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An Analysis of Global Chondrichthyan Species Decline: Insight into Management Issues and Potential Solutions to Reverse the Effects of Shark "Finning," Bycatch, and Habitat Destruction

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Abstract

To date, there is a widespread decline in Chondrichthyan species (sharks, rays, and chimeras) in virtually every ocean. Due largely to unregulated fishing for their highly valued fins, approximately 75 to 100 million sharks are killed and "finned" every year. Millions more fall victim to accidental bycatch from non-target commercial fisheries. Though not as heavily researched, the destruction of vital nursery areas and habitat has undoubtedly served as another factor causing many species to become threatened. Management efforts to preserve these species has been lacking due to the historical low-value of the species, but is further made more difficult due to their K-selected life history and the transboundry migratory routes undergone by many different species. Proper management and scientific efforts are further hindered in developing nations where shark catches tend to be under-reported, unidentified, or not reported at all. Some specific shark species are apex predators and "keystone" species and as such, over-fishing of select species may cause adverse trophic interactions which may harm other commercially important fisheries. Some faster growing, more fecund species may be able to sustain populations under current fishing pressures; however, this does not apply to many deep sea, pelagic, and coastal species. As more scientific research and management efforts are desperately needed to preserve current stocks, some conservation efforts seem to be effective at reducing shark mortality. The implementation of marine reserves appears to show large promise in protecting both target and non-target species. Current research on bycatch reduction devices may limit mortality in non-target fisheries; while political efforts such as the U.S. Shark Conservation Act of 2011 may help to reduce mortality as a result of "finning."

Preface

I remember the first time I saw a shark in the ocean. We were driving down the coast of Florida making our way to Key West for a family vacation. My younger siblings and I were just exposed to the movie *Jaws* for the first time and needless to say, we were afraid of going into the water for fear of being eaten alive. We arrived at our hotel for the night and decided to take a walk out onto the pier to stretch our legs and enjoy a little sea air. After constant reassurance from our mom that no, we will not even come close to seeing a shark, let alone be eaten by one, I swear I did not get more than 10 feet out on the dock before I saw it. Gliding effortlessly along the ocean floor, in less than three feet of water, was, and remains today, the biggest shark I have ever seen. It was a hammerhead shark slicing through the water. To my surprise I was not afraid, I was now *obsessed*.

I have been extremely fortunate enough to relive this encounter multiple times with a wide-variety of species throughout the world and to share these encounters with researchers, friends, and family. My goal in this report is to expose the plight of one of the most demonized, yet misunderstood species in human history and to propose potential solutions to save this beautiful species that until very recently, for some reason or another, has escaped the attention of the majority of the public. Throughout this report I will examine and trace the history of management efforts and the difficulties when trying to sustain shark and ray populations. In the final section of the report I address the all-important question: *What can we do about it?*

Shark populations around the world are diminishing at a rapid pace as a result of many different human activities and it is up to us to fix the problem we started. Whether on a fishing boat or in the water, I have never experienced such a raw feeling when interacting with sharks and rays. As such, throughout this report I will argue for the preservation of sharks and rays for their sake and for ours. Sharks have been the very top predators in the world's oceans for millions of years. They have evolved to be perfect in their environment and yet it is because of us that, for the first time in millions of years, they are the ones who are in danger.

Acknowledgements

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Introduction

There is currently a wide-spread and dramatic decline in many Chondrichthyan species (sharks, rays, and chimeras) throughout our world's oceans. Some of the most extreme estimates indicate a 90 percent decline in some specie stocks, with declines around 70 percent being the norm over the past 20 to 30 years. If current trends continue, we may very well see the ecological extinction of many Chondrichthyan species, resulting in devastating ecological and economical consequences. Drawing upon scientific reports, books, documentaries, and newspaper articles, this thesis will identify the three major threats to, as well as the three principal causes of, this large-scale reduction that for some reason or another, has been unnoticed by the general public despite being a key environmental issue in our oceans. The most publicized threat -- and one that will be discussed in detail throughout this report -- are targeted shark fisheries which kill up to 100 million sharks each year for their highly-prized fins – a delicacy in a rapidly expanding Chinese middle-class. "Shark finning;" however, has perhaps over-shadowed two other preeminent threats which have undoubtedly contributed to the global decline of many species and which this report reviews – the unregulated deterioration of Chondrichthyan stocks as a result of accidental bycatch by commercial fishing ventures and the unpublicized destruction of vital shark nursery grounds and congregating sites.

While this thesis will be based on issues brought up in a 2010 report, *The potential inaccuracies in field measurement techniques for Chondrichthyan species and possible ramifications for fisheries management* that I wrote as part of an internship project at James Cook University's Fishing and Fisheries Research Centre, it will also explore management inadequacies that have failed to properly manage the sustainable use of shark and ray species.

Due to their relative and historically low economic value, proper management has been overlooked for some time. Furthermore, effective management by local shark fishing States has been hindered to some degree by the lack of basic scientific research on many species' biology, migratory, and breeding behavior. The issue at hand is complicated as many developing nations rely on shark meat as a principal source of income and in some cases, a basic source of protein. Due to low funding and a general lack of interest when compared to other environmental issues, it is imperative that current research be aimed to determine species-specific data in order to create regional field guides to identify species caught in fisheries.

It seems that lack of effective management for shark and ray species has also been a result of a public perception that most, if not all, sharks are "man eaters." Though this is far from the truth, this report will instead demonstrate the ecological role that many apex shark and ray species serve in our oceans. As some notable species are top predators, they serve to keep many marine food webs in balance. Throughout this thesis I will demonstrate the importance of sharks and rays and why, we as people, should shed our unfounded fears from these species and instead, work toward protecting them. While drawing on specific findings, in this section of the report I will demonstrate the ecological and biological impact overfishing has on shark species, ecological communities, and even our own economy.

Perhaps the underlying theme that is present in this thesis is the question: can Chondrichthyan species being harvested sustainably? Due to relentless pressure from a host of threats, many species cannot be sustained due to their K-selected life history, which is usually characterized by slow-growth, late maturity, and low fecundity. Yet, some species with a high "rebound" potential can be fished, if said fishing is properly managed. In this part of the report, I will draw heavily on species-specific data; while also using certain species as case-studies to demonstrate the sustainability of current fisheries and how mismanagement can have catastrophic consequences.

In the fifth and final section of this report, I will make personal recommendations which may prove beneficial to help stabilize, if not reduce the decline of many shark and ray species. Using specific reports, I propose three potential solutions which seem to be the most effective ways of limiting shark mortality. I will also look at current policies that if properly enforced, can be beneficial in protecting a wide-array of over-fished species.

The issue of shark fishing is a tricky if not, very difficult task to try and find a "best fit" solution for. As such, this report will rely on extensive research from a wide-array of sources which bring unique, if not sometimes opposing views, on the matter at hand. I will also rely on first-hand experience and interviews which will bring a unique aspect to this report. The overall aims of the project are to: (1) identify the major factors that have led to the decline of Chondrichthyans throughout the world's oceans; (2) provide an critique of current management efforts while examining the difficulties current groups face when trying to allow for the sustainable use of species; (3) demonstrate the ecological roles that many sharks and rays serve in their environment and create an argument for a drastic reduction in shark fishing and consumption; (4) present that under certain circumstances, some species can be fished sustainably, while others are more vulnerable to extinction if fishing efforts do not cease all-together; and (5) suggest ways to overcome the general decline in Chondrichthyan species and provide recommendations for conservation initiatives focusing on the long-term survival of the species.

Chapter 1. Decline in Shark Populations

Chondrichthyan Species

Today we know of about 1110 living Chondrichthyan species (sharks, rays, and chimeras), but this number is rising as more species new to science are continually being discovered and named (Compagno et al. 2005). There are two main groups of Chondrichthyan fishes. The largest of these is the subclass Elasmobranchii ('elasmo' meaning plate and 'branchii' meaning gills), which includes the sharks and rays. The subclass Holocephali, contains the chimeras, which are a smaller group of fishes (Compagno et al. 2005).[1] Members of this group have been present in the world's oceans and have survived for 400 million years (Pikitch et al. 2008), while having played vital roles as predatory fish. Despite being such an enduring presence in virtually every ocean environment -- from near shore to depths of 3,000 m (Pikitch et al. 2008), with even a few occurring in freshwater and hyper-saline habitats (FAO 2000) -- we know very little about the biology of sharks and rays compared to other marine fauna (Dobson 2008) and we know almost nothing about their migratory and breeding behavior (Davis et al. 1997). At present, 416 species of shark have been identified and observed by scientists. Yet of this 416, 45 sharks (and a further 65 rays) are listed as globally threatened (those species that are considered to be critically endangered, endangered, or vulnerable) by the International Union for Conservation of Nature's (IUCN) Red List of Threatened Species (Dobson 2008).

[1] This study will focus primarily on Elasmobranchs; however, many of the issues addressed will apply to the subclass Holocephali as well. Throughout this report the term "shark" will be used interchangeably as a reference to the batoids (sharks and rays), as well as the true sharks.

Fisheries

Over the past 50 years, commercial fisheries have caused a steady decline in many of the ocean's top-marine predators (Nance and Hearn 2008). Although cartilaginous fishes comprise less than one percent of the world's fish catch (with sharks comprising just half this percent themselves), commercial fishing is having a major impact on shark and ray populations (Tricas et al. 1997; Walker 1998; Compagno et al. 2005). Despite making up such a tiny majority of the annual global catch, this amounts to some 700,000 to 800,000 tons; perhaps constituting of 70 to 100 million animals caught in fisheries each year (Compagno et al. 2005). It is estimated that actual catches may be twice as high as reported (Stevens et al. 2000; Compagno et al. 2005), with some researchers believing that shark catches alone may be three to four times larger than reported by fishers to the United Nations Food and Agriculture Organization (FAO) (Dulvy et al. 2008). The number of actual individuals caught often goes "under-reported" as many fishers may not record or choose to ignore bycatch (an issue discussed further in the study) and discards. This number does not reflect the number of individuals caught and killed during recreational fishing or as a result of habitat modification (Compagno et al. 2005). Instead, it only focuses on those Elasmobranchs caught in commercial fishing vessels.

100 million sharks and rays are killed each year as a result of human consumption for their fins and flesh for food, liver for oil as a source for pharmaceuticals and vitamins, hides for leather, skin for abrasive sheets and for surgical skin implants, and teeth and skeletal parts for jewelry (Tricas et al. 1997). Though sharks and rays have long been utilized as a traditional resource and are of cultural and social significance (Castillo-Géniz et al. 1998), recent fishing practices and rates of decline are clearly unsustainable. It is estimated over the past 20 to 30

years that some shark stocks alone have decreased by 90% (Dobson 2008; Heithaus et al. 2008) as a result of target and/or bycatch fisheries, while population declines of 70 percent over the past 20 to 30 years are the norm (Compagno et al. 2005).

Due to unsustainable fishing practices that result in dramatic overfishing, data sets from throughout the world indicate that industrial fisheries (on average) reduce biomass by 80 percent during their first 15 years of exploitation (Walker 2005). Targeted shark fisheries are still; however, relatively uncommon (and short-lived)[2] compared to Teleost (bony fish) fisheries. There have been many notable target shark fisheries throughout history including (but not limited to): the Norwegian porbeagle shark (*Lamna nasus*) fishery, European spiny dogfish (*Squalus acanthias*) fishery, Australian southern school (*Galeorhinus galeus*) and gummy shark (*Mustelus antarcticus*) fishery, coastal fisheries for a variety of large sharks in Australia and the USA, and reef sharks in the Red Sea and Indian Ocean (Compagno et al. 2005). As most sharks and rays are taken in multispecies fisheries, where the fishers tend to target more highly valued species (Walker 2005), sustainable management for Chondrichtyhyans is a particularly difficult task to implement upon policy makers and fishermen. In the following section, I will examine some of the major anthropogenic uses of shark and ray which have created a highly valuable market for Elasmobranch products.

Shark Finning and Shark Fin Soup

The increasing (and largely unregulated) trade in shark fins represents one of the most serious threats to shark and ray populations worldwide (Clarke et al. 2006). Shark fin soup is

[2] It generally takes about ten years or less for a shark fishery to go through a classic "boom and bust" pattern of initial high landings followed by a rapid population crash (Walker 1998; Compagno et al. 2005).

considered an aphrodisiac in parts of Asia; with Hong Kong being the world's largest shark fin market (Clarke et al. 2006). Hong Kong is the "hub" of the international trade market for shark fins and it is estimated that between 50 and 85 percent of the world's sharks fins are exported to Hong Kong from 86 different countries (Camhi et al. 2008). Shark fin soup has been regarded as a delicacy by the Chinese for more than 2,000 years (Tricas et al. 1997) and has long been noted as a sign of privilege among many of Asia's upper elite classes. Due to a rapidly growing population and middle class, there has been a drive to consume more Elasmobranch fins in many nations. The push for more shark fin soup has made the fins of many species of shark and ray currently among the world's most expensive fishery products (Tricas et al. 1997; Walker 1998), with some fins being worth US $800 for a 1.6-pound bag (Brown 2011). Recent data suggest that the world trade in shark fins was 11,000 tons (just the fins) in 2000, which suggest that the shark biomass needed to support the global fin trade every year, ranges from 1.21 to 2.29 million tons – an equivalent of 26 to 73 million sharks (Camhi et al. 2008).

A fin, on average, only makes up about 5% of the total weight of the shark or ray (Musick 2005). Due to current demand levels, Elasmobranch fins are actually worth more than their meat,[3] which creates an economic incentive to retain the fin and discard the carcass at sea (Dulvy et al. 2008). As countless more fins can fit into a ship than the whole animal, millions of sharks and rays often have their fins cut off -- while alive -- and are thrown back into the water to either drown, bleed out, or be consumed by another animal. This raises ethical concerns over the rationality of usage which is in blatant contradiction to the FAO's Code of Conduct for

[3] Though not as popular, marketing campaigns have been introduced to overcome consumer resistance to shark meat for human consumption. Shark is often sold under false market names designed to disguise its true identity (Tricas et al. 1997). For example, in Australia shark meat is often sold under the alias of "flake" (Personal Observation).

Responsible Fisheries, stressing the importance of avoiding waste and discards in fisheries (Musick 2005). Recently there has been an increasing awareness of the vulnerability of shark species to exploitation that has contributed to growing concerns among the general public and policy makers that the fin trade may be driving shark catches to unsustainable levels (Clarke et al. 2006; Huepel and Simpfendorfer 2010).

Fishing for Oil

When examining the anatomy of a shark or ray the most notable organ one can easily observe is the large, brown liver which makes up most of the body cavity (Personal Observation). To give one a reliable estimate of just how massive this organ truly is, in the basking shark (*Cetorhinus maximus*) – the second largest shark on the planet -- the liver makes up about a quarter of the body weight and may weigh up to a ton (Compagno et al. 2005). Livers were the major product in traditional basking shark fisheries because it contains up to 80 percent in weight of high quality squalene oil -- important for industrial, cosmetic, and pharmaceutical use (Compagno et al. 2005). The high demand of this oil almost led the basking shark to the verge of extinction.

Though not as detrimental --and popular -- when compared the fin industry, hunting for shark oil has significantly impacted shark populations throughout the world. There have been noticeable collapses in shark fisheries as a result of fishing for liver oil, even here in the United States. Take the example of the school shark (*Galeorhinus galeus*) – also known as the soupfin shark -- fishery off the Californian coast. This population became commercially extinct in the 1940's because of a dramatic decline in the proportion of mature females in the population (Tricas et al 1997). The soupfin shark has indeed also faced similar fates in Australia and South

Africa (Walker 1998). Though the liver is not in as high of a demand as shark fins, the fishing for shark and rays for the oil their liver contains is undoubtedly a cause of historical and perhaps, even recent declines in their populations.

Other Anthropogenic Uses

While not all sharks and rays are fished for their fins and oil, it is important to recognize the other factors which have led to the deliberate fishing of these species. Historically, sharks and rays have been fished for Vitamin A. During WWII, target shark fisheries formed in response to an increased market for Vitamin A – which was found in high supply in shark livers (Castillo-Géniz et al. 1998; Stevens et al. 2000). The Vitamin A deficiency during WWII was a significant threat to populations, as catches in the Pacific Northwest of Mexico alone, reached a peak of 4833 tons in 1944 (Castillo-Géniz et al. 1998). Thankfully, this particular market collapsed during the 1950's when synthetic Vitamin A became available (Tricas et al. 1997).

Products from sharks and rays have also found a market as jewelry in many coastal states. Sharks in particular are fished for their highly prized teeth and jaws. The price of a set of shark jaws can range anywhere from US $10 (Personal Observation) for infant --or "young of the year" – jaws, to offers of US $20,000 to $50,000 for a set of great white shark (*Carcharodon carcharias*) jaws -- with offers of US $600 to $800 for individual great white shark teeth (Fergusson 2010). Recently, shark and ray products are increasingly being used for medicinal purposes, further limiting their populations and creating a pressure for all products shark. Increased markets for shark and ray products have resulted in millions Elasmobranchs to be caught and killed each year in fisheries and yet, it still may not be the greatest threat these creatures face in the ocean.

Bycatch

Accidental bycatch is perhaps the single-greatest threat to not only Chondrichthyan species, but to all marine species. The FAO estimates that fisheries now take about 20 million tons of bycatch annually (Christie 2006). It is estimated that in 2004 the United States alone, discarded about .9 metric tons (that's one million tons) of fish – about 25 percent of the total commercial catch and more than three times the total catch of recreation fishers (Garrison 2007). Accidental bycatch is a huge waste of marine resources as most non-target species are not utilized and are discarded at sea due to a lack of markets, regulations prohibiting possession the bycatch, or to maximize the value of the harvest (this is known as "high-grading") (Christie 2006). More often than not, the bycatch is killed in the netting, on the line, or on board and is simply tossed back into the water unused – a complete waste of life. Bycatch is a critical issue which threatens countless marine species including: marine mammals, turtles, sharks, countless fish species, and marine birds.

Like many marine species, sharks and rays fall victim to bycatch in demersal trawls, longline, and gillnet fisheries around the world (Stevens et al. 2000). In fact, it is estimated that some fifty percent of the global catch of Chondrichthyans are taken as bycatch. This bycatch does not appear in any official fisheries statistics, and is almost totally unmanaged (Stevens et al. 2000). Many experts agree that annually, some 750,000 tons of Chondrichthyans are taken as bycatch in the world's fisheries, most of which is unfortunately discarded dead (Rigg et al. 2009). Those sharks that are actually utilized as bycatch tend to be the ecologically important, apex shark species (Walker 2005). Regardless of their economic or ecological value, when taken as bycatch most sharks and rays are subjected to high fishing mortality directed at the target species. Consequently, some skates, rays and sawfish have been extirpated from large regions due to bycatch (Stevens et al. 2000).

As most bycatch is accidental, it is also unregulated. Most sharks are taken in non-target fisheries meaning that this bycatch often goes unreported or labeled as "unidentified shark" or "mixed fish" (Walker 1998; Heupel et al. 2009). This means that most of the time, we don't know what species are being exploited and by what fishing methods they are falling victim to. As such, it is very difficult to implement some form of bycatch management of the non-target species. (This lack of species identification will be addressed in more detail further on in the report). In cases where the species are properly identified, the amount of individuals killed as a result of bycatch is staggering. In their 2000 study, *The effects of fishing on sharks, rays, and chimaeras (chondrichthyans), and implications for marine ecosystems,* Stevens et al. estimate that between 6.2 and 6.5 million blue sharks *(Prionace glauca)*, oceanic white-tip (*Carcharhinus longimanus),* and silky sharks (*Charcharhinus falciformis)* are taken in accidental bycatch each year. It is without question that bycatch is one of the most serious concerns to not only the sustainability of Chondrichthyans as resource, but to their survival as well.

Habitat Modification

Though not as widely publicized and researched as shark finning, habitat destruction as a result of human induced changes is a major detriment to the survival of many Chondrichthyan species. It should be known that changes to a habitat can be both natural and induced by humans. Natural disturbances such as cyclones and typhoons can damage coral reef and inshore habitats (Tricas et al. 1997) which are essential habitat for sharks and rays (Personal Observation); however, Chondrichthyans have learned and adapted to combat natural and irregular habitat modification. They are not well adapted to cope with the more permanent habitat changes induced by human activity (Tricas et al. 1997).

However overlooked by mainstream media and policy makers, habitat loss (and ecological impacts of invasive species) were the cause (or at least part) of the extinction for 25 of the 32 extinct finfish populations.[4] Chondrichthyan species seem to face a number of threats from human activities outside the realm of fishing, including: increases in oceanic pollution, the destruction of nursery grounds by coastal developments (Dobson 2008), construction of physical barriers such as dam walls and the collection of water for heavy industry and agricultural irrigation (Tricas et al. 1997), and the introduction of invasive species (Pikitch et al. 2008). Fertilizer runoff from farms is a critical threat to many marine ecosystems and has been known to make its way down rivers where it becomes deposited in oceans or bays, creating "algae blooms;" in which the increased production of algae literally starves the water of its available oxygen – making the area unsuitable habitat for many marine species. The impacts of these unnaturally large concentrations of dinoflagettes has numerous ecological and health impacts ranging from marine mammal and fill kills, to shellfish poisoning, while even causing respiratory problems in humans (Tomlinson et al. 2004).

Everyday, essential mangrove habitat is cleared for the ever-alluring beach front property as well as for the production of aquaculture.[5] Mangroves, as well as productive shallow coastal

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[4] Exploitation was a driving force in cause of extinction for all 32 of the sharks and rays along with habitat destruction (Pikitch et al. 2008).

[5] The growth in aquaculture as a means of supplying the world with a stable supply of fish has been at best, a "mixed blessing." Fish produced from these practices currently account for over one quarter of all fish directly consumed by humans. Yet for some type of aquaculture activities (notably shrimp and salmon farming), the potential damage to oceanic and coastal resources can

zones and estuaries, serve as vital nursery areas for many shark species because they provide low levels of predation and an abundance of prey like small fishes and crustaceans (Curtis 2008). Over the past 20 years the world has lost about five million Ha of mangroves, with mangroves becoming critically endangered and nearing extinction in 26 countries in 2001 (Kathiresan 2001). The loss of mangrove habitats has declined fishery resources, livelihoods, and caused biodiversity losses (Kathiresan 2001). Mangroves also serve as crucial “buffer zones” during large tropical storms and arguably the loss of mangrove forests has caused the effects of severe storms to be all the more noticeable. Unfortunately, these areas are heavily influenced by anthropogenic changes which though poorly researched, have unquestionably caused a decline in certain species that rely on these inshore habitats by causing a high juvenile mortality rate.

Inshore nursery habitats are also radically impacted by oil spills, most noticeably (and recently) the BP oil spill in the Gulf of Mexico. It is estimated that more than two million tons of oil escape into the marine environment each year. Yet, only about 15 percent of this is a result of natural seepage (Tricas et al. 1997). The impact from oil spills is most likely seen through damage to vulnerable coastal sea grass, mangrove, salt marsh, coral reef, rocky reef, and polar habitats (Tricas et al. 1997) – many areas that are essential to not only the survival of the reproductive potential of sharks and rays, but to many other marine species as well. Unfortunately, once a mangrove forest is affected by oil pollution it will take an estimated minimum of 10 years for the forest to fully recover to its pre-spill state (Kathiresan 2001). Oil is devastating to the fragile ecological community of these coastal areas as it prevents the diffusion of gases, clogs adult organisms’ feeding structures, kills larvae, and decreases sunlight available

be widespread; ranging from habitat destruction, issues of waste disposal, introducing exotic species, and increased likelihood of pathogen invasions (Naylor et al. 2000).

for photosynthesis (Garrison 2007). To date, the impacts of habitat destruction of mangroves, coral reefs, coastal areas, and other vital oceanic habitats is not widely understood, poorly researched, and overlooked in many management efforts (see Chapter 2). In the following chapter, I will address the difficulties in management efforts that sharks and their relatives currently face that make the conservation of Chondrichthyans a hard issue to implement some form of management or possible solution upon.

Chapter 2. Management Difficulties

A major difficulty in assessing shark fishery stocks and one which has prolonged effective management measures is that the number of Chondrichthyan species directly targeted in fisheries is small and therefore they have not been intensely studied as a group (FAO 2000). This apparent lack of action is the result of both the traditional low economic value of shark fisheries (when compared to Teleost fisheries) and the small volumes of shark-based products produced; while it is also in part due to the poor public images of the animals (Walker 1998; Compagno et al. 2005). Consequently, most shark fisheries around the world are virtually unmonitored and are for the most part, completely unmanaged (Compagno et al. 2005). This has led to the vulnerability of stocks to over-exploitation and which has also led to a dramatic reduction in shark populations (Baum et al. 2003). In this chapter, I will provide a background of the specific management issues facing Chondrichthyan species that have led to improper management of the species, ultimately contributing to their decline. What are these issues? How are they impacting sharks and the fishers? Chapter 2 will address the specific questions of why there are so many management issues that conservationists, fisheries, and political groups face (and furthermore need to solve) when trying to maintain sustainable populations of sharks and rays.

The Biology of Sharks and their Relatives

If properly managed, fish (as well as other biological resources) can be viewed as a renewable resource (Garrison 2007). Yet one of the major difficulties in trying to manage shark and ray populations -- like many other marine species -- is that we know so little about them. Management measures have traditionally been looking at this problem in the wrong way. As a resource, we cannot exploit Chondrichthyans to the same degree we would a Teleost species because of the radically different life histories the two groups have. Sharks and rays are particularly more vulnerable to over-exploitation because of their K-selected life history strategy (characterized by slow growth, late attainment of sexual maturity, long life spans, low fecundity, and low natural mortality) (Walker 1998; Stevens et al. 2000). It is in fact their K-selected life history that makes the dynamics of fishing shark and ray stocks actually have more in common with whales and other marine mammals -- than those of Teleost and other invertebrates (Walker 1998; Pikitch et al. 2008; Camhi 2008). Sharks produce only a small number of relatively large young that have a good chance of survival to adulthood (compared with the tiny percentage of bony fishes that develop successfully from huge number of small eggs produced during spawning) (Compagno et al. 2005). In a simple food web/pyramid, one can notice that there are relatively few top predators while there are high abundances of prey species. Large sharks that occupy the top of the marine food webs have few natural marine predators, and have adapted to produce only the very few young needed to maintain a stable population (Compagno et al. 2005). Due to their life histories and increased fishing pressures, sharks are; however, particularly at risk for extinction (Pikitch et al. 2008). As such, the first management issue that has been overseen is that we our extracting sharks and rays at a rate which we would other, more productive fishes. If this critical error continues to be ignored this could not only lead to drastic decline in Elasmobranch species, but may also lead to their extinction.

Management Issues – Migratory Species and Exclusive Economic Zones (EEZs)

As mentioned in the previous section, we know relatively little about the life history traits of most Chondrichthyan species and we are just beginning to gain an insight into the life history patterns of some species (Carrier et al. 2004; Rigg et al. 2009). As more species are being discovered, we are finding that some species of sharks and rays are actually quite social animals, with a few species living in large groups, hunting prey in packs (Compagno et al. 2005), or expressing hierarchal feeding behavior (Casey 2006). Recent research has found that some shark migration patterns are even more complex than in birds, with different journeys being carried out by mature and immature animals as well as by both males and females (Compagno et al 2005). These migrations and trans-continental journeys are massive, with blue sharks being noted as routinely crossing the Atlantic Ocean (Pikitch et al. 2008) and shortfin makos (*Isurus oxyrinchus*) traveling 5,550 km in the Pacific (Camhi et al. 2008). In her 2005 novel, The Devil's Teeth: A True Story of Survival and Obsession Among America's Great White Sharks, Susan Casey noted how upon the arrival of a killer whale pod,[6] one tagged great white shark began an nonstop route across the Pacific Ocean from California to Hawaii. More recently, in 2009 the National Oceanic Atmospheric Administration (NOAA) reported one great white swimming a total of 6897 miles from South African to Australian waters in less than 99 days. To the surprise of all those involved in the project, the shark was found back in South African waters not more

[6] Killer whales (*Orcinus orca*) are known to be one of the only "natural" predators of great white sharks.

than nine months later. Science is only just beginning to gain a basic understanding of these complex migratory and social interactions.

The problem of issuing some sort of overall-guiding management strategy for migratory species is that it is a logistical nightmare -- though some progress has been made by the Convention for International Trade in Endangered Species (CITES), conservation groups, and marine parks (note that this will be addressed further on in the study). The 370 kilometers (200 nautical miles) from a nation's shoreline constitutes that country's Exclusive Economic Zone or EEZ. Each nation with a shoreline holds sovereignty over resources, economic activity, and environmental protection within their zones (Garrison 2007). In theory, the creation of a 200 mile EEZ would make entry into fisheries a controlled process thereby reducing both the potential for overfishing and overcapitalization of fishing fleets (Christie 2006), but in some cases this is not true. As human population has increased, there has been a greater worldwide demand for fish products as a source of basic protein. Though a country has exclusive rights to fish within their EEZ, many wealthier nations can actually buy the right to fish in other countries EEZ. Since the extension of jurisdiction over EEZ by coastal states, fishery products have increased worldwide from about 60 million tons in 1970s to a highpoint of 94.8 million tons in 2000 (Christie 2006).

Sharks and rays often migrate along the coastlines of many different nations throughout their lives, with some starting at a relatively young age. This provides a particularly difficult challenge that current fishery management efforts face because where a species may be protected in one country, it can easily swim into the borders – and jurisdiction -- of a country where it is not protected and can ultimately be fished. This implies that successful conservation and sustainable use of sharks and rays as a fisheries resource requires both regional and cooperative multinational efforts (Castillo-Géniz et al. 1998; Camhi et al. 2008). Multinational efforts and cooperation is often difficult to implement as many nations have different environmental attitudes – particularly with sharks -- and their own economic agendas. If managing shark and ray populations along a country's own or bordering EEZ is a difficult task in itself, EEZs only constitute about 40 percent of the world's oceans -- meaning that 40 percent of the world's oceans are under the control of coastal countries (Garrison 2007). The remaining 60 percent of the world's oceans are deemed "high seas" and are under even more limited management.

International Management and Regional Fisheries Management Operations (RFMOs)

There has been a lack of responsibility particularly in international waters concerning management and collaboration of information regarding transboundary shark species (FAO 2000). International waters or "high seas," are all areas outside a country's 200 mile EEZ (as mentioned earlier this accounts for about 60 percent of the world's oceans). If fishery management within a country's EEZ has "some potential for management" (Pikitch et al. 2008), than in simplistic terms, fisheries management in the high seas is severely lagging. In tradition, the high seas are common property to be shared by the citizens of the world (Garrison 2007) and as such, fisheries management of the high seas does not fall into the jurisdictions of any one country as all the world's people are free to exploit it equally. Part of the difficulty in implementing some form of high seas management for sharks and rays is that oceanic ecosystems lie far from land, making it very difficult to monitor the consequences of human activities on biodiversity (Dulvy et al. 2008). Though deep sea fisheries account for only about five percent of the total marine share for fisheries (Christie 2006), the apparent lack of management for high seas Chondrichthyans makes species who occupy this marine habitat vulnerable to overfishing.

Due to excessive and relentless fishing efforts from a host of countries on the high seas and in part due to their specific life history characteristics, some species of pelagic (meaning species living in the open ocean) shark and rays are vulnerable to overfishing. Pelagic sharks are taken in international waters and by multinational fisheries, where enforcement is lacking and limits on shark fishing are non-existent (Camhi et al. 2008). The lack of regulation for high seas stock is taking a toll-- and arguably has been for sometime -- on pelagic shark species populations. For example, in a recent stock assessment of 21 pelagic Elasmobranchs it was revealed that 75 percent are at risk of extinction due to unchecked and unregulated fishing practices in the open ocean (Nance and Hearn 2008). Indeed, the proportion of oceanic pelagic sharks and rays threatened (52 percent) is considerably higher than all Chondrichthyans that are threatened (21.3 percent) (Dulvy et al. 2008).[7] As fishing of pelagic sharks continues with virtually no constraint, catch-rate data analysis is beginning to show a 45 to 90 percent decline for many pelagic sharks -- with no population showing an increasing trend (Camhi et al. 2008). This unprecedented decline means that the preservation of remaining pelagic stocks must be made a top priority of fisheries management and conservation efforts.

One such measure was the adoption of the 1999 United Nations Food and Agricultural Organization's (FAO) International Plan of Action for the Conservation and Management of Sharks (IPOA–Sharks). The IPOA-Sharks urged signing nation's Regional Fishery Management

[7] Semi-pelagic sharks face equal if not greater threats of extinction due to their tendency to congregate in inshore areas to reproduce and mature – while also utilizing open ocean areas (Nance and Hearn 2008).

Organizations (RFMOs) to produce shark assessment reports and adopt shark management plans by 2001 (Compagno et al 2005; Pikitch et al. 2008). More specifically, the IPOA-Sharks requests that fishing nations and RFMOs conduct voluntary assessments of their target and bycatch fisheries (Camhi et al. 2008). The key word here – and one which has further since hindered any real progress of the program – is voluntary. The IPOA-Sharks is largely a voluntary agreement among nations to promote conservation and sustainable management of sharks (IUCN 2008), in which nations have no real legal obligation to join or even pursue management efforts. In 2005, an entire six years after the adoption of the program, only 16 shark-fishing nations had reported that they actually produced shark assessment reports or management plans (Compagno et al. 2005). In 2008 – now a full nine years after the IPOA-Sharks was formed – only 22 of 113 shark-fishing states within the IPOA-Sharks have completed any assessment of current shark populations or any type of management plan for sharks and rays (Pikitch et al. 2008). Only half of the 113 states that reported shark landings to the FAO stated that they had "some progress" implementing the IPOA-Sharks -- which most likely does not include any management or conservation measures (Compagno et al. 2005). Progress has been so slow that that in 2004 the United Nations General Assembly (UNGA) declared that "there has been little progress with respect to the conservation and management of sharks since the IPOA-Sharks in 1999" (Camhi et al. 2008).

International fisheries instruments like the IPOA-Sharks and the UN Driftnet ban are voluntary and do not translate directly into management action or enforcement – that is left to the RFMOs and the individual fishing States to implement (Camhi et al. 2008). The IPOA-Sharks has; however, produced very significant and important documents which will ultimately help benefit both people and the species at hand -- many of which were used in this report. As such, it is not necessarily the fault of the IPOA-Sharks for its slow progress; it is actually the RFMOs of local and national governments of various States who are to blame for the failure of this management. In fact, most of the RFMOs established to manage fisheries for high seas and shared fish stocks are not specifically monitoring shark catches (they tend to focus on the more economically valuable Teleost fishes) and in 2004 none of them were managing shark fisheries (Compagno et al. 2005). Since 2004, most of the world's RFMOs have taken that first initial step toward conserving sharks and rays as most have adopted some form of finning bans and at the very minimum, most require catch statistics on Elasmobranch landings (Camhi et al. 2008). The International Commission for the Conservation of Atlantic Tunas (ICCAT) was the first RFMO to request that its member nations report shark landings from the tuna and billfish fisheries it currently oversees (Camhi et al. 2008). As addressed later on in the report, ICCAT serves as a model that other RFMOs can follow in order to implement a basic management plan for these species. Management has also improved within other RFMOs, but it may be "too little too late" (Pikitch et al. 2008). For example, the Northwest Atlantic Fisheries Organization (NAFO) was the first RFMO to adopt Elasmobranch catch limits (for the thorny skate (*Amblyraja radiata*)) in 2004. Unfortunately, as of 2008 they were the only RFMO to have an established catch limit for any shark or ray species (Camhi et al. 2008).

Management Issues with Developing Nations and Fisheries

Today, hundreds of millions of people barely have enough food to survive and thousands starve to death each year. Many developing nations rely heavily on fish as their major and traditional source of protein (Vig and Kraft 2006). The IPOA-Sharks recognizes that in some low-income, food defecite regions and countries, shark catches provide a continued source of food, employment, and income to local communities (IUCN 2008). This makes fishing for not only Chondrichthyans, but many other marine species as well, a tricky and sensitive issue to solve – or at least manage to some degree.

In 2002, there were 22 major shark-fishing nations with Indonesia, India, Spain, Pakistan, and Taiwan reporting the highest landings, accounting for 42 percent of the global landings that year (Camhi et al. 2008). Most of the shark-fishing nations without proper fisheries management are developing countries, whose fishing undoubtedly has drastic impacts for Elasmobranch stock. Take for example, the case study of Indonesia. Indonesia has the richest biodiversity of Chondrichthyans in the world, with an estimated 350 plus species (Camhi et al. 2008). Nowhere on Earth is their more biodiversity among the wide-array of Chondrichthyan species than the 17,000 islands that make up the country of Indonesia. Considered one of the worlds' most important Elasmobranch fishing nations, in 2002 Indonesia reported catches of 106,000 tons -- accounting for 13 percent of the global Elasmobranch landings that year (Camhi et al. 2008). Despite its dramatic overfishing of shark and rays, it is a way of life for the people and their culture. It is estimated that some 53 percent of Indonesia's total animal protein supply comes from fish – well above the reported global average of 16.5 percent and much greater than for developed nations such as the United States and Australia (Dutton 2006). Though sharks and rays only make up a minority of this overall protein supply, they do serve vital roles in not only the Indonesian economy, but to other nations' as well. In Mexico, finfish and sharks are the cheapest seafood available for the lower economic strata to purchase and their fisheries generate several thousand jobs (Castillo-Ǵeniz et al. 1998). Ultimately, fishers need to utilize these species for their basic forms of both income and protein.

A serious threat to the conservation of Chondrichthyans within these nations and one that has to be addressed is that they lack the economic and scientific resources for effective fishery-based research and management. Conservation of biodiversity is largely unregulated in waters of developing countries and the scale to which it is regulated depends on the capacity and willingness of the coastal state to monitor or limit the exploitation of marine resources (Zeeberd et al. 2006). While many developing States are more focused on political and economic stability, fisheries research, especially Elasmobranch research, is not a top priority. The scientific basis for data collection and analysis is also frequently inadequate, as the data requirements for catch quotas are particularly difficult to meet for developing States (Christie 2006). In 2000, developing countries, like Indonesia, had virtually no data on the status of individual Elasmobranch stocks (Stevens et al. 2000). Though the situation has improved since then, little species-specific or fishery-specific data are available from areas of the highest catch rates (Stevens et al. 2000). The lack of species-specific and stock-specific data, as well as other crucial life-history data is not only an issue that bestows itself upon developing nations, but is in fact a global issue found even within the most developed of nations, like for instance, the U.S.

Management Issues - Lack of Science, Basic Biology, and Life History of Species

As mentioned previously in the study, sharks and rays have historically been less economically valuable when compared to Teleost species. Largely because of their generally low economic value and the low volume of sharks in fisheries (compared to Teleost species), fisheries research for shark and ray species is virtually non-existent in many countries (Stevens et al. 2000; Compagno et al. 2005). Despite being demonized as “man eaters” and their current alarming rates of exploitation, we still know very little about the biology and behavior of sharks and their relatives, as it is only recently that we are gaining an insight into the life history patterns of some species (Carrier et al. 2004; Rigg et al. 2009). To date, there is not a lot of species-specific data on various sharks and rays. Little information currently exist on individual species migration patterns, reproductive ages, longevity (Compagno et al. 2005), and as new species of Chondrichthyans are continually being discovered, scientists do not even know the exact number of extant species (Personal Observation). Many argue that it wouldn't be surprising to discover that some deep sea sharks may well be immature until they reach 40 years old or more and that they could potentially live for over 100 years (Compagno et al. 2005).

The underlying issue that surrounds this whole problem of overfishing, bycatch, habitat modification, and effective management is that we really do not have basic information on many species and as such, how can we effectively manage Elasmobranch stock? For example, of the 53 percent of extant shark species with sufficient data for an IUCN assessment, 17 shark species are considered threatened (i.e. critically endangered, endangered, or vulnerable) and 36 percent are in lower risk categories (i.e. near threatened or of least concern). If data-deficient species are excluded, then 32 percent of shark species are threatened and 68 percent are at lower risk. There is currently insufficient data to determine the status of 47 percent of shark species (Heupel and Simpfendorfer 2010). "Data deficient," according to IUCN, means that "available information is insufficient to produce an assessment" (IUCN 2008) and does not necessarily mean the species is threatened; it simply means there is not enough data available on the species. The number of sharks in the IUCN data-deficient category is; however, the largest proportion for any vertebrate group, which highlights the need for further collection of biological, ecological, distributional, and genetic data (Heupel and Simpfendorfer 2010) in order to produce accurate stock assessments of the species for fisheries management.

To date, the greatest shark research priorities are to improve understandings of their biology and ecology, critical habitats, population structure, age and growth, reproduction and life history, and trends in catches per unit effort (Compagno et al. 2005). At James Cook University's

Fishing and Fisheries Research Centre, I worked on age and growth projects for a variety of Elasmobranch species including the blacktip reef shark (*Carcharhinus melanopterus*), white-spotted guitar fish (*Rhinobatos albomaculatus*), and the giant shovelnose ray (*Rhinobatos typus*). Age and growth studies are critical to proper fisheries management as they provide assessments of the status of exploited stocks and help to predict that particular stock's capacity of recovering from periods of overfishing (Cailiat and Goldman 2004; McAuley et al. 2006; Heupel and Simpfendorfer 2010). In his 2005 report, *Age and growth in Elasmobranch fishes,* Kenneth Goldman notes that these studies determine the life history of species by determining biological processes such as productivity, reproduction cycles, yield per recruit, prey availability, habitat suitability, and feeding behavior. Age and growth studies can even determine the mortality rates among individuals in a specific stock (Heupel and Simpfendorfer 2010). This data is deemed essential to determining whether current fishing levels are sustainable; while also helping to develop a strategy to conserve and manage shark populations (Pikitch et al. 2008). Data collection efforts – and the concurrent management associated with these efforts -- are; however, limited in that species-specific data is often hard to determine as well as to collect across many different fisheries and that many nations simply cannot afford age and growth studies.

Under-Reported and Issues with Shark Identification

Due to the historical low economic value of sharks and their relatives in many countries, there have been poor baseline data collection efforts concerning species identification among fishers (Stevens et al. 2000). Most shark catches generally do not get reported or have been reported as "unidentified sharks" instead of being properly identified by their species name (Pikitch et al. 2008). As mentioned previously in Chapter 1, this poses a significant threat for the species at hand (and management efforts targeted at certain species) because we do not even know what sharks or rays are being exploited. Certain Elasmobranch species are indeed very hard to differentiate from one another while some, to the untrained eye, are virtually indistinguishable when compared to a similar species and can only be properly identified by looking at variations in teeth structure (Personal Observation). As such, the lack of species-specific data poses a significant challenge to quantify the impacts of exploitation and may even “mask” Elasmobranch decline (Dulvy et al. 2008).

More countries than ever before are reporting shark landings, though many nations have no data on shark catches prior to the mid-1990s, and species level reporting is still inadequate (Camhi et al. 2008). Indeed, only 15 percent of all catches are reported to the FAO at a species level (Dulvy et al. 2008). Taking this into account, the available data we have are very limited in that, as mentioned previously, the actual catch of Chondrichthyans throughout the world’s oceans may be twice as high. In 2002 for instance, only 26 percent of the Chondrichthyan catches in the Atlantic, 11 percent in the Pacific, and seven percent in the Indian Ocean were identified to species levels (Camhi et al 2008). In order to have effective fisheries management, we need to know how many sharks of each species are being killed and in what fisheries (Pikitch et al. 2008). The most reliable method for obtaining this information involves the long-term use of scientific observation onboard commercial fishing vessels during their operations to record accurate data (Hazin et al. 2008). This would be perhaps, the most effective way of ensuring that accurate recordings and measures are carried out and yet, funding for this type of fisheries research is not usually a high priority in most countries, especially in developing States. As such, fisheries data must come from the fishermen and their landing data (however inaccurate or underreported it may be) (Christie 2006).

The practice of shark finning is the largest reason why it is often difficult to identify species caught in fisheries back on the mainland. Most of the time when a shark or ray is landed, the fins are removed at sea and body is discarded. With only the fins being brought to market, proper identification is often very difficult (Stevens et al. 2000). Even when an intact carcass is brought back, the process of properly identifying a shark is further complicated as the shark may be headed, gutted, or finned (Stevens et al. 2000). This particular issue was made of special note of in Clarke et al.'s 2006 study, *Identification of Shark Species Composition and Proportion in the Hong Kong Shark Fin Market Based on Molecular Genetics and Trade Records.* In their study, Clarke et al. determined that most fins – within the world's largest shark fin market, Hong Kong -- are not labeled properly and that many fins were clumped together under a single name, despite being from a wide variety of sharks and rays. Using genetic sampling of fins, many experts have come to the conclusion that pelagic species such as the oceanic white tip (*Carcharhinus longimanus*), big eye thresher (*Alopias superciliosus*), silky shark (*Carcharhinus falciformis*), blue shark (*Prionace glauca*), other thresher shark species (*Alopias* sp.), and hammerhead shark species (*Sphyrna* sp.) make up the bulk of the fins sold in the global shark fin trade (Dulvy et al. 2008). It is estimated that pelagic sharks account for one-third of the fins traded in the Hong Kong market and yet, experts have routinely been only able to identify 54 percent of these shark fins (Camhi et al. 2008). Most of these species listed are pelagic sharks, meaning that like hammerhead species, many are highly migratory and may be subject to relentless fishing pressures by a host of countries. As such, management efforts should be largely concerned with protecting these species as they are particularly vulnerable to finning.

Genetic sampling was effective in the previous study, but generally techniques for genetic sampling require expensive and time consuming procedures which are usually not suitable for routine monitoring or surveillance (FAO 2000). One also has to take into account that many less developed countries are without adequate fisheries information gathering systems in the first place. Though funding for proper fisheries research in these countries should be a high priority, there may be a cheap, effective way of at least recording what species are caught. Many suggest that accurate field guides be prepared to enable species identification from whole animals, carcasses, and if possible, for fins, skins, vertebrate, and heads (FAO 2000). Providing fishers with species and regional specific field guides would be an excellent start if also structured with better educational initiatives and perhaps, more funding from developed nations. In the next chapter, I will look into the validity of the two primary arguments that are used amongst scientists and conservationists as to why people should not eat, let alone overfish Elasmobranchs and discuss how these arguments may impact current fishing and educational efforts.

Chapter 3. Why Sharks Deserve to Live

In the previous chapters I have examined the declines in shark populations as a result of three major human-induced factors and I have discussed the management difficulties concerning the wide-array of species filed under the singular names of “shark” or “ray.” In Chapter 3, I will be addressing the arguments which many conservationists, scientists, and policy makers have made regarding the importance of sharks in maintaining healthy fish populations throughout every ocean. Many sharks and rays are undoubtedly “keystone” species and in this section I will examine the ecological roles they play and how they shape their ecosystem – as well as ours; while highlighting the impacts these top predators have in marine environments. I will also be looking at the current impacts overfishing has on not only on the Elasmobranch species at hand, but to other economically important fisheries for humans. I then go on further in this chapter to address the issues of human consumption regarding sharks fins and flesh.

Apex Predators

Sharks have evolved throughout millions of years to become seemingly the perfect predators in their environment. Throughout countless years of evolutionary adaptation, some species of sharks have become apex predators in a wide-variety of marine environments (Walker 2005). As relentless fishing pressure increases on Chondrichthyan fishes (as discussed in Chapter 1 and Chapter 2), we are beginning to notice dramatic reductions in population size and diversity of Elasmobranchs throughout the world's oceans (Rigg et al. 2009). Though the ecological impact of such as wide-spread and large-scale removal of the ocean's top predators is poorly understood (Camhi 2008), the effects of overfishing these species can result in: changes in abundance, size, stock structure, life history parameters, rebound potential, and in some cases, can ultimately lead to their extinction (Stevens et al. 2000; Christie 2006).

The removal of apex predators has been demonstrated to profoundly impact some marine ecosystems (Pikitch et al. 2008). As a top predator, sharks have a fundamental influence on the structure and function of marine communities (Heithaus et al. 2008). If left unchecked or unmanaged, the long-term impacts of over-fishing apex shark species can cause a "cascade" of adverse trophic interactions by causing an ecological release (also known as a "competitive release") of meso-predator species populations (Myers et al. 2007; Heithaus et al. 2008), which may also cause apparent species replacement and shifts in community compositions (Stevens et al. 2000; Zeeberg et al. 2006; Camhi 2008). The removal of top-predatory sharks can also alter the composition of benthic assemblages and increase the abundance of smaller fishes at lower trophic levels (Ceccarelli et al. 2006) -- further disrupting the ecological balance of marine ecosystems that have taken millions of years to evolve. Sharks and rays are essential to a healthy marine ecosystem and their prodigious removal has a "destabilizing effect" on ecosystems making them more vulnerable to other natural and anthropogenic disturbances (Friedlander and DeMartini 2002).

The Cost of Overfishing Elasmobranchs

The impact of overfishing sharks and rays is far-reaching and not only effects marine species, but it directly impacts nation's economies. In Indonesia for example, it is estimated that the economic losses from all sources of reef degradation and overfishing are at some US $\$410,000/km^2$ per year (Dutton 2006) (though overfishing of Elasmobranchs accounts for only a fraction of this estimation). When fishers remove sharks from their environment it does not necessarily mean that their prey animals will increase, resulting in improved yields of other fish species in fisheries; rather, the reduction of Elasmobranchs may instead result in an apparent decline of other economically important species (Compagno et al. 2005). In their 2007 report, *Cascading effects of the loss of apex predatory sharks from a coastal ocean*, Myers et al. examined the impacts of the loss of large predatory sharks in the Northwest Atlantic and the impact this would have on local scallop fisheries. With no large, apex predatory sharks to help reduce their abundances, small ray and skate populations began to grow exponentially. As a result, many species – notably the cownose ray (*Rhinoptera bonasus*) -- increased its predation on bay scallops, eventually causing a collapse in the century-long scallop fishery (Myers et al. 2007). Research surveys throughout the U.S. Eastern seaboard indicate that a rapid decline in the abundance of 11 large shark species has resulted in the concurrent "release" and increases in 12 Elasmobranch mesoconsumers (Heithaus et al. 2008). Stevens et al. noticed a similar effect in their 2000 report, *The effects of fishing on sharks, rays, and chimeras (Chondrichthyans) and the implications for marine ecosystems*, where in Tasmania, the reduction of local shark populations --as a direct result of overfishing -- caused a dramatic and unchecked abundance of local octopus species which severely depleted local crayfish fisheries. In these two prominent examples, the removal of top predators from marine ecosystems can harm -- if not destroy -- the economic viability of important commercial fisheries. Hence, this further proves the economic importance of maintaining healthy large shark and ray populations.

Smaller Sharks

Overfishing of Chondrichthyans can directly affect population status and may even cause a reduction of mean body size in some species (Camhi 2008). Fishermen tend to remove the largest of the species first (as they are most profitable) and then work their way down the food chain catching smaller species (Stevens et al. 2000). As a result of these pressures, we are noticing a steady decrease in the length of sharks over the years, which is a clear indication that over-exploitation is beginning to leave a long-lasting and telling effect (IUCN 2008). In her novel, The Devil's Teeth: a True Story of Obsession and Survival Among America's Great White Sharks, Susan Casey noted how researchers were beginning to notice that the larger great whites, the "sisters" as the researchers called them, were becoming far rarer and indeed harder to find. Instead, researchers began noticing a larger abundance of smaller great whites. The effect of overfishing on shark size was noted over time in Campana et al.'s 2000 study, *The rise and fall (again) of the porbeagle shark*. In their study, Campana et al. noted that a biological indicator of high exploitation rates is a long term decline in the fork length (the length from the tip of the snout to the distinct fork in the tail) in the catch of porbeagle shark (*Lamna nasus*) between 1960 and 2000 in the Northwest Atlantic (Campana et al. 2008). Indeed, it seems that over this 40 year period there has been a dramatic decline in the fork length of porbeagle sharks (Figure 1).

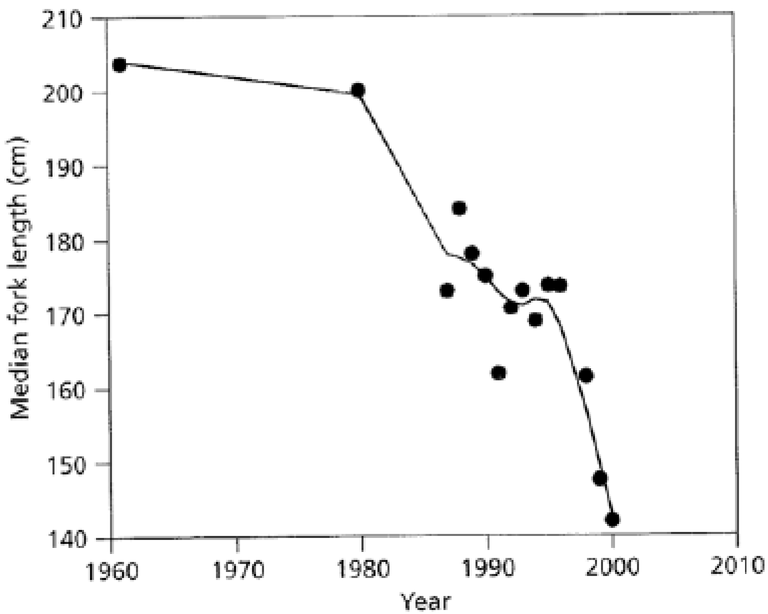

Figure 1. The results of Campana et al.'s 2008 study. The graph shows the reduction of median fork length measures (cm) of *L. nasus* over a 40 year period as a result of overfishing in Newfoundland mating grounds (Campana et al. 2008)

The ecological impacts of having smaller sharks are unknown, but in terms of an economic sense, a smaller shark (and a resulting smaller fin) is worth less (Personal Observation). This could ultimately harm the economic stability of not only the fisheries involved, but to the entire shark fin market. As such, overexploitation of shark and ray populations is not in the best interest of: the conservationists, the fishermen, the shark fin markets, scientists, and most especially, the sharks and rays themselves.

Mercury

Mercury is a potent neurotoxin that is especially dangerous to fetuses and growing children, as well as harmful to pregnant mothers, in whom it can create severe developmental neurological problems and can potentially be deadly (Vig and Kraft 2006; Garrison 2007). Humans are exposed to mercury emissions from medical and municipal waste incinerators, electrical power plants, chlorine chemical manufacturing plants, and iron and steel plants which recycle automobile parts (Vig and Kraft 2006). The major unregulated source of mercury is coal-fired electric-generation facilities, which in the U.S., discharge 40 percent of the nation's mercury air emissions – about forty-eight tons a year (Vig and Kraft 2006). Through natural processes, mercury emissions often make their way into water sources, where as methyl mercury, it becomes concentrated in the tissues of large predatory fish and marine mammals (Garrison 2007). Originally, mercury finds itself in small phytoplankton and other small plant-like organisms; however, when these organisms are in turn eaten by larger prey, the concentrations of the pollutants increases again (usually by 10 times), and so on up the food chain through a process called "bioamplification" (Tricas et al. 1997). Sharks, as well as many tuna and swordfish species are currently listed as seafood to "avoid" under Monterey Bay Aquarium's Seafood Watch due to "concerns about mercury and other contaminates" (Monterey Bay Aquarium 2011). Though one would have to eat large concentrations of shark fin and meat to become poisoned, it nevertheless is a threat to human health which should encourage consumers to at least limit shark within their diet – if not eliminate it completely. In the following chapter, I will examine the critical question that is underlying throughout this entire report and is a matter that needs to be properly addressed if we are to manage and protect these species: can exploitation of sharks and rays be sustainable?

Chapter 4. The Sustainability of Shark Fisheries

Too often fishery managers and the public have this perception that these wide-ranging, trans-oceanic migrants are immune to overfishing (Camhi et al. 2008). This perception is unfounded given the biology, apex predatory status (and the resulting smaller populations), the apparent overfishing, and the lack of proper management that are unique to Chondrichthyan species. Many experts; however, believe that sustainable fisheries for these species are possible provided that exploitation of their stocks proceeded slowly enough to allow the populations to recover (Walker 1998; Stevens et al. 2000; Musick 2005). Yet, over the past several decades it's "obvious that fisheries for Chondrichthyan species have not been easily sustainable" (Cailiet and Goldman 2004). To make this issue further more complicated and as mentioned previously in this report, data on shark catch landings, discards, and mortality are often lacking and rarely to recorded to the species level – thereby limiting scientists and resource manager's ability to determine what is in fact, as sustainable level of fishing for these species (Camhi et al. 2008).

What makes implementing a sustainable fishery management plan difficult for policy makers and to further see carried out regarding these species is that there is, and cannot be, no "one size fits all" policy for effective management. Indeed, generalizing across shark populations is not possible given their wide diversity, varied life history, and variable movements and distribution (Heupel and Simpfendorfer 2010). For instance, some fast growing, early maturing, relatively short lived, inshore coastal species can be exploited more sustainably than larger, slow-growing, less fecund species that live in colder environments because they have a higher rebound potential (Walker 1998; Stevens et al. 2000). Proper management would require intense study of the unique life history characteristics of species and -- as mentioned previously – these studies are often few and far in between -- as it is only recently that the conservation of

Chondrichthyan species has become an important topic to scientists, resource managers, politicians, and to the general public (Heupel and Simpfendorfer 2010).

. Only a handful of fast growing, fecund species are able to be fished sustainably (Campana et al. 2008). Some small coastal shark species begin to reproduce at as little as two or three years old (Compagno et al. 2005) and as such, more of the population can be removed without causing substantial and irreversible damage to the stock. In Southern Australia for example, it is estimated that around five to six percent of the gummy shark (*Mustelus antarcticus*) can be taken each year without any serious threat to the population (Tricas et al. 1997). Yet, exploitation at this rate could not be sustainable for a species like the soupfin shark (*Galeorhinus galeus*), which is known to reach ages of over 50 years and in which no more than two or in some cases, three percent, of the population can be removed each year if the population is to remain stable (Tricas et al. 1997). This; however, has not been the case as historically local populations of the soupfin shark, like the porbeagle shark, have been extirpated by targeted-fisheries (as mentioned in Chapter 1). Proper management and conservation should be on a case-by-case assessment (Heupel and Simpfendorfer 2010); and yet, to go one step further, management of each specific stock has to vary in order to see that exploitation occurs at an appropriate rate. For example, certain populations of the blacktip reef shark (*Carcharhinus melanopterus*) can produce four "pups" a year or they can produce five to six live pups every other year (A. Chin and J. White Personal Correspondence). In this case, a species-wide management plan would not be effective because in theory, a population that produces four pups each year will, over time, produce more offspring. As such, if both populations were filed under the same management –and had the resulting same levels of fishing pressures—the blacktip reef shark stock that gives birth every two years would ultimately be depleted. In order to have effective management to ensure the long-term sustainability of shark and ray species, one would have to acknowledge an individual stock's unique life history patterns – regardless if it is of the same species.

To further ensure that exploitation remains sustainable, a species' "catchability" has to be determined. A species' catchability is both the result of the fishing gear used and based on the particular species unique biology (Personal Observation). Due to the hammer-shaped head of hammerhead shark species (*Sphyrna* sp.) and the rostral teeth protruding from a largetooth sawfish (*Pristis microdon*), these two species are more susceptible to become entangled in nets, stressed, and eventually die when compared to other species -- which has ultimately lead to severe depletions of both species (A. Chin and J. White Personal Correspondence). Due to their biology and preferred habitat settings, pelagic and semi-pelagic sharks are more likely to encounter a gill net or a baited longline and therefore have a higher catchability in these fishery types than species who rest on the seabed, like angel sharks (*Squatina* sp.) and dogfish (*Squalus* sp.). It is due to the placement and gear type used, that pelagic Elasmobranchs are subjected to high and often unrestricted levels of bycatch from non-targeted fisheries (Dulvy et al. 2008). Conversely, bottom dwelling species are more vulnerable to falling victim in demersal trawling fisheries than Carcharhiniformes and Lamniformes (Walker 1998).

Species Vulnerable to Extinction

Throughout the majority of this report, I have discussed how various specie types have different life history traits and are therefore, affected differently by fishery pressures due to their biology, their habitat preference, the fishing gear deployed, and the susceptibility of each species to bycatch or habitat modifications. Coastal species seem to be threatened more by loopholes in

EEZ policy and coastal development; while pelagic shark-types are threatened due to longline fisheries and their migratory nature, making them the targets of high seas fishing operations; and most species are often victims of unregulated bycatch. Indeed, the resilience of a particular species to fishing pressures depends both on its vulnerability and its production (Stevens et al. 2000) and yet, unregulated fishing pressures has caused the numbers of Chondrichthyans to dwindle. Many species are threatened, with some, like the largetooth sawfish, facing ecological extinction (Personal Observation). In this next section I will address the ever-present threat that all too many species face: extinction.

Of the 133 marine invertebrate, vertebrate, and known algae populations that have gone locally, regionally, or globally extinct in the past 300 years, 64 were marine fishes, of which 32 were sharks and rays. Taking into consideration that sharks and rays only account for about five percent of all marine fishes, the fact that half of the extinct populations were Elasmobranchs is alarming (Pikitch et al. 2008). Yet, many Chondrichthyans are listed as "Least Concern" or "Near Threatened" – two categories deemed as "Lower Risk" – by the IUCN Red List of Threatened Species (IUCN 2008).[8] Those deemed as at a "Lower Risk" of extinction, are Elasmobranchs that have either fast, resilient, life histories or are species with a slower, less resilient life history, but are subjected to fisheries management such as the salmon shark (*Lamna ditropis*) (Dulvy et al. 2008). Species that are of higher risks of extinction include deep water sharks, sharks restricted to freshwater, and coastal endemics whose entire range is subjected to high levels of fishing effort (Compagno et al. 2005). In their 2010 report, *Science or slaughter:*

[8] Though the IUCN Red List confers no official protection status, it is effective as serving as a "red flag" which can help initiate or improve conservation and management for species listed (Camhi 2008).

the need for lethal sampling of sharks, Heupel and Simpfendorfer concluded that there are indeed some species of sharks that are in dire need of conservation action and improved fishery management; however, this does not apply to the majority of shark species. Many species might not be currently threatened, but if the shark fin market continues growing at its expected rate of 6.1 percent per year (Camhi 2008) and bycatch continues to go unregulated and unmonitored, those species which may be at present, resistant to fishing pressures may very well become overfished. All three thresher sharks (*Alopias* sp.), the white shark, the oceanic whitetip shark (*Carcharhinus longimanus*), the porbeagle shark, and both species of mako shark (*Isurus* sp.) are currently listed as globally vulnerable. As of 2008, virtually nothing is known of the status of pelagic stingrays (Camhi 2008).

The deep sea off the edge of the continental shelf is the most recent fisheries frontier, where fishers and now targeting deep sea sharks (Compagno et al. 2005). To date, we know very little about the biology of deep water sharks (Stevens et al. 2000) and deep sea fishers are not only exploiting unnamed and unknown species never seen by a scientists, but they could also be driving species to extinction before they can even be described (Compagno et al. 2005). Due to the low energy environment in which these species inhabit and their extremely slow growth rates, any exploitation of deep sea Elasmobranchs is not sustainable under current fishing efforts and should cease immediately to ensure the survival of the species.

Conclusion

Chondrichthyan species are threatened by a wide-array of factors including commercial fishing ventures for their highly valued fins, falling victim to accidental bycatch, while having vital nursery grounds destroyed due to anthropogenic development and pollution. Due to the reproductive characteristics of Elasmobranchs, these groups of fishes are vulnerable to intensifying anthropogenic threats and impacts (Snelson Jr. et al. 2008). These species have persisted throughout major extinctions, with a select few evolving throughout time to be the top predators in the world's oceans. Their intrinsic biodiversity value and long evolutionary history, indeed provides strong arguments for appropriate management and conservation of these species (Dulvy et al. 2008). Current human-induced declines in shark and ray species are unsustainable, as we are putting relentless pressure on Elasmobranch stocks from a wide-variety of threats. As such, management of Chondrichthyan species for sustainable use requires much stronger commitments to fishery monitoring, biological research, and management of fishing efforts (Walker 1998).

One of the recurrent issues throughout this thesis is that we are overfishing a very diverse group of species that to date, we still know very little about. For most species improved information is required on critical habitats, size, sex composition of catches, species' "catchability" from various fishing gear, and gear selectivity with respect to understanding the biological traits of the shark or ray (Walker 1998). Perhaps even more importantly, we need to know how many sharks of each species are being killed and in what fisheries (Pikitch et al. 2008) in order to apply effective management. We know so very little about the biology, behavior, migration routes, and the stock structure of most species that there is a dire need for more research on various species and their habitats. If more data could be collected and used to elucidate patterns of movement, it may be possible to enact short-term spatial and temporal closures in an attempt to manage stocks, which could limit fishing to those specific times and places where species are in large, healthy abundances (Hazin et al. 2008).

Lack of data; however, should “not be used as an excuse for management inaction” (Camhi et al. 2008). Current management measures should be concerned with incorporating a “precautionary approach” towards fisheries management for most shark fisheries. A precautionary approach means that fisheries are only conducted when detailed stock assessments are available and when there is detailed and effective monitoring and management of fisheries (Compagno et al. 2005). The precautionary approach to conservation and management is also embraced when fisheries data are insufficient or unreliable (FAO 2000) – as is the case for many Elasmobranchs, especially in developing States. When faced with such uncertainties, managers are required to ensure that exploitation is conducted at a minimal level (FAO 2000). Though a precautionary approach may be impossible in the majority of large shark fishing States due to ineffective management and legal enforcement (Compagno et al. 2005), it would be in the best interests of both man and shark to apply such an approach. If a precautionary approach is not an applicable approach, then those countries should adopt an “ecosystem approach” to fisheries management -- where management is considered not only for the conservation of the target species, but to all species belonging to the same ecosystem or dependent on the target species (FAO 2000). To apply any of these approaches; however, many developing shark fishing States will need to considerably rely on resources and collaborative efforts from developed nations. If current rates of exploitation continue to go unchecked, many ecological and economically important Elasmobranch species will fall victim to extinction. As a result, many other commercially important species will decline as well. Sharks and rays provide a balance in our oceans. Arguably, a world without these species would inevitably come back to haunt us and as such, these species are in dire need of conservation, scientific efforts, and proper fisheries management if we are to insure their survival – for their sake and for ours.

Chapter 5. Recommendations

There are many different issues one encounters when trying to implement some type of conservation and fisheries management plan concerning Chondrichthyan species. On the one hand, these species serve essential roles in their environments and without sharks or rays, arguably there would be a collapse of vital marine ecosystems – making the preservation of this species a must. On the other, one also has to take into account that countless people rely on fishing sharks and rays as their principal source of income and means of support. The issue here then, is primarily concerning the sustainability of the stock in a way in which both man and species can benefit from in the long-term. As I have mentioned previously throughout this report, the three principal causes of this wide-spread decline in shark and ray stock are the result of current fishing efforts for fins, accidental bycatch, and habitat destruction. In this section, I will propose personal recommendations which may serve as effective means to reverse, or at least stabilize, the decline of shark and ray populations. By drawing on specific scientific publishing and successful policy measures, I will examine what are indeed the best solutions out there to limit and even reduce the decline of these species.

The Use of Marine Protected Areas as "Safe-Havens" for Chondrichthyan Populations

My first recommendation to ensure proper management and the long-term sustainability of Chondrichthyan species is the incorporation of Marine Protected Areas (MPAs) and marine reserves as a way to limit fishing mortality. Marine reserves are a particular type of MPA in which exploitation is prohibited and illegal (Smith et al. 2005). Long seen as an important part of marine conservation, by eliminating fishing pressure in a particular area, a marine reserve allows biomass within the no-take area to rebuild overtime (Smith et al. 2005). Indeed, the biological responses within a marine reserve appear to develop quickly and last through time; making them an increasingly popular alternative to traditional fishery management (Halpern and Warner 2002). In their 2002 study, *Marine reserves have rapid and lasting effects*, Halpern and Warner conducted 112 independent empirical measurements of 80 different reserves and found that on average, values of all biological measures that they tested for were higher inside the marine reserve when compared to a reference site.[9] Their findings were so promising that they estimated that population densities inside the reserve were 91 percent higher, biomass was 192 percent higher, and average organism size being 20 to 30 percent higher on average when compared to areas outside the jurisdiction of a marine reserve (Halpern and Warner 2002).

As promising as marine reserves seem for the preservation and protection of vital stocks, they may also prove to be in the best interests of the fishers targeting not only Chondrichthyans, but also other species as well. As mentioned previously, marine reserves reduce fishing mortality and allow for stocks to rebound from fishing efforts. Over time, populations will rebound so much so that they will begin to "spill out" of the reserve and into the surrounding area (Smith et al. 2005). This phenomenon is known as the "spillover effect" in which a non-fished and off-limits population may provide stability to an exploited population by bringing in new recruits to the fished stock (Friedlander and DeMartini 2002). If one "source" population which is off-limits to fishing pressures is continuously replenishing a "sink" or exploited population, in theory, the sink population can always be fished. This is because there is a stable stock of individuals that are free from fishing pressures. The spillover effect has made many believe that the creation of

[9] In Halpern and Warner 2002, the reference site was either the same site before the area was created into a reserve or a location neighboring the current reserve.

MPAs and marine reserves is an effective means to conserve shark populations -- especially in areas where sharks are vulnerable to capture and other human activities (Walker 2005).

One place where the use of MPAs and marine reserves seems to be working is in Glovers Reef, Belize. Glovers Reef was highlighted in Erik Olsen's 2010 *New York Times* article "Hope for Sharks and Reefs in Belize" as an ideal representation of how the use of marine parks can be effective for both sharks and for other species. Glovers Reef is Belize's largest no-take marine reserve in which the coral reefs outside the reserve are heavily fished (Olsen 2010). As a result of the closure, Belize is seeing an increase in shark populations not only within the no-take zone, but in other areas of the reef. By closing a part of the reef from fishing, the off-limits population is growing and repopulating the remainder of the reef -- a prime example of the "spillover effect."

When creating a reserve, policy makers, fishery managers, and local governments need to focus on determining a location that will ultimately best serve a species' long-term survival. I suggest that the creation of these reserves should focus on the protection of vital nursery grounds and areas where the reproductive potential of a stock are known to congregate. Nursery areas are usually characterized by the simultaneous presence of gravid females and free swimming juveniles (Castillo-Ǵeniz et al. 1998), often referred to as "young of the year" individuals (A. Chin and J. White Personal Correspondence). Nursery areas should be considered of paramount importance for any management plan for sharks (Castillo-Ǵeniz et al. 1998) as it is imperative that the juveniles and the associated reproductive potential of population are protected (Cortés 2007). If the reproductive potential of a population and the young of the years were to be extirpated from a region it could dramatically impact the longevity and success of a stock. For example, Cleveland Bay, Townsville, Australia has been identified as a major shark nursery ground in which a wide-range of species use (Simpfendorfer and Milward 1993). Though Cleveland Bay is considered a marine reserve, juveniles in this area are particularly vulnerable to being caught in gill-nets (Personal Observation). If large-scale fisheries were allowed within the bay, due to the high susceptibility of the young of the years to netting, these fisheries could easily wipe-out a particular stock under relentless fishing pressure. In terms of the older individuals, many Elasmobranchs have sites where they aggregate for mating or use for migration routes. It is also important to identify these sites and routes as they might need special protection from fishing through the use of closed areas or closed seasons to protect the reproductive potential (FAO 2000).

Despite Dr. Ellen K. Pikitch's[10] claim that "parks do work for sharks, they are actually effective at keeping populations stable" (Olsen 2010); many would argue that the effectiveness of these reserves depends on the life history traits of the target species, current fishing pressures, and proper enforcement within the reserve from management authorities. In his 2006 documentary, *Sharkwater*, Rob Stewart repeatedly exposes illegal long-lining, finning, and other fishing practices being undertaken within established marine reserves. Stewart's documentary shows that the effectiveness of marine reserves may be limited to management difficulties in terms of a particular country's ability to limit and restrict illegal fishing practices. Many also suggest that closing off fishing areas for seasons or permanently must be economically feasible (Zeeberg et al. 2006) and that areas must be thoroughly investigated to avoid merely displacing (and potentially increasing) fishing effort in sensitive areas (Smale 2008). This issue is further made more complicated by the lack of species-specific and catch-landing data available at

[10] Dr. Pikitch is a Marine Biologist at the Stony Brook University of Marine and Atmospheric Sciences (Olsen 2010).

present for most species. In determining the efficiency of marine reserves one also has to examine the fishing pressures and the degree at which exploitation has occurred –which influences a species ability to rebound and the potential success of a reserve (Halpern and Warner 2002).

. Though management difficulties may hinder the long-term success of a reserve, many believe that the long-term gains from a marine reserve outweigh the losses resulting from the reduction in the fishing area (Smith et al. 2005). From my experience reserves seem effective at protecting a wide-array of species when properly enforced. The selection of future reserves should be focused primarily on the areas where young of the year are present and where reproductive individuals tend congregate. While effective in doing so, marine reserves are useful management strategies which provide protection for both target and non-target species. As such, the implementation and creation of more marine reserves is beneficial for marine species, but as stated previously, they may also be beneficial for the fishers. Perhaps the largest criticism regarding marine reserves is that they are only effective at reducing bycatch on the rare case when target and non-target species separate spatially (Erickson and Berkley 2008). The long-term sustainability of Chondrichthyans will need to thus be based on efforts both to preserve vital habitats and in limiting bycatch – an issue addressed in the next section.

Bycatch Reduction: Implementing Turtle Exclusion Devices (TEDs) and other Gear Selectivity as Effective Measures to Limit Bycatch

Given the current concern over the rates of shark exploitation globally, it seems unwise not to examine the potential of bycatch reduction management strategies (Hazin et al. 2008). In order to preserve current stocks and limit the overwhelming large numbers of Chondrichthyans killed each year as a result of accidental bycatch, my second recommendation is to focus on creating ways to limit shark mortality in non-target fisheries. To date, there are currently few existing methods to reduce Elasmobranch bycatch (Rigg et al. 2009) and yet, millions of sharks and rays are killed and seemingly discarded as a result of bycatch each year. Accidental bycatch is an issue that affects countless species such as sea turtles, various Teleost species, and even marine mammals. For instance, it is estimated that within the U.S. Gulf Coast shrimp fishery, four pounds of bycatch is discarded for every one pound of shrimp caught (Garrison 2007). Bycatch is also a hindrance on the fishers themselves as it has direct monetary benefit for the fishers. When species are caught as a result of bycatch it increases what is called "robbing time" for fishers in which additional time is spent removing the bycatch from the gear – time well otherwise spent fishing for their target species (Rigg et al. 2009). Bycatch may also damage fishing gear (such as creating large tears in netting) causing additional –and unwanted -- expenses to the fishers (Personal Observation). It is then in the best interests for both marine species and fishers to implement fishing practices which limit bycatch.

As a means of limiting bycatch, one such option is the development of modifications to the current fishing gear being used in non-target fisheries (Hazin et al. 2008). Most large-scale commercial fisheries involve some heterogeneity in their gear choices (Smith et al. 2005) and the implementation of bycatch reduction devices to these fisheries have already seen promising results. The use of Turtle Exclusion Devices (TEDs) has proven to be beneficial in reducing bycatch for many shark and ray species (Zeeberg et al. 2006). TEDs, which guide pelagic megafauna deflected by a large filter to an escape route along the bottom of the trawl, are now mandated for shrimp fishing vessels in U.S. territorial waters (Garrison 2007). Extremely effective, some studies suggest that TEDs may be able to achieve a 40 to 100 percent reduction of bycatch of vulnerable megafauna (Zeeberg et al. 2006).

Some studies suggest that the most promising approach for mitigating bycatch is to exploit the difference between the sensory organs in Teleost and Elasmobranch species (Rigg et al. 2009). Sharks and rays have a strong electro-sensory system that relies on the receptors in jelly-filled sensory organs called the ampullae of Lorenzini (Compagno et al. 2005), that are lacking in Teleost species. Located around the head or the mouth, the ampullae of Lorenzini are capable of responding to thermal, mechanical, and electrical stimuli (Rigg et al. 2009).[11] In their 2009 study, *Do elasmobranch reactions to magnetic fields in water show promise for bycatch mitigation?* Rigg et al. investigated the use of magnetic fields generated by ferrite magnets as a means of reducing Elasmobranch bycatch in gillnets without reducing the target Teleost catch. Using three magnetic blocks suspended in the water column in a laboratory setting, Rigg et al. tested whether or not the use of magnets can initiate a reaction response – in this case avoidance -- in Elasmobranchs. In their study they noticed that the Elasmobranchs seemed to overwhelmingly avoid the magnets so much so, that the team further concluded that "the application of magnets worldwide to mitigate bycatch of Elasmobranchs appears promising" (Rigg et al. 2009). Furthermore, there was no recorded decline in the catch rate of Teleost species.

The use of magnetic fields as a means to mitigate bycatch seems to be an effective measure; however, widespread use of this method has its difficulties which will need to be addressed. As it was only tested in a laboratory setting, this method needs to be tested extensively in a field setting, where the effects of the magnet may be less potent and therefore less likely to generate an avoidance behavior out of the Elasmobranch species. In their study,

[11] Many researchers believe that sharks and rays are able to navigate long migration routes by detecting the Earth's magnetic field using this organ (Compagno et al. 2005).

Rigg et al. noticed that adding magnets to a net may affect the buoyancy of the net by adding additional weight (Rigg et al. 2009). The attachment of large magnets onto fishing gear may also make fishing gear all the more difficult to properly maintain. In spite of potential difficulties with this method, Rigg et al. also proposed the idea of a pulsing magnetic force throughout the entire net -- an intriguing solution to help spread the magnetic force and its effects throughout the net. The idea of using magnets to limit bycatch seems like a promising solution that should be a large focus of current research initiatives aimed at reducing Elasmobranch bycatch.

Though the use of magnets seems to be promising for limiting bycatch in net fisheries, there may be an even easier and more cost-effective way to reduce shark mortality in other fisheries. High seas longline fisheries account for as much as 80 percent of the Elasmobranch catch by weight (Camhi 2008) and as such, we should not only innovate new technologies to reduce bycatch in net fisheries, but also in non-target longline fisheries. In their 2008 study *Methods to reduce bycatch mortality in longline fisheries*, Erickson and Berkley used the implementation of hook timers to record the precise moment when a fish would strike a baited hook to the time a species could remain on a singular line before it would ultimately give in, and die. Each of Erickson and Berkley's longlines were "soaked" for 20 hours in which they noticed that the mortality of pelagic fishes increased with greater time spent hooked on the longline (Erickson and Berkley 2008). What was most significant about their study is that they determined that mortality varied by species, ranging from 100 percent within 12 hours for swordfish to only 30 percent of sharks after 12 hours (Erickson and Berkley 2008). As long as there is enough length on a line for a shark to pass water over its gills, an Elasmobranch can survive for a longtime on a line – though it is never in the best interest for the shark to be caught in the first place (Personal Observation). Erickson and Berkley then go on to suggest that if fishers were to find the “optimal duration” (i.e. significantly less than 20 hours as there was a 100 percent mortality in sharks at this time) it may increase the survival of bycatch species; while maintaining the catch of the target species.

Creating an “optimal” fishing time does appear like an overall cost-effective and easy way to reduce the mortality of sharks on pelagic longlines, but there are still a few concerns that may limit the success of implementing a time quota in which fishing gear is allowed in the water. The first is that it would be extremely difficult to convince fishers to haul in their gear a full, say eight hours earlier than a full 20 hour “soak” time. Simply put, the more time a baited hook is in the water, the more likely it is to catch something. Secondly, though this method seems effective in keeping the Elasmobranch alive, it does nothing to prevent them from being hooked in the first place. As such this method does nothing to reduce initial bycatch or the effects of an increased “robbing time” for fishers. Finally, the enforcement of a legal “soak” time would be hard to bring about as many longline fisheries operate illegally (Stewart 2006) and legalities would only apply to those State-recognized fisheries. Nevertheless, this study does appear promising in the sense that if fisheries managers and RFMOs could enact policies to limit soak times to 12 hours –as compared to 20 hours -- then there would be an increased survivorship amongst shark species caught in these fisheries.

Perhaps the most simplistic way to decrease bycatch of Chondrichthyans in non-target fisheries is to merely modify the existing fishing gear. Indeed, gear adaptation may be of lower cost (than implementing management policies) and has proven effective as such with TEDs (Zeeberg et al. 2006). In the second part of their 2008 study, Erickson and Berkley noted that bait type is one of the most important gear parameters for species selectivity in longline fisheries (Erickson and Berkley 2008). In their study, they showed that artificial bait fished as well as (or in some cases better than) natural baits for target species; while at the same time, the use of artificial bait significantly reduced the amount of Elasmobranch bycatch (Erickson and Berkley 2008). When paired together, the idea of producing species-selective bait and reducing soak times of longlines will increase the likelihood of these animals being released in a stable, living condition (Camhi et al. 2008). Wide-spread use of these methods does seem to be very promising, but more experimentation is needed in order to find the best option available. In order to be successful, much more research needs to be carried out on this matter. Even the subtlest modifications in fisheries gear may influence the catch rate of shark (Hazin et al. 2008) and yet; however, some modifications can ultimately cause an increase in non-target bycatch if not properly tested.[12]

Sharks and rays are the most significant bycatch species (by both weight and numbers) in pelagic longline and net fisheries in offshore domestic waters and on the high seas (Camhi 2008). Consequently, perhaps the most promising way of eliminating, or at least reducing Elasmobranch bycatch, may be a combination of all the methods that have been reviewed in this section: the implementation of TED’s in net fisheries, the use of magnetic fields, reducing soak times, and the adoption of artificial baits. I propose that as bycatch is largely unregulated and a “chaotic” source of Elasmobranch mortality, that this issue be made a top-priority in current scientific research and fisheries management measures. Limiting Elasmobranch bycatch may be one of the most cost-effective solutions to preserving current stocks; even though the distinction between targeted and bycatch fisheries is becoming increasingly “blurred” as more and more fisheries are transitioning to targeting sharks seasonally (or even in some cases daily) when their traditional target is less abundant (Camhi 2008). In the following section, I will make my final

[12] Camhi et al. 2008 noted how one study found that the implementation of circle hooks may actually increase the likelihood of blue shark (*Prionace glauca*) bycatch.

recommendation which will address this issue, as well as issues to limit fishing efforts on Chondrichthyans, by endorsing current policies to eliminate the act of "shark finning" once and for all.

An End to "Finning": Seeking Effective Policy Measures to Prohibit and Restrict the Practice of Shark Finning

The act of shark finning has been widely criticized by conservationists and governments as a wasteful, irresponsible, and cruel process (Camhi et al. 2008). In my personal opinion finning is "the be-all and the end-all" for many Chondrichthyan species. Though, as I have listed above and have presented throughout this report, many different factors have led to the global decline of shark species, the act of fishing sharks for their fins is widely-regarded as the biggest threat to their longevity to date (Personal Observation). Millions of sharks are killed each year for a bowl of soup. As mentioned previously, in total, shark fins only account for five percent of the entire animal and yet only the fine collagenous fibers – which support the fin margin – make their way into a bowl of shark fin soup (Musick 2005). The overwhelming small proportion of shark meat that actually makes its way into a bowl of shark fin soup makes this practice seem utterly wasteful.

Due to recent fishing pressures for their fins, sharks and rays have been overfished to the point where the survivorship of many species has come into doubt. Though fins provide a stable source of income for fishermen, especially in many countries where a stable income may be hard to come by, I argue that it is ultimately in the best interest of fishermen to stop overexploiting many stocks and many select species (see Chapters 3 and 4). From a fisheries management perspective, finning is likely to result in unsustainable fishing mortality (Camhi et al. 2008). Sharks that are finned are often done so alive, while having their body discarded overboard, to eventually bleed-out or drown to death. By only storing the fins, fishermen can kill many more sharks per trip than when the whole carcass is retained, hence increasing their overall profit (Camhi et al. 2008).

Thanks in part to the works of current conservationists groups, scientific research, and increased media attention, most notably Rob Stewart's film *Sharkwater*, finning has come under multinational scrutiny which has caught the attention of policy makers. Many national governments are invoking finning bans, which prohibit the retention of shark fins on board vessels without the corresponding carcass (Dulvy et a. 2008). My final recommendation to help combat the current unsustainable decline of Elasmobranchs is the wide-spread illegalization of shark finning by national governments. It should be noted that I am not saying shark fishing should be made illegal, instead I am proposing that the act of removing fins at sea should be illegal. Finning bans curb mortality and reduce waste (Dulvy et al. 2008) and as the whole carcass has to be brought into port, less individuals will be killed as there is less space on board a vessel. Furthermore, sharks retain urea in their blood to control osmosis. When a shark dies the urea in their blood breaks down and gives the carcass the characteristic smell of ammonia (Last and Stevens 2009), which may "spoil" the meat of other fish when in close proximity (Stewart 2007). With the implementation of finning bans not only will fewer sharks be killed in theory, but I would argue that more fishermen would be discouraged to engage in the act, especially those who also partake in multispecies fisheries – as it may be detrimental to the value of their target catch.

The illegalization of finning shows promise and measures to ban or at least, limit finning, have been enacted in varying degrees by nations such as: Australia, Brazil, Canada, Costa Rica, Ecuador, Egypt, the European Union, Israel, Namibia, Nicaragua, Oman, Palau, South Africa, and the United States (Pikitch et al. 2008). In 2010, the Shark Conservation Act was passed in the United States Congress which serves as an amendment to the High Seas Driftnet Fishing Moratorium Protection Act. Signed into law by president Barack Obama on January 4, 2011, the Shark Conservation Act specifically prohibits that any vessel in U.S. territorial waters to; (1) remove any shark fin (including the tail) at sea; (2) have a fin aboard a fishing vessel unless the fin is naturally attached to the carcass; (3) transfer a fin from one vessel to another or receive a fin unless it is naturally attached; or (4) land a fin that is not naturally attached to a carcass or land a carcass without fins naturally attached (Govtrack.us 2011). The Shark Conservation Act is a promising start to help preserve species within the U.S. territorial waters. Hawaii; however, has gone a step further than the Shark Conservation Act and has passed Senate Bill 2169. This bill makes it "unlawful for any person to possess, sell, offer sale, trade or distribute shark fins" (SB No. 2169 2010). Restaurants have until June 30th, 2011 dispose of their fin inventories in Hawaii, with penalties of possessing a shark fin accounting anywhere between US $5,000 to US $15,000 for a first offense alone (SB No. 2169 2010). As of this writing, similar bills have introduced in the state legislatures of California, Oregon, and Washington State and are currently awaiting approval.

Many RFMOs are also beginning to implement finning bans within their fisheries in international waters. In 2004, the International Commission on the Conservation of Atlantic Tunas (ICCAT) passed the first resolution banning finning in international waters by all ICCAT member nations (Pikitch et al. 2008). In 2005, similar resolutions were passed by the General Fisheries Commission of the Mediterranean (GFCM), the Inter-American Tropical Tuna Commission (IATTC), the Indian Ocean Tuna Commission (IOTC), and the Northwest Atlantic Fisheries Organization (NAFO), and in 2006, by the Southeast Atlantic Fisheries Organization

(SEAFO) (Pikitch et al. 2008). Though enacting finning laws is a great start to limiting Elasmobranch mortality as a result of shark finning, the act of illegal shark finning operations will still occur. As such, proper enforcement of these laws is needed if we are to ensure that they are being carried out appropriately. Shark finning laws may also be limited in terms of their effectiveness in many developing States and I suggest that developed nations and RFMOs put more pressure on these States to create and implement some form of these laws on their own. This; however, cannot be achieved unless there is multinational efforts to help developing States adopt and implement these measures in order to allow for the sustainable use and the perseverance of the species.

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