Smooth Hammerhead Target Fishing and By-catch in Puerto López, Ecuador: Trends in Catch and Recommendations for Mitigation

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Smooth Hammerhead Target Fishing and By-catch in Puerto López, Ecuador: Trends in Catch and Recommendations for Mitigation

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Abstract

Sharks have not historically been considered a valuable resource but, with the increase in demand for their fins, shark catch numbers have risen dramatically and many shark populations are suffering. It is difficult to know the extent of the problem because there is a lack of information about sharks and shark catch is vastly under-reported. The smooth hammerhead shark (*Sphyra zygaena*) is valuable in the shark fin market for its eight, large fins and is frequently landed at the Puerto López fish market in Ecuador. EquilibrioAzul is a marine conservation organization that has been keeping track of shark catch in the Puerto López market for the last seven years. Analyses of these data show that juvenile and male smooth hammerheads are being overfished and that total catch and average total length have remained relatively static since 2007. It is important to use this data to drive future regulation and fishing methods in the area in order to protect the local populations of sharks. Based on this data I recommend that conservation efforts focus on changing fishing locations to prevent landing juvenile sharks, improving data collection, community education on the importance of shark conservation, and continuing research on smooth hammerhead behavior and ecology worldwide.
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Preface

In the spring of 2013 I was fortunate enough to have the opportunity to spend my semester exploring Ecuador with the study abroad organization SIT (School for International Training). SIT provides a unique study abroad experience because not only do you get to spend a third of the semester traveling around the country for classes, you also have the opportunity to spend your last month in a location of your choice doing an independent research project. This is how I became connected with Puerto López and EquilibrioAzul. I arrived in Puerto López with no idea of what my project would be, just that I would be working on marine conservation and community education projects. I was thrilled when I learned that they wanted me to assist on their shark project by updating their shark catch database.

I spent every morning of my month in Puerto López walking through pools of blood as the fishermen cleaned their daily catch, looking for sharks and the afternoons entering years worth of data into the computer. It was definitely not the most glamorous job but I was instantly hooked on the topic. Learning about the various political, social, economic, and environmental aspects of shark catch for my final project fascinated me, which is why I am so pleased I was able to continue my work on the subject through this thesis.

Many people contributed to the success of this project. Without them I would not have been able to finish it. I would first like to thank everyone at EquilibrioAzul for providing me with their database; Cristina Miranda for answering my many emails and connecting me with the database, Andrés Baquero and Peter Rodríguez for their assistance in understanding the database and editing my paper, and Carolina LeMarie for introducing me to the subject. A huge thank you goes to both Dale Miller and Alexander Cruz for their hard
work and patience in guiding me through this process. Thank you Heidi Souder for stepping up as an adviser at the last minute; you are a lifesaver! Finally, a special thank you to Sierra Love-Stowell who assisted in working out my issues with manipulating and analyzing the data.

I hope that my work on these data will add to the conversation about shark conservation and encourage governments and/or marine conservation organizations to begin to take similar data and for scientists to continue to research shark behavior and ecology. It is so important to learn as much as we can about sharks and shark catch before the global community can make educated decisions about conservation and mitigation.
**Introduction**

Sharks, as top-level predators, play a key role in maintaining the health of marine ecosystems; but since the mid 1990s shark fisheries have seen large declines in populations as the pressure from target fishing and by-catch has increased (Worm et al., 2013). Shark species are especially vulnerable to overfishing because they generally have slow growth, late attainment of maturity, and low fecundity (Stevens et al., 2000). Sharks are not historically a popular item to catch due to the low value of their meat; but recently the demand for their fins has dramatically increased. In small fishing markets, such as the one in Puerto López, Ecuador, the fin industry has become a lucrative business for local fishermen (Jacquet et al., 2008).

The smooth hammerhead shark (*Sphyrna zygaena*) is a species commonly found on the coast of Ecuador and is highly sought after in the fin industry for its eight large fins (Clarke et al., 2006; Bester, Florida Museum of Natural History). According to the IUCN Red List the Sphyridae family is listed as vulnerable and has seen global decreases in abundance by 89% since 1986 (Casper et al., 2005). The accuracy of this number, however, is largely unknown due to a lack of catch and disposal records. This is a common occurrence worldwide; only 15% of catches reported list species (Dulvy et al., 2008). Clarke et al. (2006) estimated that FAO reports are three to four times lower than actual catch numbers. Without reliable reports it is extremely difficult to understand the scope of the fishing, the possible implications, and to decide on proper mitigation and management techniques. There are; however, organizations around the world that have been collecting useful data, like EquilibrioAzul in Puerto López, Ecuador.
EquilibrioAzul is a marine conservation organization in Puerto López that has been collecting data on shark catches at the local fish market since 2007 including information on species caught, size, and sex. Based on this information and the available literature on shark catch, this thesis will address the following questions: What are the trends of the landings in Puerto López and how can these guide efficient and effective conservation methods?

Although multiple species are recorded, *S. zygaena* landings hold an overwhelming majority, which is why I only analyzed data on this species. Due to the intensity of fish fishing that has occurred in this area I hypothesized a net decline in catch numbers and individual size.

In my analysis I looked for trends in catch size, individual size, and sex. Analyzing these data will help to provide information about the local population as well as the impacts that catching smooth hammerheads in the Puerto López area may be having on them. Using this information, along with available literature on shark fisheries and management techniques I developed a list of recommendations to encourage sustainable fishing in the area. It is my hope that these data will provide insight into other shark fisheries around the world and emphasizes the need for more species specific data like EquilibrioAzul’s in order for policy makers and conservationists to make informed and useful decisions.

**Background and Literature Review**

**About *Sphyrna zygaena***

The smooth hammerhead, *Sphyrna zygaena* is not a very commonly studied species and there is only very basic information available on their biology and ecology (Diemer et al., 2011). It is the second largest of the hammerhead family next to the great hammerhead, believed to reach an average total length of three meters (Compagno, 2001). This species is

dispersed around the world in temperate water; sticking to shallow areas of about 20 meters deep along coastlines (Bester, Florida Museum of Natural History).

Their hammer-shaped heads, called a cephalofoil, and well-developed brains make these sharks fierce predators (Compango, 2001). The eyes on either end give them a wide field of vision. The wide snout has enlarged nasal capsules and a greater area, called the Ampullae of Lorenzini, containing electroreceptor organs give them high efficiency in sensing and hunting prey. The shape of the cephalofoil also provides hammerheads with better lift in the water and increased maneuverability (Lim et al., 2010). The smooth hammerheads’ diet composition mainly depends on their location and the availability of food but they are know to prey on wide variety on bony fishes, smaller sharks (at times in their own species), rays, cephalopods, and occasionally crustaceans (Compagno, 2001).

There is little information available about the behavior of smooth hammerheads other than the following. They have been observed traveling as individuals and in groups. This could be seasonal or depend on the location of the sharks. Young have been observed forming schools of over 100 individuals. Little is known about this phenomenon but theories suggest that is occurs as a part of migration, protection against predators (for immature sharks), or for reproductive activities (Bester, Florida Museum of Natural History). They are also known to be a highly migratory species, however; studies are inconclusive on the details and patterns of their migration routes (Diemer et al., 2011).

*S. zygaena* and the other species in the *Sphyrnidae* family have a K-selected life history, which is categorized by slow growth, late attainment of maturity, and small litter sizes (Dulvy et al., 2008). They take between one and two years to mature and can live to be more than 20 years old (Casper et al., 2005). Females reach maturity when they are about
2.65 meters in length and males when they are 2.5 to 2.6 meters (Compagno, 2001). Hammerheads are viviparous species meaning that embryos develop in eggs during the ten to eleven month gestation period and are nourished by the yolk sac placenta. They are then are then hatched inside of the mother and live birthed (Bester, Florida Museum of Natural History; Stevens, 2000). Hammerheads have been found to give birth to a relatively large number of pups (average of 32-33.5) when compared to many other shark families who only give birth to one or two pups at a time (Castro & Mejuto, 1995). Pups are about 50 cm at birth and litters have a sex ratio of 1:1. Nursery areas can be found in areas with smooth, sandy substrate in shallow waters up to ten meters deep (Heithaus, 2007).

**Role of Sharks in Marine Ecosystems and Impacts of Reducing Shark Populations**

Marine ecosystems play a large role in maintaining natural global functions that all species rely on for survival. Almost half of the planets primary production and three-quarters of global fishery yields are provided by ecological communities in the ocean (Myers & Worm, 2003). Sharks are top-level predators in marine ecosystems and therefore assist in maintaining trophic balance. When shark populations are over-fISHED there are both direct and indirect impacts to shark species themselves and the ecosystems with which they interact. In their article “The effects of fishing on sharks, rays, and chimaeras (chondrichthyans), and the implications for marine ecosystems,” J. D. Stevens et al. (2000) describe these impacts in detail. The main direct impacts are: changes in abundance, size structure, growth and development cycles, and potential extinction. Changes in size structure occur due to the type of fishing gear used while harvesting. Gear that allows for smaller individuals to easily escape has become popular as a conservation method. This is a strategy
that allows for individuals to reach maturity and reproduce before they face the risk of being caught. These nets can eventually change the size of the entire population by allowing only small individuals to reproduce. Smaller mature individuals generally produce smaller clutch sizes and smaller offspring than larger individuals. Overfishing can also impact the growth and development cycle of the species by lowering the age at which individuals become mature. This type of response would take many generations to have a noticeable effect. Earlier attainment of maturity could protect a species but also has many potential and unknown biological and ecological implications (Stevens et al., 2000).

Since sharks are a high level predator they are often considered a keystone species their removal has many indirect ecological impacts. The main impact that the reduction of a top predator is trophic cascade (Jacquet et al., 2008). Trophic cascade is a term to describe the impact of the removal or addition of a top-level predator. The addition or removal of an apex predator has an effect that “cascades” down the food chain or food web and impacts the biomass of organisms at least two levels below the predator (Meyer, 2011). This process can often lead to the destruction of primary producers because there are not enough herbivores to maintain healthy populations (Brierley, 2007). When shark populations are significantly reduced, competitor and prey population thrive until their numbers become unsustainable and crash. A study by Myers et al. (2007) showed that the reduction of shark populations in coastal northwest Atlantic ecosystem caused an increase of the cownose ray populations which caused a crash in the population of its prey, the bay scallop. This example could be a predictor of the consequences of the removal of sharks in marine ecosystems worldwide but ecosystem functions are still extremely difficult to predict.
These are all speculations on what could happen if shark populations are reduced. It is extremely difficult to predict exactly which species would thrive and which would suffer due to the complexity of ecosystems and ecosystem functions. There is no model that can account for every variable in an ecosystem (Stevens et al. 2000). The loss of sharks could trigger the extinction of other species that we rely on for food and to support the economy (Meyer, 2011). Bornatowski et al. (2014) determined that \textit{S. zygaena} has one of the largest values as a keystone predator. This means that the loss of this species would have consequences that impact many marine ecosystems on a global scale.

\textbf{Current Status of Shark Fisheries}

The IUCN Red List labels \textit{S. zygaena} as a vulnerable species. The main reason for this listing is overfishing via by-catch and target fishing (Casper et al., 2005). A catch is categorized as target fishing when fishermen intentionally seek out and capture sharks. A shark is considered by-catch when it is caught in a net intended for another species. Sharks are caught intentionally and unintentionally in pelagic long lines, hand line, gillnets, purse-seines, and pelagic and bottom trawls in both artisanal and industrial fisheries world-wide (Bonfil, 1994).

Another reason for the reduction of shark populations globally is a process called finning. Finning is the process of capturing live sharks, removing their fins, and then throwing the body back to the ocean. The still living shark is then left to suffocate because it cannot move water over its gills or to be preyed upon by other sharks (Worm, 2013). The act of finning occurs in cases of by-catch and target fishing and has received much negative attention due its cruel nature. Finning is the most efficient method of harvesting shark fins
because dropping the body allows for more space on boats and fins bring significantly more profit than any other part of the shark.

There are very few data on shark fisheries around the world for several factors. One reason is that sharks are often a low priority or completely ignored in most fisheries because they have historically had a low economic value. Next, much fining activity is illegal and/or unregulated so many sharks are killed and it is never reported. Catch reports have only been filed on S. zygaena since 1991 (Maguire et al., 2006). In cases where numbers are reported, different species and even different families are lumped together into one, total count (Abercrombie et al., 2005). The shape of the cephalofoil is necessary to identify the various species of the Sphyrna genus. The smooth hammerhead has a slight dent in the center of its snout and two larger ones right before the eyes, but even to the trained eye can be difficult to distinguish between individuals in the Sphyrnidae family (see Figure 1) (Clarke et al., 2006a). In cases where reports include species the identifications are not always accurate because of the similarities between species and the cephalopfoil is often missing. In most cases, reported harvest numbers are much lower than actual numbers. Multiple studies have found that harvest numbers reported by the Food and

![Figure 1: Four cephalofoils in the family Sphyrnidae showing how difficult identification of individual species within the family can be. (A) S. zygaena (B) S. lewini (C) S. mokarran (D) S. tiburo](From: www.flmnh.ufl.edu/ichthyology)
Agriculture Organization of the United Nations (FAO) are three to four times lower than 
actual harvest numbers (Clarke et al., 2006b; Jacquet et al., 2008). Underreporting and lack 
of information make it extremely difficult, if not impossible, to understand the impact fishing 
is having on shark populations or to implement effective conservation measures.

Due to the factors discussed above, only rough estimates are available on the number 
of sharks that are killed each year (by-catch, target, and finning). One estimate says that 26-
76 million sharks are killed each year for their fins (Clark et al., 2006b). Of this total, 1.3-2.7 
million are *S. zygaena* and *S. lewini* (Clarke et al., 2006a). According to the IUCN Red List, 
the Sphyrnidae family has declined in worldwide abundance by 89% since 1986 and by more 
the 99% in the Mediterranean due mainly to by-catch and target fishing. In Ecuador it is 
estimated that *S. zygaena* comprises 11% of total chondrichthyan catch (Casper et al., 2005).
In some areas sharks have already been completely eradicated. For example, in 1995 and 
1996 there were a total of 2,004 individuals caught in the Tres Marias Island and Central 
California Gulf and there have been no sharks caught in that area since (Perez-Jiménez et al., 
2005). 35% of these individuals were recognized as *S. zygaena* and it is speculated that the 
population was completely eradicated in the area.

**Reasons for shark catch**

Sharks have always been caught in both artisanal and industrial fishing operations 
worldwide. They have many traditional uses but were not a popular or valuable item to catch 
until the growth in demand for shark fins. Currently, most common and economically 
beneficial use of a shark is their fins (Jacquet et al., 2008). Shark fin soup is an extremely 
popular delicacy in China. The shark fin market is extremely lucrative; one kilogram of fin 
can sell for over $700 USD in Hong Kong’s largest market (Abercrombie et al., 2005). The
profit from selling shark fins is equivalent to or more than some types of drug trafficking but come at a fraction of the legal risk (Jacquet et al., 2008). The dorsal, pectoral, anal, ventral fins, and lower section of tail are used to make shark fin soup in many Asian cultures. *S. zygaena* has some of the most desirable and valuable fins because of the size and number (they have a second dorsal fin, not seen in all shark species) (Casper et al., 2005). It is because of this that *S. zygaena* and *S. lewini* (a closely related species) provide 45% of fins sold worldwide (Clarke et al., 2006).

Shark fin soup was created during the Ming Dynasty (1368-1644) as a food that was exotic and health promoting. The shark fin provides no flavor to the soup, only a chewy, crunchy texture. Because the main ingredient was difficult to find and was only available in small amounts this was a food reserved for emperors and the extremely wealthy (Vannuccini, 1991). As time passed, it remained a food for the wealthy, eaten for celebrations such as weddings and important meetings. As the middle and upper classes grew in Asia, so did the demand for shark fin soup. Today one bowl is worth around 100 USD and is not just found in China. According to the Animal Welfare Institute there are more than 55 restaurants in the US that sell the delicacy. It is revered for not just its exclusivity but also its believed health benefits. In Chinese medicine it is believed that consuming shark fin provides one with rejuvenation, appetite enhancement, blood nourishment, energy, and benefits to many parts of the body including kidneys, lungs, and bones (Vannuccini, 1991). Many argue; however, that shark fin soup has very few actual health benefits and may in fact be harmful. Shark fins have been shown to have high levels of mercury and other toxins. The levels of these dangerous materials in fins have be studied and contain levels that fall within food safety
limits according to the FDA; but due to bioaccumulation concentration levels are rapidly increasing (Escobar-Sánchez et al., 2010).

Besides shark fin soup, sharks can be used in many other ways. Their liver oil is used in the production of textiles, tanning, production of cosmetics and pharmaceuticals, and creation of lubricants. It used to be popular to use for its high levels of vitamin A but now a synthetic version is more common. Their skins can be used to make leather and abrasives and the carcass is often used for fishmeal (Vannuccini, 1999 & Bester, Florida Museum of Natural History). Shark meat is, at times, sold in markets but is not a desirable choice for consumers in most areas of the world. Many times the meat is miss-labeled in markets as marlin fillets, sea bass, or flounder which can be dangerous to human health via unknown levels of mercury and other toxins (Jacquet et al., 2008).

**Shark Catch Regulation and Methods of Mitigation**

**Current methods of mitigation**

There are many methods and levels at which shark catch regulation currently occurs. Legal regulation, recommendations, and resolutions exist at the domestic level, in regional fisheries, and in protected marine areas (Humane Society International, 2005). These legal regulations focus on controlling the following aspects:

- If sharks can be landed without question, as by-catch, or not at all
- The ratio of the number of bodies to the number of fins that are required on-board
- The ratio of the number of bodies to the number of fins that can be sold
- If fins are required to be attached to any landed sharks
- If shark fins and other products can be sold
• If fins can be sold as a separate entity than the body

These regulations can help fishermen to know how they are required to handle sharks by law but the ocean is a difficult place to regulate behavior and the black market for shark fins is extremely lucrative (Jacquet et al., 2008). One of the most difficult regulations to monitor is when fishermen are able to bring in sharks that are by-catch. There are currently very few ways of knowing whether they are actually bringing in by-catch or if the sharks were their targeted catch (Jacquet et al., 2008)

Another important aspect of mitigating shark catch and protecting populations is research. Creating a better understanding of the shark trade, its drivers, and its impacts on marine ecosystems are imperative in creating effective protection plans. Studies have been done to identify the number of sharks, the species, and the measurements of the individuals being caught. Other areas of interest include where shark products are ending up: what markets are the bodies delivered to, for what purpose and where are the fins going? There are also efforts to further understand sharks, their populations, and their interactions within their species and with the ecosystems they live in. These studies are tremendously important to maximize the effectiveness of the regulations discussed above.

Global Regulation

Regulation on shark catch is a relatively new thing with the first ban on any shark fishing happening in 1980 in Israel (Humane Society International, 2014). The majority of regulations focus on reducing or eliminating the practice of finning. Since 1980, 34 countries have established some sort of regulation program. Eleven of these have a complete ban on all shark fishing, eight have a ban on possession, sale, and trade of fins and other products
twenty-one countries plus the European Union have other various catch regulations such as the ones discussed in the previous section (Humane Society International, 2014). There are also regional fisheries finning regulations. Most of these follow International Commission for the Conservation of Atlantic Tunas proposal, which was established in 2005, and requires that the full body of any shark landed must be utilized. The fisheries that follow the ICCAT model are (abbreviation and year adopted in parentheses):

- General Fisheries Commission for the Mediterranean (GFCM) (2005)
- Inter-American-Tropical-Tuna-Commission (IATTC) (2005)
- Indian Ocean Tuna Commissions (IOTC) (2005)
- South East Atlantic Fisheries Organisation (SEAFO) (2006)


The international community has also recognized the overfishing of sharks as a problem and has taken several steps to minimize the negative impacts. Three hammerhead shark species (S. zygaena, S. lewini, and S. mokarran) have recently been added to the Convention on International Trade in Endangered Species (CITES) Appendix II. This is a list of species that may be in danger of over fishing and are “look-alike species” and provides recommendations of how trade should be regulated. CITES recommends that permits should
be required for the trade *Sphyrna* species (The CITES Appendices, n.d.) The Food and Agriculture Organisation of the United Nations created the International Plan of Action for the Conservation and Management of Sharks (IPOA-Sharks) in 1999. This is a document that provides the following recommendations to states whose fisheries are directly connected to shark trade on how to develop a national plan for the management of sharks. This is a document that establishes strictly voluntary measures and states are responsible for the development, implementation, and monitoring of their plan. It is also recommended that states complete a stock assessment of their fisheries focusing on improving species identification and determining abundances, look at current management measures and their effectiveness, work together with other states since sharks are transboundary, straddling, and highly migratory. IPOA-Sharks advises that plans make sure catches are sustainable, assess the health of current populations, protect vulnerable or threatened stocks, minimize by-catch, minimize finning, encourage full use of caught sharks, and improve landing data. States are encouraged to report the status of their management plans to the FAO as part of their biannual reporting (Food and Agriculture Organisation of the United Nations, 1999).

As of today IPOA-Sharks has seen little success. In the U.S., no full stock assessment has been completed. These are hugely important to learn important life history characteristics and discover important areas to protect, such as aggregation sites and nurseries (Casper et al., 2005).

**Ecuadorean Shark Catch Regulation**

Shark fin trading has existed in Ecuador since the 1960 and the Galápagos since the 1950s and continued without any kind of regulation until 1993 (Carr, Stier, Fietz, Montero, Gallagher, & Bruno, 2013). The Galápagos Marine Reserve (GMR) has been crucial in
driving shark conservation because it is such a huge source of income from tourism for Ecuador. In 1993, as a response to shark harvesting occurring in the GMR, the government implemented a law that required sharks to be landed with fins intact. Requiring that fishermen transported intact shark bodies lowered the amount that they could bring in from each trip. In 2000 the government attempted to stop all shark harvesting activity in the GMR by banning all fishing, landing, and trading of shark. Then, in 2004, they took it one step further by banning the export of shark fins from the Galápagos and the mainland. These laws backfired by opening up a black market where all fins were send through Peru or Columbia before they were exported Asia. Before the black market, it was difficult for the Ecuadorean government to regulate shark fishing activity; but with the formation of the black market it was impossible (Jacquet et al., 2008). That is why, in 2008, the government decreed that any shark by-catch could be brought to shore fully intact and sold. This meant that the entire shark had to be used but once again fins could be sold directly out of Ecuador (Coello, 2005). This helped to decrease black market activity but has not solved the issue. Since there is no monitoring in fishing areas it is impossible to tell if what fishermen are bringing to shore is by-catch or illegal target catch.

**Nation Plan for the Conservation and Management of Sharks of Ecuador (PAT-Ec)**

The Ecuadorean Ministry of Foreign Trade, Industrialization, Fishing, and Competition also developed the Nation Plan for the Conservation and Management of Sharks of Ecuador (PAT-Ec) in 2006 outlining the objective of shark management, components of the plan, regulations, and methods of control. The objectives include sustainable maintenance of shark stocks, participation at the local level, prioritizing protecting sharks in the Galápagos, to eliminate the practice of finning, focus attention of vulnerable and
threatened species, educate people about sharks and the importance of protecting them, improving data collection on shark populations and catch, identifying threats to sharks, identifying critical habitats, and to improve surveillance, control and implementation of regulations. The PAT-Ec also includes the goal of promoting alternative activities to fishermen and establishing a system of certifying that fins were ethically and legally harvested before exportation (Ministerio de Comercio Exterior, Industrialización, Pesca y Competitividad, 2006).

Ecuador is a large contributor to the global shark fin market but due to lack of monitoring and regulation it is impossible to know exactly how large. It was not until 2005 that Ecuador began to report the shark exports to FAO. Based on these reports 11% of all chondrichthyans (sharks, rays, and chimeras) landing in the country consist of S. zygaena (Casper et al., 2005). Unfortunately, the number of sharks caught and exported in Ecuador is vastly under-reported. There are 28 species of shark that live in Ecuador’s water but only six categories are reported: thresher, short fin makos, miscellaneous sharks, requiem sharks, hammerheads, and houndsharks and smooth hounds (Jacquest et al. 2008). These groupings lead to flawed data that does not effectively demonstrate the scope of the harvesting activity.

**Difficulties in management**

The FAO Fisheries Report No. 795 cites the common problems with management all around world as follows: improper identification, inaccurate recording of catch and discards, high amounts of fishing, and lack of trade information (Food and Agriculture Organization of the United Nations, 2006). S. zygaena has been listed an Annex I, highly migratory Species, by the UN Convention on the Law of Sea (Casper et al., 2005). Since this is a highly migratory species it is difficult to create effective national level policy for conservation.
In a critique of the current UN International Plan of Action for Sharks (IPOA SHARKS), FAO Fisheries Report No. 795 identifies the problems that have been discovered since its establishment in 1999. The goal of this plan was to: enhance conservation and management, improve data collection, monitor and manage fisheries, know state contributions to shark mortalities, and establish a National Shark plan by 2001. This plan was largely unsuccessful (Worm et al., 2013). The problems include lack of species identification in reports, lack of information on populations, lack of funds, lack of human resources, competition from other projects, lack of effective policy and institutional practices, lack of data for catch to inform management, weak or no capacity for control in developing countries, and low political priority. This assessment has made it clear that it is necessary for more research to be completed on shark population, catch, and attempted mitigation plans before larger conservation goals can be reached.

Another issue with current fisheries management strategies is that they generally focus efforts toward one species rather than the ecosystem/s in which that species resides. Often, seeking to maintain a single species does not eliminate the reason why the species needs protection. Single species focused plans fail to eradicate damage to the ecosystem/s caused by the reduction of the species in question or other factors. These ecosystems are vital to maintaining the health of the species being protected. Focusing on both the species in danger and the ecosystem improves the chance of success for both (Brierley, 2007).
Methods
Data collection

EquilibrioAzul has been collecting data on the sharks that are brought to shore at the Puerto López fish market since April 2007. Their database covers years 2007-2010 and 2012-2013. In 2011 EquilibrioAzul lost funding and was unable to keep records. Each morning from 8 am to 10 am Monday through Saturday EquilibrioAzul sends two to three volunteers and/or staff members to the market to identify, count, and measure each shark and ray they find given they have permission from the fishermen who own them. Observers are provided with a data entry sheets (Appendix A), instructions on measurements (Figures 2 and 3), a tape measure, and an Ecuadorian shark identification guide (Appendix C). Sex is determined based on the presence of claspers. If the individual has claspers it is a male, if not it is female (see Figure 3). If allowed by the fishermen, the observers take measurements of each individual. Measurements (see Figure 2) include total length (snout to tip of caudal fin), fork length (snout to the fork the in tail), pre-caudal length (snout to right before the caudal fin), inter-dorsal length (length between the first and second dorsal fins), and if the individual is a male, the length of the claspers (from cloaca to tip of clasper)(see Figure 3). The species, sex, and measurements are recorded onto a data sheet that is then stored in binders according to year. This information is then put into a spreadsheet using Microsoft Access.
Figure 2: The measurements taken on each individual. Total length is from snout to tail (green), pre-caudal length is from snout to right before the caudal fin (red), fork length is from the snout to the fork of the tail (blue), and inter-dorsal length is between the first and second dorsal fins (yellow).

Figure 3: The difference in the ventral side of male and female sharks as well as the proper way to measure clasper length (shown in red).

This database was provided to me in multiple forms. Years 2007-2010 were in CSV and 2012-2013 was in Microsoft Access. The CSV files were exported as Microsoft Excel files and information pertaining to this thesis was copy and pasted from the Microsoft Access files into Excel.

**Data analysis**

Using Microsoft Excel these data were used to create graphs showing trends in total catch numbers per month, average total length of catch per month, percentages of immature...
versus mature sharks caught, gender ratios according to month, and percentage of total males, females, and non-identified sharks. I also compared EquilibrioAzul data to the records of *S. zygaena* catch from the Ecuadorian Ministry of Agriculture, Livestock, Aquaculture, and Fishing by creating a cluster bar graph of total catch per month. Ministry data was found through the Ecuadorian Ministry of Agriculture, Livestock, Aquaculture, and Fishing website (Ministerio de Agricultura, Ganadería, Acuacultura, y Pesca, 2011). This database has counts on all species landed in fish markets throughout the Ecuadorian coast up to December 2011. Since government workers are still taking counts at the markets it can be assumed that the website has not been updated with counts from 2012, 2013, and 2014. The Ministry’s data on smooth hammerheads landed in Puerto López goes from 2008 to 2011 and EquilibrioAzuls is from 2007 to 2013. Since the sets did not match up properly I only graphed months in which both the data set were present for each month and year.

Statistical analysis was done using the program R. A linear regression was performed on the total catch per month for both the EquilibrioAzul (2007-2010 and 2013-2013) and government (2008-2011) data sets.

**Results and Discussion**

**Average Total Length per Month**

Figure 4 shows the average total length of all individuals landed and measured at the fish market from April 2007 to April 2013. There is a clear cyclical trend that shows more smaller individuals being caught in the spring and summer months (April through August) with larger individuals appearing in in the winter (September through January) and then getting smaller again in February. This cycle could be an indicator of breeding season and/or
migration patterns. There is little information on the migration of the smooth hammerhead and no studies have been done on the migration of them on the eastern Pacific coast so it is difficult to know if this cycle is due to migration. It is known that smooth hammerhead prefer nurseries in smooth, sandy substrate that is about 20 meters deep and give birth to pups in the summer months (Heithaus, 2007; Bester, Florida Museum of Natural History). Since there are more small individuals April through August it would suggest that this is the time when mature females are coming closer to shore to give birth. This would also suggest that the Puerto López market is close to nursery areas and the fishermen know the best locations to catch the most sharks. In November of 2010 there is an uncharacteristic drop in total length. This cycle is very clear in 2007 through 2009 but becomes less obvious in late 2010 through 2013. This is due to two factors. One is that fewer personnel at EquilibrioAzul made it more difficult to record data consistently from 2010 to 2013. Another factor that could have lead to the reduced the consistency of data collection were changing regulations and fishermen losing trust those collecting data. The Ecuadorian government started taking counts in 2008 and as time went on fishermen became hesitant to participate in data collection projects for fear of stricter regulation and harsher punishments.
Figure 4: The average total lengths of each *S. zygaena* individuals landed in Puerto López, Ecuador and measured by EquilibrioAzul per month.
**Total Individuals Landed and Counted**

Figures 5 and 6 show the total number of individual smooth hammerhead that were landed and counted at the Puerto López fish market per month. These data show that the most individuals were landed and counted March through July with a significant majority (66%) caught in April and May. It also shows that the most records were taken for years 2008, 2009, 2012, and 2013. Records are provided for all six years only for April. There are five years of records for February, March, May, and November; four years for January, July, September, October, and November; and only three years for June. Although April and May have some of the most records (six and five years respectively), the rest of the months with five years of data show much lower catches than May and April, specifically February and November. June is also a month with high catch levels. It only has three years of data and is the third largest percentage. High catch numbers in the spring could be indicative of multiple factors. One is the greater number of volunteers at EquilibrioAzul in the spring. More manpower within EquilibrioAzul allows them to collect more consistent records. There may be more sharks in the area due to the high breeding activity in the spring and summer. Finally, the demand for and price of shark fins may be higher in the spring and summer because of the frequency of special events in which people eat shark fin soup, like weddings and graduations. There are, however, no available data to support this theory.
Figure 5: The total number of *S. zygaena* landed and counted by EquilibrioAzul in Puerto López, Ecuador per month. An outlier (April 2013, 5,989 individuals caught) was removed.

Figure 6: The total number of *S. zygaena* caught and counted by EquilibrioAzul in Puerto López, Ecuador from 2007-2013 divided into percentage by month.
A linear regression of these data showed an upward trend; however did not yield statistically significant results. The adjusted R-squared value was 0.02292 and the P value was 0.1424 (see Figure 7)(significant data has a P value <0.05). This test showed that there is no a relationship in the number of sharks landed over time. This means that the total catch has not increased or decreased in the seven years that data has been collected. This indicates that stocks have not been reduced do to catch in the area.

Figure 7: A linear regression of the total number of *S. zygaena* landed and counted by EquilibrioAzul in Puerto López, Ecuador. R-squared= 0.02292 and the P value= 0.1424 so the regression line is not statistically significant.
EquilibrioAzul’s Total Count Compared to the Ecuadorian Ministry of Agriculture, Livestock, Aquaculture, and Fishing’s Total Count

Figure 8 compares EquilibrioAzuls’s total catch numbers to the Ministry of Agriculture, Livestock, Aquaculture, and Fishing’s total catch numbers of *S. zygaena*. The government’s counts are significantly higher than the EquilibrioAzul’s every month. This could be because volunteers who have little training and a high turnover rate put the EquilibrioAzul database together and a paid government employee puts the Ministry database together. In the EquilibrioAzul count many individuals and entire days go unrecorded.

Figure 8: A comparison of the total counts of *S. zygaena* caught and counted in Puerto López, Ecuador from the Ministry of Agriculture, Livestock, Aquaculture, and Fishing (in blue) and EquilibrioAzul (in red). An outlier (June 2008, Ministry total= 25,454, Equilibrio total= 1635) was removed.
A linear regression of the governmental total counts from 2008 to 2011 showed a net decrease in catch but results were not significant with a p-value of 0.1788 and an adjusted r-squared of 0.01806 (see Figure 9). This shows that there has been no net increase or decrease in catch numbers from 2008 to 2011 meaning smooth hammerhead stocks by Puerto López have not been depleted due to shark catch.

Figure 9: A linear regression of the data from the Ecuadorean Ministry of Agriculture, Livestock, Aquaculture, and Fishing of total *S. zygaena* landed in Puerto López, Ecuador. The R-squared = 0.01806 and the P value = 0.1788 so the regression line is not statistically significant.
Ratios of Males to Females in Total Catch

Figures 10 and 11 show the ratios of males and females in the total catch, divided into males (blue), females (red), and non-identified (green). Both show that there are more males being caught each month than females. Figure 10 shows that the frequency of non-identified individuals increases in 2010 through 2013. This could be due to changes in EquilibrioAzul that prevent sufficient personnel to identify sex and policy changes that make fishermen more wary of allowing researchers closer to their catch. Figure 11 shows that males are caught 8.41% more frequently than females. Although 27.32% of the total catch was recorded as non-identified the other 72.68% show that males are caught more frequently than females. This could be because they are easier to catch, school together, or that there are simply more males in the Puerto López area. There is not enough information available in the literature to say which of these theories may be correct. This data could provide interesting information about the behavior of sharks if we could learn why more males are being caught in this area. Since a population only needs a few males to support growth this is not a concerning trend. This data also shows that fishermen are not actively selecting for large individuals. Since females are the larger sex in smooth hammerheads a preference for large individuals would show heavier catch intensity on them.
Figure 9: The total catch of *S. zygaena* recorded by EquilibrioAzul by month divided into males (blue), females (red), and non-identified, Puerto López, Ecuador. An outlier (April 2013 males= 1,330, females= 1,034, non-identified= 3,625) was removed.

Figure 10: The total catch of *S. zygaena* landed in Puerto López, Ecuador and counted by EquilibrioAzul broken into percentages of males (blue), females (red), and non-identified (green)
Ratios of Sexually Immature to Mature Individuals in Total Catch

Figures 12 shows the percentage of mature and juvenile individuals in the measured total catch. Female smooth hammerheads are considered to be mature at 2.65 meters and males at 2.5 meters (Compagno, 2001). For both males and females over 99% of the total catch in Puerto López consists of individuals that have not yet reached sexual maturity. These data suggest that fishermen are targeting nursery areas or schools of young sharks. The analyses of average total count and average total length also suggest that fishermen in Puerto López are targeting nursery areas. Some studies suggest that juvenile smooth hammerhead school to protect themselves from predators (Bester, Florida Museum of Natural History). This would support the idea that fishermen are also targeting schooling young sharks in the area. These are areas in which fishermen could catch a high number of sharks in a short amount of time while remaining close to shore.

An analysis of the number of mature and immature sharks landed per month showed no trend. These data suggest that catching mature individuals is random. These could be females who moved closer to shore to give birth, fishermen moved further from shore, or that the mature individual was inland randomly. Since there is little information in the literature on the behavior of smooth hammerheads it is difficult to determine what causes this disparity in the catch data.
Implications and Recommendations

In fisheries science there are two distinct aspects of exploitation to consider: exploitation rate and exploitation pattern. Exploitation rate looks at the proportion of the population biomass extracted by year and is quantified by fish mortality. Exploitation pattern focuses on the distribution of age or length composition of the catch. In order for fishing activity to be sustainable there needs to be a trade off between these two aspects. If the exploitation rate is low the exploitation pattern is not as important and vice versa. If exploitation rate is too high, however; the sustainability of the catch pattern becomes insignificant (Food and Agriculture Organisation of the United Nations, 2010). Since there
has not been a net increases or decreases in total catch in either the EquilibrioAzul data or the Ministry data it can be assumed that the exploitation rate in the Puerto López area is sustainable. This means that the dangers the smooth hammerhead populations could be facing are due to exploitation patterns.

Analysis of EquilibrioAzul’s database made clear four potential problems with the current methods of fishing in the Puerto López area: the inconsistency of EquilibrioAzul’s data, the low count when compared to the Ministry of Agriculture, Livestock, Aquaculture, and Fishing, and the overwhelming number of immature individuals caught. The following sections will explain these problems and offer suggestions on managing their consequences.

**Inconsistency of EquilibrioAzul’s Data**

EquilibrioAzul’s data is inconsistent in that there is a year, months, and days in which no data or limited data were recorded, volunteers have insufficient training, and few measurements are available in the total sample. A missing year, and missing months, and days creates a lot of error when looking at trend in total catch, which limits the reliability on information about exploitation rate. The limited training of volunteers also creates error because they often improperly identify species and take incorrect measurements. Incorrect identification and measurement make the data less reliable. Another limitation of this data is the number of measurements taken. Measurements are extremely important in analyzing exploitation patterns and fishery sustainability.

In order to solve these issues EquilibrioAzul should focus more energy on their shark project. One option for this would be to have an employee whose focus is training volunteers and overseeing data collecting and data entry to be sure everything is accurate as possible.
This would require increased funding for the shark project which could be found through grants, increased volunteer living fees (to live in the volunteer house an work on projects), and donations.

**Government Counts Higher than EquilibrioAzul’s**

The fact that the government counts are higher that EquilibrioAzul’s do not discredit the size and sex ratio information found in the later data set. The information about sizes and sex is very important in understanding how fishing may be impacting the local shark population. Since EquilibrioAzul relies heavily on volunteers and is low on funding it would be beneficial to team up with the government workers to supplement each database. This would provide EquilibrioAzul with much needed personnel and potential funding and the government would receive more detailed reports. Unfortunately the Ecuadorean government does not generally form good relationships with non-profit organizations such as EquilibrioAzul. EquilibrioAzul would also hesitate to work with the government for fear of worsening relationships with fishermen and harsher restrictions on their marine conservation projects.

**Overfishing Immature Sharks**

An important aspect of maintaining healthy populations is allowing individuals to reach recruitment age, or sexual maturity. This is referred to as the “spawn at least once” principle, which is an idea that if species are allowed to reproduce at least once healthy population sizes can be maintained (Vasilakopoulos et al., 2011). In an analysis of this principle Vasilakopoulos et al. (2011) say that if fishing mortality of immature individuals is over half that of mature individuals than the population is at risk of falling to dangerously low numbers. The methods of fishing used by fishermen in the Puerto López area are
somehow targeting immature individuals. The high number of immature sharks in their catch suggests that the areas off shore in Puerto Lópe may be nurseries for smooth hammerhead. Since there is a direct correlation between the breeding stock and the number of individuals that reach recruitment age, overfishing sexually immature could lead to a reduction in the breeding population, which could have extremely harmful consequences for the entire population.

The first aspect of managing this problem would be to identify potential nurseries in the Puerto Lópe area. Then, fishermen could be informed on locations and educated on their role in protecting the total shark stock. This would hopefully encourage them to avoid nurseries and increase the size of the sharks they land. With this method young sharks would have a chance to grow to recruitment age and only sharks that had reproduced would be caught. This method would not jeopardize their catch profit. Fishermen would need to catch fewer sharks in order to meet the same net weight in their catch. If they fail to protect the immature sharks, legal regulation and enforcement would be required. This type regulation would have to set a minimum size of sharks that can be landed would force fishermen to throw back any small sharks. Both education and enforcement would require increased manpower and funding.

**General Recommendation-Local Participation and Education**

Education and local participation are a crucial aspect of any conservation plan. It has been found that locals are more likely to participate in conservation efforts if they feel that the regulations are necessary, the organizing agencies are legitimate, and if they feel involved (Viteri & Chavez, 2007). Educating the community about the role that sharks play in their everyday lives will help them to feel ownership of the problem.
There main way to show sharks importance is through the economy. Having a healthy population of sharks maintains income brought in by shark catch long into the future and can increase interest in Puerto López as a tourist destination. It has been found that sharks have huge potential to attract tourists. One study found that 71% of scuba divers are willing to pay more to see sharks than any other species (Gallagher & Hammerschlag, 2011). Making locals feel an economic incentive to protect sharks will increase their participation and cooperation in all measures taken through various management plans.

**Conclusion**

The issues discussed above are specific to the Puerto López area and therefore require management at the local level. Overfishing of sharks; however, is a global issue that deserves global attention. The current regulations on shark catch are too focused on reducing finning and do not focus enough attention on improving available information on sharks. The main problem discovered through this project is the lack of basic information on sharks. We need a better understanding of shark behavior and ecology an to perform stock assessments around to world in order to understand the true impacts that shark by-catch and target fishing are having on global populations. Since sharks area migratory species this must be a global effort. Global declines in shark populations have top down effects that change species abundances and food web connectivity in all marine ecosystems. Without this basic information it is impossible to establish a framework that will begin to solve the problem. If nothing is done quickly oceans could be facing losing top-level predators, which puts entire ecosystems in danger. International communities should be focused on completing stock assessments and learning about shark behavior. Once this is done a global
standard for shark catch levels can be established. Marine ecosystems contain some of our most valuable natural resource and rely on top-level predators to maintain them. In order to protect these resources the global community needs to take action protect their sharks.


Appendix A
Translated from Spanish

EquilibrioAzul
Data Sheet—Sharks

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<th>Sex</th>
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**KEY**

LT-Total length
LF-Furcal length
LPC-Precaudal length
LID-Inter-dorsal length
LC-Clasper length
source Ministerio de Agricultura, Ganadería, Acuacultura, y Pesca de Ecuador
(Translation: Ministry of Agriculture, Livestock, Aquaculture, and Fishing of Ecuador)