens were approximately three times larger in length compared to the eight inch average at all other sites. The sea cucumbers were found at much greater depths between eight and fourteen feet while sea cucumbers at all other

locations had been found at depths no greater than six feet. Unlike the other visited sites the team found no H. mexicana. The sea cucumber, A. multifidus, in Figure 20 was documented one time by the team. I. badionotus, of the chocolate chip variety, was documented once. Figure 20 below provides a clear visual of the yellow podia of the A. multifidus.

Figure 20: A. multifidus

The GPS coordinates of the site named Daquiti were N18°17’ 09.4”, W65° 16’ 52.6”. The location had no reports of sea cucumber fishing. The water clarity was higher than other locations because of the increased depth and current which allowed for less algae and sediment to maintain suspension giving Daquiti a high level of clarity. The site was populated with dense patches of manatee and turtle grass. Overall this site was not as protected as others due to a significant current and surge, receiving a high current rating. The depth at which sea cucumbers were found at this site ranged from four to ten feet. Both H. mexicana and I. badionotus could be

found in pure sand or grass at this site. H. mexicana outnumbered I. badionotus by a ratio of approximately three to one.

The GPS coordinates of the second unfished site, Pelaita, were N18° 17’ 55.9”, W65° 15’ 10.6”. This location contained dense patches of turtle and manatee grasses with the highest densities occurring in the shallows. As depth increased the density of both species of grasses was reduced. The water clarity at this site received a medium rating with low levels of detritus in the water compared to other locations. Although there was not major protection nearby, outer cays protected the site receiving a low current rating. H. mexicana dominated the area’s sea cucumber population in depths between three to five feet in dense turtle grass. In the shallower depths, H. Mexicana outnumbered I. badionotus by a ratio approximately three to one. Other species were generally found at depths of six to nine feet in less dense vegetation with a ratio two to one. The team documented its second A. multifidus or “Furry Sea Cucumber” as seen in Figure 21.

Figure 21: Astichopus multifidus

The third site, Punta Cabra or William Bay, had the GPS coordinates of N18°18’ 09.1”, W65° 16’ 48.5”. This site was not fished according to DNER Rangers. The water clarity at this

location was low with large quantities of suspended algae and sediment. Sea cucumbers could be found well protected in the mangroves as well as in dense turtle seagrass. The entire site was well protected by mangroves and had little wind or surge, warranting a low current rating. The sea cucumbers generally ranged in depth from two to seven feet. Although the majority of sea cucumbers were found in two to four feet of water, there were a variety of species and sizes at this site The H. mexicana to I. badionotus ratio was estimated to be one to one. Figure 22 shows two I. badionotus underneath the mangroves at a depth of three feet. Figure 23 shows H. atra that had not been present at any other fished or unfished site.

Figure 22: I. badionotus in Mangroves

Figure 23: H. atra

Fished

The location named Punta Carmelo had the GPS coordinates of N16° 17’ 43.3”, W65° 16’ 34.1’. According to the DNER Rangers this was the location where the family fished for sea cucumbers. The water at this location had medium-high amounts of sediment and algae in the water. This location has a high current rating due to limited protection from a seagrass covered sediment outer rim about one foot below water level H. mexicana was the dominant species with only one documented I. badionotus. The depths of sea cucumbers ranged from three to seven feet. However, the sea cucumbers were mostly present in the heavy, shallow turtle seagrass

dense locations. Compared to other sites, there were a variety of sizes within the H. mexicana species ranging from juveniles to large adult sea cucumbers.

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