7-27-2017

# Shark Bycatch in Commercial Fisheries: A Global Perspective

Stephanie M. Bettis
sbettis91@gmail.com

## NSUWorks Citation

Stephanie M. Bettis. 2017. *Shark Bycatch in Commercial Fisheries: A Global Perspective.* Capstone. Nova Southeastern University. Retrieved from NSUWorks, . (331)
https://nsuworks.nova.edu/cnso_stucap/331.

HALMOS COLLEGE OF NATURAL SCIENCES AND OCEANOGRAPHY

# Shark Bycatch in Commercial Fisheries: A Global Perspective

By
Stephanie Bettis

Submitted to the Faculty of
Halmos College of Natural Sciences and Oceanography
in partial fulfillment of the requirements for
the degree of Master of Science with a specialty in:

Marine Biology

Nova Southeastern University

07/29/2017

# A Capstone Paper

Submitted in Partial Fulfillment of the Requirements for the Degree of

# Masters of Science:

# Marine Biology

Stephanie Bettis
Nova Southeastern University
Halmos College of Natural Sciences and Oceanography

July, 2017

Capstone Committee Approval

Dr. Mahmood Shivji, Major Professor

Dr. Brad Wetherbee, Committee Member

# TABLE OF CONTENTS

1. Abstract……………………………………………………..………..……………4

2. Introduction……………..……..………………………….……….……………..5

3. Bycatch……………….…………………………………..…….…………………7

a. Definition and Background Information……..………………….………………7

b. Longline Fisheries…………….………………......…………………………9

c. Gillnet Fisheries……………………...….………………………………14

d. Trawl Fisheries…………………………….…..…………………..…..15

e. Purse Seine Fisheries…………………………….………………………16

4. Data Gaps………………………………………………...………………………..17

5. Sharks Most at Risk……………………..……………………………………..…18

6. Current Options for Bycatch Reduction………………………………………21

7. Conclusion…………………………………………………………………….26

8. Literature Cited…………………...……………………………………………..…29

## *Abstract*

Many shark species have global distributions and are caught incidentally in different types of fisheries. Over the last two decades, shark populations have declined tremendously, with one of the leading causes of this decline bycatch in primarily teleost fisheries. Bycatch occurs throughout the world's fisheries, but is not well documented in terms of species composition and numbers of each species captured. Information on shark bycatch is spread through the primary and grey literature, but has not been compiled in summary to date. The goal of my capstone is to present global shark bycatch data and provide a comparative review to determine fishery types that affect shark populations and identify shark species at risk as a result of bycatch. Longline fisheries caught a larger variety of shark species, and the post-release mortality was generally low. In contrast, trawl fisheries caught mostly the same few species, but post-release mortality was extremely high. Blue sharks (*Prionace glauca*), silky sharks (*Carcharhinus falciformis*), and spiny dogfish (*Squalus acanthias*) were caught most often in trawl fisheries, and in large numbers that likely adds to risk of overexploitation of their populations. This literature review revealed a severe lack of standardization in bycatch data reporting by different fishing nations, and in documents prepared by management agencies and scientists, including the definition of bycatch used and the way it was recorded. Establishing a universal definition of bycatch and standardizing its reporting would vastly improve ability to assess the scale and composition of shark bycatch and its impacts on shark populations. Systematic and standardized accounting of shark bycatch would provide information helpful for collaboration among regulatory agencies. Rather than simply document bycatch, a number of fishing gear alterations show promise for bycatch reduction and are worthy of integration into fisheries by managers. Additional important steps that can improve bycatch assessment is increased observer coverage in fisheries, marine protected areas, and making bycatch data public.

## *Keywords*

Elasmobranchs, incidental catch, post-release mortality, fishing mortality, finning, bycatch reduction, trophic cascade, worldwide shark catch

## *Introduction*

Sharks occur in all the world's oceans, occupying benthic to pelagic ecosystems. Most fishery exploited sharks exhibit K-selected life history characteristics such as late age at maturity, low fecundity, slow growth, and long gestation periods, making them highly vulnerable to fishing pressure (Romanov 2002; Baum et al. 2003; Walker et al. 2005; Barker and Schluessel 2005; Mandelman et al. 2008; Thorpe et al. 2009; Blaber et al. 2009; Baeta et al. 2010; Benjamins et el. 2010; Lyons et al. 2013; Dapp et al. 2013; Passantino 2014; Hutchinson et al. 2015; Eddy et al. 2016). In addition, many shark species aggregate by sex, size or reproductive stage, putting entire demographic groups at risk from fishing (Barker and Schluessel 2005; Gilman et al. 2016). These typically large bodied sharks are often keystone species assumed to play important roles as meso- or apex predators in ecosystem function and long-term stability (Myers et al. 2007; Dulvy et al. 2008).

With intensive removal of sharks by fisheries, two major community-level responses may occur: Other high trophic level predators may take the place of sharks at the top of the food web, resulting in little to no trophic cascade effects (Gilman et al. 2016). Alternatively, if no other predators fill the gap, top down trophic cascades may occur (Gilman et al. 2016). However, studying such trophic effects are difficult due to a lack of reliable long-term data and a lack of understanding of ecosystem dynamics (Grubbs et al. 2016). The difficulties of determining trophic cascades in the wild have led to controversial papers on the subject. A notable case: a trophic cascade was proposed after a fishery-caused decline in the abundance of several species of sharks off the eastern central United States. Myers at al. (2007) documented that large bodied, coastal sharks in this region had declined by about 90% between 1970 and 2005, while their mesopredator prey species had increased exponentially (known as mesopredator release). One such mesopredator species that increased substantially was the cownose ray (*Rhinoptera bonasus*), which preys on bivalves, resulting in subsequent large declines in the regional scallop population. This decline in scallop abundance, in turn, is blamed for collapse of the east coast scallop fishery (Myers et al. 2007). Furthermore, Myers et al. (2007) also hypothesized that the hyper-abundant cownose rays would potentially damage seagrass habitats while foraging for other bivalve species in response to the shortage of scallops, which in turn could remove critical fish nursery areas, thus exacerbating top-down trophic cascades. However, Grubbs et al. (2016) refuted this trophic cascade with several key points. Cownose ray population increases do not line up with the decreases in shark and scallop abundances to be attributed to a trophic cascade (Grubbs et al. 2016). Furthermore, the cownose ray diet consists primarily of small crustaceans and polycheates rather than scallops and so would not be responsible for the large decline in east coast scallops regardless of their population increases (Grubbs et al. 2016).

While field studies of trophic cascades can be difficult and controversial, ecosystem modeling is a helpful alternative. Both types of ecosystem responses were found in ecosystem modeling studies utilizing reef associated sharks in the French Frigate Shoals (Ferretti et al. 2010). Upon simulating a decline in medium-sized reef sharks which mainly function as mesopredators, there was little effect found on the ecosystem, posited by the authors as likely a result of other predators taking the place of the reef sharks in the food web. However, when the study authors simulated a decline in apex predator tiger sharks there was an increase in their prey including seabirds, turtles, monk seals and smaller reef sharks, followed by a rapid decline in commercially important tuna and jacks. This response is typical of top-down trophic cascades. The trophic cascade caused by the decline in tiger sharks was attributed to the increase in monk seals and smaller reef sharks, which prey on jacks and tunas.

Similar to the Frigate Shoals result, Ferretti et al. (2010) also found that ecosystem models that simulated a local loss of all large sharks around Floreana Island in the Galapagos resulted in an increase in toothed cetaceans and a decrease in commercially valuable reef fishes. The decrease in reef fishes also caused an increase in small invertebrates in the area, demonstrating a four level trophic cascade and altering the dynamics of the local ecosystem (Ferretti et al. 2010). These empirical and modeling studies suggest that with sharks being over-exploited in large numbers globally, top-down trophic cascades may occur more frequently, potentially putting many ecosystems and fisheries at risk.

Relatively few fishing nations have management regimes in place for elasmobranchs, despite population declines over the last two decades due to heavy exploitation from directed fisheries and to a large extent bycatch in teleost fisheries (Beerkircher et al. 2002; Baeta et al. 2010; Cosandey-Godin and Morgan 2011; Oliver et al. 2015). Over 18% of elasmobranchs are now listed as Vulnerable, Endangered, or Critically Endangered on the IUCN Redlist (Gilman et al. 2016). The number of sharks caught incidentally is difficult to quantify due to under or lack of reporting from different nations, but bycatch is believed to be one of the leading causes of shark population declines globally (Hall et al. 2000; Cosandey-Godin and Morgan 2011; Brodziak and Walsh 2013; Jordan et al. 2013; Oliver et al.2015). This paucity of records is because many countries only require the reporting of fish species landed, and since bycatch is often discarded given no commercial value it is therefore unrecorded (Field et al. 2009; Molina and Cooke 2012). This lack of reliable data makes shark bycatch difficult to manage, presenting challenges in enacting and enforcing regulations. Furthermore, the lack of data also presents significant difficulties for fisheries managers in identifying geographic problem areas and providing targeted solutions. Although some countries have produced regional fishery assessments of shark bycatch (Anderson 2013; NOAA Office of Science and Technology 2014), to date, there has been no global-scale characterization of shark bycatch. Given this information gap, my Capstone paper will aim to provide a global perspective of shark bycatch prevalence and its impacts by surveying the published literature on shark bycatch data across multiple commercial fishery types.

The specific objectives of this Capstone is to 1) provide an overview of the published shark bycatch data, 2) identify fishery types with high shark bycatch and shark species that comprise the majority of bycatch , and 3) recommend possible solutions for bycatch reduction to inform shark conservation and management efforts.

### *a. Bycatch Definition and Background Information*

To discuss bycatch, the term first needs to be defined. The use of a diversity of definitions of bycatch is a common problem in the fisheries literature, making elasmobranch bycatch especially difficult to quantify. A number of sources define it as all animals caught that are not the target species (Stobutzki et al 2002; Romanov 2002; Campana et al. 2009; Cosandey-Godin and Morgan 2011; Dapp et al. 2013; Jordan et al. 2013; Cosandey-Godin et al. 2015; Favaro and Coté 2015; Oliver et al. 2015). Other studies limit the definition of bycatch to all non-target species landed, disregarding those that are discarded at sea (Kotas et al. 2012). Still others define it as any non-target species that is not commercially valuable, or not retained (Hall et al. 2000; Walker et al. 2005; Campbell and Cornwell 2008; Cedrola et al. 2012). Worse, much of the literature does not provide any definition of bycatch.

It is also important to ensure that the standardized definition of bycatch is communicated to the fishing community. There is currently a disconnect between what scientists and fishery managers regard as bycatch and what the fishers who are recording the data regard as bycatch (Davies et al. 2009). Fishers are more likely to consider any species that has commercial value as target catch rather than as bycatch despite being caught incidentally. As different species become commercially valuable, less species are considered as bycatch by the fisher and recorded as such, while managers and scientists are still considering the species as bycatch. This lack of a standardized definition between all parties can make management of incidentally caught sharks and comparison of data across fisheries and studies difficult (Davies et al. 2009). The ability to compare data collected by different countries is important because many exploited shark species are highly migratory and their ranges often stretch over multiple national management jurisdictions. In addition, sharks have a wide-ranging post-release mortality rate of 6-100%, depending on the species (Musick et al. 2000; Campana et al. 2009; Eddy et al. 2016). Therefore, only recording sharks landed does not give scientists and fisheries managers an accurate idea of how the non-landed component of incidentally caught sharks is affecting shark population dynamics. For this paper, I use the most common definition of bycatch found in the literature, which is all non-target species caught, whether discarded or landed.

Elasmobranch bycatch in fisheries around the world has become one of the main sources of population declines (Cosandey-Godin et al. 2013; Dapp et al. 2013; Favaro and Coté 2015). Juvenile sharks are caught in large numbers in purse seine and trawl fisheries, contributing to long-term declines in populations that may not be immediately apparent (Stobutzki et al. 2002; Campbell and Corwell 2008; Blaber et al. 2009; Kotas et al. 2012; Poisson et al. 2014; Hutchinson et al. 2015; Eddy et al. 2016). Furthermore, recent studies show that sharks caught today are smaller on average than those caught in past decades, indicating structural demographic changes in populations in response to fishing pressures (Baum and Myers 2004; Barker and Schluessel 2005; Dudley and Simpfendorfer 2006; Bustamante and Bennet 2013; Hutchinson et al. 2015; Gilman et al. 2016). A shift to smaller sizes could diminish a shark's role as top predator, which would change the food web dynamics of the ecosystem (Dapp et al. 2013; Gilman et al. 2016). There is an urgent need, therefore, to reduce bycatch to avoid creation of a demographic size shift so large that sharks are essentially removed from their functional roles as meso- and apex predators in their communities.

Fishers worldwide experience some type of shark interaction. Sharks are caught incidentally in a number of fisheries, with most bycatch occurring in longline, gillnet, and trawl gear fisheries (Stobutzki et al. 2002; Jordan et al. 2013). In addition to causing direct population and ecosystem impacts, incidental shark catch can also be deleterious to fishers. When sharks are not retained for economic use, removing them from the fishing gear can be both costly and dangerous to fishers (Campbell and Cornwell 2008; Jordan et al. 2013; Cosandey-Godin et al. 2013; Torres-Irineo et al. 2014; Favaro and Coté 2015). Sharks caught incidentally increase time and effort to remove from the fishing gear, can destroy gear, and take up gear space or hooks that the target species could have otherwise taken (Campbell and Cornwell 2008; Jordan et al. 2013; Cosandey-Godin et al. 2013; Torres-Irineo et al. 2014; Favaro and Coté 2015). When sharks are retained, they take up space on the boat and can cause fishers to take more trips (Campbell and Cornwell 2008). Finally, the ecological changes caused by a reduction in shark populations can also impact fishers by indirect means. A decrease in shark populations can cause trophic cascades resulting in changes to the quality and productivity of ecosystems that support a multitude of other economically important species. (Barker and Schluessel 2005; Myers et al. 2007; Baeta et al. 2010; Dapp et al. 2013; Cosandey-Godin et al. 2013; Torres-Irineo et al. 2014).

### *b. Longline Fisheries*

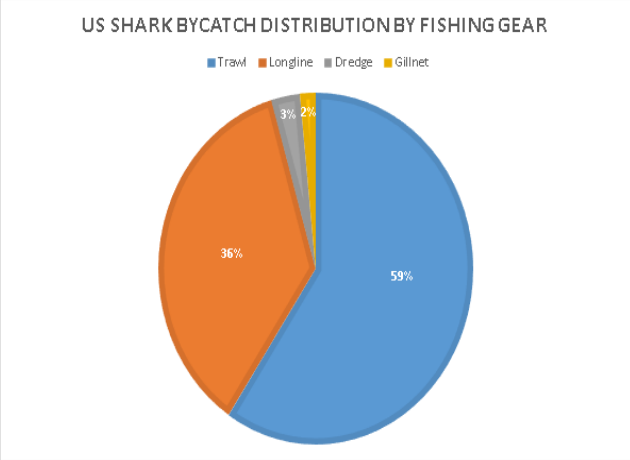

*Figure 1 - U.S. Shark Bycatch by Fishing Gear. The U.S. trawl fisheries make up nearly two-thirds of the total shark bycatch. The other one-third occurs in the longline fisheries, with <5% occurring in gillnets and dredges. (NOAA 2014)*

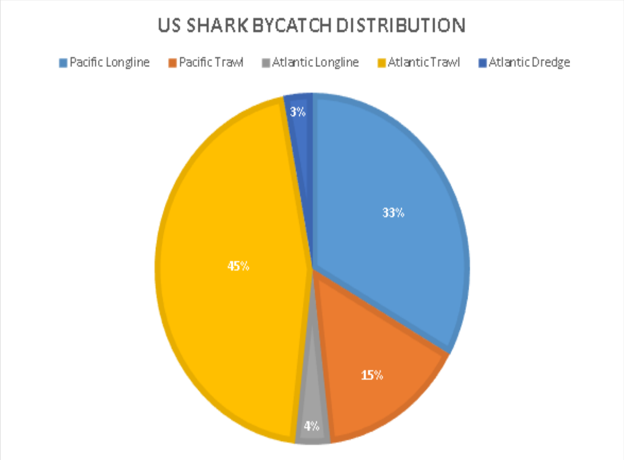

*Figure 2 - U.S. Shark Bycatch Distribution based on gear type in the Pacific and Atlantic Oceans. The shark bycatch is evenly distributed between the Atlantic and Pacific Oceans, with 52% occurring in the Atlantic and 48% in the Pacific. Nearly half of the bycatch comes from the Atlantic Trawl fisheries, while one-third comes from the Pacific longline fisheries. (NOAA 2014).*

Longline fisheries present one of the highest risks to sharks (Favaro and Coté 2015). Longlines are used in both pelagic and coastal fisheries, with bottom longlines often used

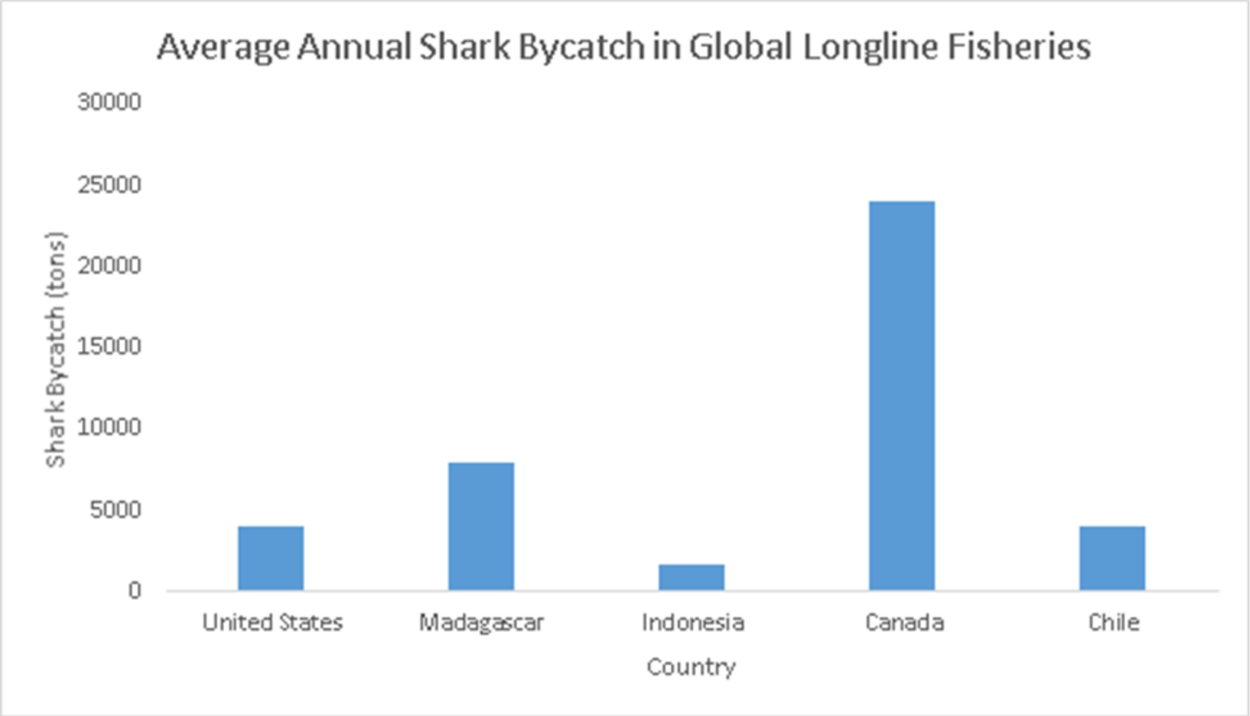

*Figure 3 - Average Annual Shark Bycatch in Global Longline Fisheries. Available global shark bycatch data for longline fisheries are plotted above. Canada catches considerably more sharks than the other countries listed. Indonesia, despite landing more sharks than any other nation, reports the least amount of shark bycatch in their longline fishery than the other nations. (Campana et al. 2009; Blaber et al. 2009; Le Manach et al. 2012; Bustamante and Bennett 2013; NOAA 2014).*

for targeted fishing and pelagic longlines used primarily to target other migratory species such as tuna and swordfish. Being non-selective gear, it is no surprise that sharks which occupy the same habitat as the target pelagic teleosts are incidentally caught. In the U.S. fisheries alone, pelagic longlines make up one third of all shark bycatch reported (Figure 1) (NOAA 2014). Most of the shark bycatch in the United States longline fisheries occur in the Pacific Ocean (Figure 2) (NOAA 2014). Overall, across countries that require shark bycatch data collection, these data are reported to management agencies by fishery observers or fishers directly, but are not always complete or accurate. For example, bycatch is known to be significantly underreported in the Hawaiian pelagic longline fishery (Brodziak and Walsh 2013). Inaccuracies in the data reported result from the fact that fishery observer programs are costly and therefore limited in coverage. It is notable that Lewison et al. (2004) reported that just between 13-37% of fisheries worldwide had observer coverage.

The United States, despite having a large biomass of shark bycatch, does not lead fishing nations in reported longline fishery shark bycatch (Figure 3). The combined Western and Central Pacific tuna longline fisheries have caught an estimated 2 million sharks each year since 1992 (Lawson 2011). A key finding, however, is that most fishing nations, including the U.S., underreport their shark bycatch (Mandelman et al. 2008; Baum and Blanchard 2010; Dapp et al. 2017). Additionally, much of the fishing worldwide is illegal or unreported and there are relatively few management regimes in place to protect sharks. For example, Madagascar’s waters are dominated by foreign vessels fishing for tuna and believed to be discarding bycatch without reporting. Of the reported shark bycatch in Madagascar waters, foreign vessels catch about 4300 tons of sharks per year, with domestic fishers reporting about 3,800 tons of sharks per year. Together, at least 8,000 tons of sharks are fished from Madagascar waters each year as bycatch in the longline fishery alone (Le Manach et al. 2012).

The Spanish swordfish surface longline fishery in the Indian Ocean reported 4,436 tons of sharks caught as bycatch each year between 2004 and 2006, accounting for 41% of the total catch. Blue sharks alone made up most of the shark bycatch, reaching three million sharks caught incidentally in 2006 (Ramos-Cartelle et al. 2008).

Indonesia lands the largest amount of elasmobranchs worldwide at over 100,000 tons, of which 11% (11,000 t) is reported as bycatch. About 15% of this bycatch occurs in the Indonesian pelagic tuna fisheries. A rough estimate of 1,670 tons of sharks are caught as bycatch in the Indonesian longline fisheries each year. With little to no management strategies in place for sharks, as well as having one of the largest elasmobranch targeted fisheries, Indonesia is one of the largest contributors to overfishing of shark populations (Blaber et al. 2009).

Canada is another fishing nation with a large amount of shark bycatch. The combined US and Canadian pelagic longline swordfish fishery in the northwest Atlantic caught 71,000-93,000 tons of blue sharks (*Prionace glauca*) per year between 2000 and 2006. About one third of this is attributed to Canadian efforts, with Canadian longline fisheries in the North Atlantic catching an estimated 24,000 tons of blue shark bycatch per year. The shark catches in this fishery made up over 30% of the total catch by weight. The mortality rate during those years ranged from 30-44% a year, resulting in 7,200-10,560 tons of dead blue sharks (Campana et al. 2009; Cosandey-Godin et al. 2013). Between 1990 and 1999, an estimated 250 tons of sharks were caught annually as bycatch in the Canadian Atlantic, demonstrating that shark bycatch has increased exponentially in Canada (Campana et al. 2005). Chinese longline observers have reported only 27 tons of sharks caught as bycatch in ICCAT waters in 2007 (Dai et al. 2009). While this is a small number, it is only a small portion of Chinese shark bycatch. China does not report shark landings to FAO (Food and Agriculture Organization) and does not monitor or manage sharks, leaving the true shark bycatch unknown (Lam and Mitcheson 2011).

There are a number of smaller longline fisheries around the world that also contribute to the overall global shark bycatch. For example, the New Zealand tuna longline fishery was estimated to catch 2,700 tons of sharks as bycatch between 1996-1998 (Francis et al. 2001). New Zealand catches many blue sharks in their tuna longline fishery, making up 30-50% of the total catch (Francis et al. 2001; Campana et al. 2009; Campana et al. 2009). Chile has experienced a large biomass of shark bycatch ranging from 237 tons/year to 4,082 tons/year for some species (Bustamante and Bennett 2013).

For those fisheries that report shark bycatch as number of individuals, the bycatch tends to be less than those fisheries that report shark bycatch by weight, but is still substantial. The tuna and swordfish longline fisheries off the coast of South Africa reported 39,000-43,000 sharks killed each year between 1995 and 2005 (Petersen et al. 2009). The Taiwanese tuna longline fishery catch 7,800 sharks each year as bycatch, making up over 4% of the total catch (Huang and Liu 2010). The Venezuelan tuna and swordfish longline fishery observed 1,895 sharks caught as bycatch between 1994 and 2000 (Arocha et al. 2002). The southern Portugal longline fishery caught over 1,300 sharks as bycatch between 2003 and 2004 (Coelho and Erzini 2008). Costa Rica recorded 3,600 sharks caught as bycatch between 1999 and 2010, many of which were juveniles. This large portion of bycaught shark juveniles in the Costa Rican fisheries indicates fishing was occurring in potential nursery areas. While less than 4,000 sharks caught in a ten-year period is a relatively small number, catching juveniles before they have had a chance to breed could significantly reduce later populations (Dapp et al. 2013). As K-selected species, shark populations are quick to decline but slow to recover, making shark nurseries a priority for protection (Gilman et al. 2016).

Finally, although the number of sharks incidentally captured are not accurately or fully reported by most nations, there are many other countries with bycatch in their longline fishery. Sharks comprised over 70% of the total catch landed in the Spanish Atlantic longline fishery targeting pelagic teleosts (Cosandey-Godin and Morgan 2011). Sharks also comprised 16% of the South African longline fishery in 2005, and 25% of the Fiji tuna longline fishery in 1999 (Cosandey-Godin and Morgan 2011). The Japanese tuna longline fisheries catch a large amount of elasmobranch bycatch, of which 59% is composed of blue sharks alone (Campana et al. 2009). India reportedly caught 131 tons of sharks in 1997, most of which was bycatch (Barker and Schluessel 2005). The huge amount of bycatch in Hawaiian pelagic fisheries had a notable impact. Between 1999 and 2010, the Hawaiian pelagic longline fishery showed a 90% decrease in the catch-per-unit effort numbers of oceanic whitetip sharks (*Carcharhinus longimanus*), resulting in this species officially declared in 2012 as overfished in the Pacific (Brodziak and Walsh 2013).

Despite the large amounts of bycatch in the various longline fisheries, the mortality rates for sharks in this fishery type, although highly variable by species (Beerkircher et al. 2002; Gallagher et al. 2014), are overall among the lowest of the different fishery types due to lower stress levels experienced by the sharks (Brooks et al. 2012; Hyatt et al. 2012). Immediate mortality (haulback mortality) is considered mortality that occurs before the sharks have been brought on deck for processing (Dapp et al. 2017). Post-release mortality is the mortality that occurs once the shark has been released. Both types of mortality are relatively low for many sharks caught as bycatch in longline fisheries. When sharks are caught and their movements restricted, their bodies switch to anaerobic metabolism causing a build-up of lactate and $H^+$, resulting in high levels of stress and ultimately death (Hyatt et al. 2012; Dapp et al. 2013). Most of the time, when sharks are caught on longlines, they are still able to swim for a while and do not switch to anaerobic metabolism immediately. This results in a smaller build-up of lactate and $H^+$ (Brooks et al. 2012; Hyatt et al. 2012; Dapp et al. 2013). Thus, longlines generally have a lower immediate and post-release mortality than gillnets and trawls that restrict the mobility of sharks when caught (Brooks et al. 2012; Hyatt et al. 2012).

In the U.S. pelagic longline fisheries, immediate mortality rates for blue sharks were 15-19% and only 3% for tiger sharks (*Galeocerdo cuvier*) (Dapp et al. 2017). Post-release mortality rates in this fishery range from 12% for blue sharks to 35% in shortfin mako sharks (*Isurus oxyrinchus*) (Campana et al. 2009; Hyatt et al. 2012). For the U.S. bottom longline fishery, immediate mortality rates for tiger sharks and sandbar sharks (*Carcharhinus plumbeus*) were relatively low at 8.5% and 36.1% respectively (Morgane and Burgess 2007). However, immediate mortality rates for dusky (*Carcharhinus obscurus*), blacktip *Carcharhinus limbatus*) scalloped hammerhead (*Sphyrna lewini*), and great hammerhead sharks (*Sphyrna mokarran*) were all above 80% in this fishery (Morgan and Burgess 2007). In New Zealand, the post-release mortality was between 6-14% for all sharks caught (Campana et al. 2009; Campana et al. 2009). The Japanese pelagic longline fishery had low mortality rates, between 6-8% (Campana et al. 2009). The Hawaiian longline fishery reported a mortality rate of about 8.5% (Campana et al. 2009). However, there are areas of the Atlantic where the longline fisheries mortality rates are as high as 80% for specific shark species (Hyatt et al. 2012).

### *c. Gillnet Fisheries*

Gillnets come in many shapes and sizes, can be used in coastal or pelagic environments, and can drift or stay in a fixed location. In the United States, bycatch in gillnets is relatively small compared to the other fishery types (Figure 1) (NOAA 2014). However, it did account for over 3.5 million pounds of shark bycatch in the U.S. in 2010 (NOAA 2014). While gillnets reportedly have less annual bycatch than most fishery types, the high mortality rates in this gear type make it dangerous to sharks (Oliver et al. 2015).

Indonesia also caught over three million sharks as bycatch in their gillnet fisheries, making up about 15% of their reported total bycatch (Blaber et al. 2009). The Japanese squid fishery, using drifting gillnets, caught nearly 201,000 sharks as bycatch between 1990 and 1991 (McKinnell and Seki 1998). Canadian gillnet fisheries reported 100,000 sharks caught per year, which was equivalent to over six tons of sharks per year over the ten-year period 1995-2005 (Benjamins et al. 2010). The European tuna drift net fishery caught an average 70,768 blue sharks as bycatch each year between 1993 and 2000 (Rogan and Mackey 2007). In the Brazil monkfish gillnet fishery, Perez and Wahrlich (2005) reported bycatch making up nearly 60% of the total catch, with sharks making up a large portion. Shester and Micheli (2011) reported elasmobranchs made up about 25% of the bycatch in gillnets off the coast of Mexico.

What makes gillnets particularly dangerous is the high mortality rates for sharks, which range from 70% to 93% for some species (Jordan et al. 2013; Cosandey-Godin et al. 2015). When sharks are caught in gillnets, they are unable to swim or move, causing them to switch to anaerobic metabolism quickly (Brooks et al. 2012; Hyatt et al. 2012; Dapp et al. 2013). The stress and buildup of lactate most likely kills them before they make it on the boat resulting in high immediate mortality rates (Brooks et al. 2012; Hyatt et al. 2012; Dapp et al. 2013).

### *d. Trawl Fisheries*

Another fishery type that causes high stress in sharks is trawl gear (Brooks et al. 2012; Hyatt et al. 2012; Dapp et al. 2013). Trawls are not species-specific and tend to have high bycatch to target catch ratios (Brewer et al. 1998). In the United States, trawl fisheries caught more sharks as bycatch than any of the other fisheries combined (Figure 1), with reported shark bycatch over 13 million pounds (6,500 tons) in 2010 (NOAA 2014). Between 1995 and 2005, the Gulf of Mexico shrimp trawl fishery alone caught an average of 592,370 individual sharks as bycatch per year (Raborn et al. 2012). Despite trawls leading the shark bycatch in the United States, Georgia's shrimp trawl fishery is a model for how trawl fisheries should be. Between 1995 and 1998, only 217 sharks were caught as bycatch in the shrimp trawl fishery (Belcher and Jennings 2011). Although there is concern that most of the 217 sharks were juveniles, such small numbers of bycatch are encouraging indications of an efficient target fishery (Belcher and Jennings 2011).

Similar to the United States, Indonesia's shark bycatch comes primarily from trawl fishing with about 3,100 tons of shark bycatch per year (Blaber et al. 2009). In Greek waters, 1,200 tons of elasmobranchs are landed each year, most of which is caught as bycatch in the bottom trawl fishery (Damalas and Vassilopoulou 2011); shark bycatch was reported to make up 14% of the total catch in the trawl fishery. In a more recent study on Greek fisheries, Oliver et al. (2015) reported that elasmobranch bycatch made up 14.5% of the total catch in the trawl fishery. While relatively lower, the Argentinian shrimp trawl fishery in the South Atlantic was reported to have an estimated 61 tons of sharks as bycatch (Cedrola et al. 2012). The International Council for the Exploration of the Sea (ICES) reported shark bycatch in the Italian trawl fisheries at 30,225 individuals for the year of 2013 (ICES 2015). The Adriatic Sea pair trawl fishery is estimated to have an annual shark bycatch of 9,531 sharks (Fortuna et al. 2010). The southern Portugal trawl fishery caught less than 800 sharks between 2003 and 2004, most of which were juveniles (Coelho and Erzini 2008).

South African trawl fisheries are a large contributor to global shark bycatch. In 1997, the South African demersal trawl fishery off the south coast reported 500 tons of spiny dogfish (*Squalus acanthias*) caught as bycatch, accounting for up to 50% of the total catch landed that year. For the same year, the west coast South African fishery reported between 759-1,347 tons of sharks bycatch, all of which was discarded. This only accounted for up to 19% of the total catch landed. Due to scattered observer data and most of the sharks being discarded at sea, the true amount of shark bycatch in the South African demersal trawl fishery may be higher (Walmsley 2004). The South African inshore trawl fishery had an annual shark bycatch of 588.8 tons accounting for only 3% of the total bycatch. Most of the sharks were discarded, making up 11% of the total discards in this fishery (Attwood et al. 2011).

Spotted dogfish (*Scyliorhinus canicula*) and blackmouth catsharks (*Galeus melastomus*) account for about 35% of the total catch landed in the western Mediterranean trawl fishery (Carbonell et al. 2003). However, there are many sharks that are discarded before landing, making the true number of shark bycatch unknown (Carbonell et al. 2003). Shark bycatch made up 40% of the total catch in coastal trawl fisheries in Kuwait (Oliver et al. 2015).

Unfortunately, survival rates of the sharks caught in trawl fisheries are not well studied. Data on survival could only be found for the northern Australian prawn fishery. About two thirds of all elasmobranchs caught in this trawl fishery died (Stobutzki et al. 2002; Barker and Schluessel 2005). Still, it can be assumed that both immediate and post-release mortalities in trawls must be similar to gillnets because both gear types result in sharks experiencing high amounts of stress and a lack of mobility (Brooks et al. 2012; Hyatt et al. 2012; Dapp et al. 2013).

### *e. Purse Seine Fisheries*

Purse seine fisheries catch a small percentage of sharks as bycatch, but are worth mentioning because they still made up an estimated 1.44-1.77 million tons worldwide in 2000 (Poisson et al. 2014). In the United States, purse seine shark bycatch for the year 2010 was reported to be 2,853 pounds (NOAA 2014). Sharks made up less than 1% of the West Indian tuna purse seine fisheries, although this was only including sharks that were retained and not those discarded, which is most likely a high value (Romanov 2002). The Western and Central Pacific tuna purse seine fisheries caught an average 53,875 sharks per year between 1995 and 2010 (Lawson 2011). The Eastern Pacific tuna purse seine fishery reported an average 24,244 sharks as bycatch each year between 1993 and 2004 (Román-Verdesoto and Orozco-Zöllen 2005). The French tuna purse seine fishery in the Indian Ocean observed over 1,300 silky sharks caught incidentally between

2005 and 2008 (Amandé et al. 2008). Nearly all of the silky sharks caught were juveniles that were discarded (Amandé et al. 2008). The French tuna purse seine fishery in the Indian Ocean only make up a small portion of the bycatch problem in the Indian Ocean however. Filmalter et al. (2013) estimates an average between 480,000-960,000 silky sharks are caught per year as bycatch in Indian Ocean purse seine fisheries. These estimates only looked at fish aggregation devices (FADs) in the Indian Ocean and did not include other types of purse seine set-ups (Filmalter et al. 2013). The European tuna purse seine fishery in the Atlantic Ocean catches far less than those in the Pacific with only 341 sharks caught as bycatch between 2003 and 2007 (Amandé et al 2010).

Despite these comparatively (to other gear) low bycatch numbers, the mortality rates of the sharks in this fishery is high (Eddy et al. 2016). Once caught, the sharks that reached the vessel have an average mortality ranging from 52% to over 80% (Hutchinson et al. 2015; Eddy et al. 2016). Vulnerable species such as the scalloped hammerhead have a 100% post-release mortality and so even a small amount of bycatch can be dangerous for their populations (Eddy et al. 2016).

### *Data Gaps*

The actual amount of shark bycatch in fisheries is difficult to determine due to a lack of reporting or underreporting at both the fisher and national levels, even in regulated fisheries. Compounding the bycatch proper assessment issue is the still extensive unregulated fisheries that occur in many parts of the world (Stobutzki et al. 2002; Baeta et al. 2010; Brodziak and Walsh 2013; Dapp et al. 2013; Jordan et al. 2013; Worm et al. 2013; Torres-Irineo et al. 2014; Oliver et al. 2015; Gilman et al. 2016). Many countries compile only the numbers reported as landed, which can be misleading as many fishers discard sharks as waste catch while out at sea, and those numbers are not recorded (Romanov 2002; Baeta et al. 2010; Kotas et al. 2012). Fishery observer programs help address this problem to some extent by recording catch discard numbers, but their coverage of fisheries is minimal relative to the scale of global fisheries. Furthermore, observers on vessels are often unable to record every species caught incidentally when fishers are sorting through their catch quickly (Baum and Myers 2004; Baum and Blanchard 2010; Torres-Irineo et al. 2014; Oliver et al. 2015; Gilman et al. 2016; Dapp et al. 2017). No nation except the United Kingdom and Italy reported sharks in their annual bycatch report (ICES 2015). This lack of reporting by most nations was at both the observer and national level (ICES 2015). In addition, for those countries that do report shark bycatch, they rely on self-reporting by the fishers, which leaves openings for under- or mis-reporting for economic gain. Furthermore, the lack of species-specific identification of the shark bycatch by fishers (Stobutzki et al. 2002; Field et al. 2009; Le Manach et al. 2012; Dapp et al. 2017) results in many country reports lumping all sharks into one generic category "sharks" (Blaber et al. 2009; Murua et al. 2013; NOAA 2014). This lack of species-specific data makes it difficult to determine the population abundance of specific species in the fishery and detect overfishing, further limiting the ability to manage sharks properly (Blaber et al. 2009; Dapp et al. 2017).

A number of fishing nations do not require or collect shark bycatch data, or they may collect it for internal use but do not make the information public, hindering scientists from combining the data from different nations for an overall analysis of bycatch biomass (Oliver et al. 2015; Dapp et al. 2017). It is important to have bycatch information across fishing regions to determine the best course of action fisheries managers need to take (Kotas et al. 2012; Jordan et al. 2013; Oliver et al. 2015). To add to the difficulty of obtaining a robust assessment of bycatch volume, fishing is often done illegally and is therefore not reported (Barker and Schluessel 2005; Le Manach et al. 2012). This could include foreign boats fishing in EEZs and then landing their catch elsewhere, making the bycatch impossible to quantify (Barker and Schluessel 2005; Le Manach et al. 2012; Worm et al; 2013).

Unfortunately, there is still a lot about shark biology that we do not know, making the true damage of bycatch on population sustainability difficult to determine (Jordan et al. 2013; Oliver et al. 2015; Gilman et al. 2016). The biology, life history, growth rates, age at maturity, stock structure, and distribution of most fishery shark bycatch species remain poorly known (Barker and Schluessel 2005; Blaber et al. 2009; Benjamins et al. 2010; Gilman et al. 2016). Recently, several shark species have been listed as Endangered by the IUCN, and we can only assume more will be added to the list if this bycatch problem continues without effective management to prevent overfishing.

### *Sharks Most at Risk*

Given differences in their physiology, shark species respond differently to being captured. Hammerhead sharks (Sphyrnidae), for example, are highly sensitive to capture stress compared to many other sharks, resulting in high mortality rates (71-100%) (Kotas et al. 2012; Jordan et al. 2013; Eddy et al. 2016). Hammerhead sharks reach maturity as late as 15 years old and have relatively low reproductive rates despite having up to 31 pups per liter (Hall and Roman 2013). Given large population declines, two of the most commonly captured hammerhead species in global fisheries, scalloped (*Sphyrna lewini*) and great hammerhead (*Sphyrna* mokarran) sharks have recently been upgraded to the Endangered category on the IUCN Redlist. Given demand for their fins, these species are now also listed on CITES Appendix II resulting in highly regulated international trade.

Blue sharks (*Prionace glauca*) are considered a hardier and high fecundity species that can withstand higher fishing pressure than other species; however, given their extensive distribution they can make up to 90% of shark bycatch in a single fishery (Cosandey-Godin et al. 2013; Oliver et al. 2015). In the United States longline fisheries, almost 3,000 tons of blue sharks were reported as bycatch in 2010, more than any other shark species (Figure 4) (NOAA 2014). Between 2000 and 2006, Canada reported 45,000-66,000 tons of blue sharks caught per year (Campana et al. 2009). Chile reported 950 tons of blue sharks landed in 2009 (Bustamante and Bennett 2013). Blue sharks comprise 50-90% of all shark bycatch in the Atlantic, West Pacific, and Mediterranean Sea (Oliver et al. 2015).

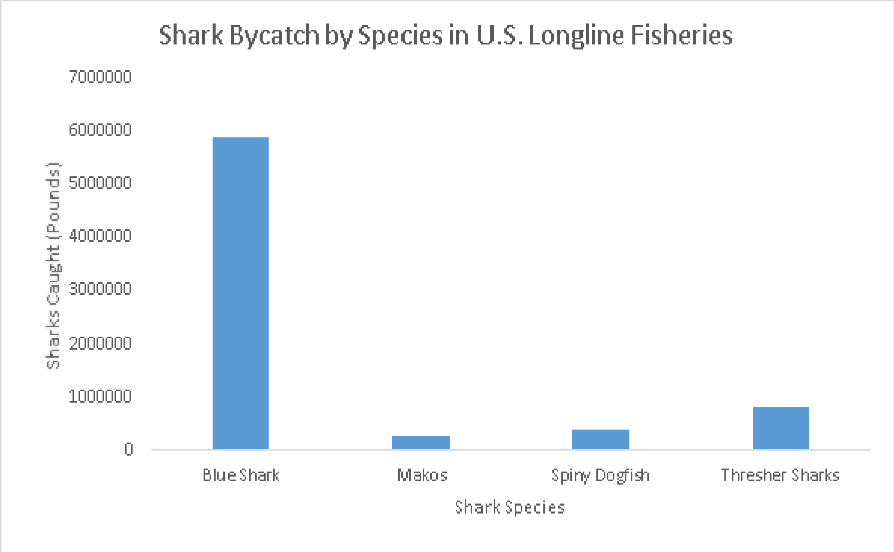

*Figure 4 - Shark Bycatch in U.S. Longline Fisheries. Looking at the U.S. longline fisheries, there are four species of sharks that are caught more often than any other. The Blue Shark makes up about 80% of the bycatch of these four species (NOAA 2014)*

Blue sharks are caught in such large numbers that many of them are discarded at sea and go unreported (Bustamante and Bennett 2013; Brodziak and Walsh 2013). While blue sharks are listed as Near Threatened on the IUCN Redlist, their population status is unknown. With an unknown population and such large numbers being fished out every year, their sustainability is questionable. Notably, Clarke et al. (2006) reported that the number of blue sharks traded globally for their fins was near or has potentially exceeded maximum sustainable yield for this species.

Silky sharks (*Carcharhinus falciformis*) are caught primarily in purse seines, but can also be found in large numbers in the Indian and East Pacific pelagic longline fisheries (Torres-Irineo et al. 2014; Oliver et al. 2015; Hutchinson et al. 2015). Reports estimate that 400 tons of silky sharks were killed each year between 1993-2009 in the eastern Pacific purse seine fisheries (Hall and Roman 2013). It is difficult to determine the impact longline fisheries have on these sharks as they have been consistently misidentified by both fishers and scientific observers in the fishery (Dapp et al. 2017). In addition to comprising the majority of purse seine shark bycatch, silky sharks tend to be caught as juveniles (Lawson 2011; Hutchinson et al. 2015; Oliver et al. 2015; Eddy et al. 2016). They have a high mortality rate between 52-84% in this fishing gear (Hutchinson et al. 2015; Eddy et al. 2016). They reach maturity between 4-10 years old for males and 7-12 years for females, with between 2-16 pups per liter (Hall and Roman 2013).

*Figure 5 - Sharks Caught by Fishery Type. Looking at the top five sharks caught by weight in the U.S. fisheries, the Spiny Dogfish is the most exploited with over 16 million pounds or 8000 tons reported as bycatch in 2010 over all fisheries. The trawl and gillnet fisheries seem to be exclusive to Spiny Dogfish, while longline fisheries catch less sharks, but more species (NOAA 2014).*

Removal of this demographic group before they have had a chance to breed puts their later generations at risk. As a result of their high bycatch, silky sharks are listed as Near Threatened on the IUCN Redlist, and may quickly make their way to Threatened status if fishing pressures continue.

Bottom trawls are not species specific in their targets and tend to catch a variety of benthic shark species, reporting them simply as unidentified sharks (Cedrola et al. 2012). This is problematic because angel sharks are vulnerable to capture by trawls (Perez and Wahrlich 2005). Angel sharks are critically endangered and are highly susceptible to overfishing with little chance of recovery (Perez and Wahrlich 2005). Identifying the shark catch to species is important if the proper management measures are to be taken to protect these species. Spiny dogfish make up most of the identified shark species in mid-water trawl fisheries bycatch (Cedrola et al. 2012; Oliver et al. 2015). They comprise the largest amount of bycatch in the United States fisheries, primarily in the trawl fisheries (Figure 5) (NOAA 2014). Spiny Dogfish live up to 70 years and do not mature until after 25 years (Simpfendorfer and Kyne 2009). They reproduce small litter sizes every three years, giving spiny dogfish an estimated 42-year population doubling time (Simpfendorfer and Kyne 2009). This population doubling time is one of the longest of most sharks (Simpfendorfer and Kyne 2009). Spiny Dogfish are listed as Vulnerable (IUCN) with a declining population so it is important to find ways to manage the trawl bycatch.

### *Current Options for Bycatch Reduction*

Reduction of shark bycatch is a problem that needs to be urgently solved. Scientists are working to reduce bycatch in a number of ways, including gear modification, alternate fishing practices, area closures, and incentive programs. Gear modifications are the most popular attempts among both scientists and fishers, the latter often advocating for these alterations (Campbell and Cornwell 2008). Inventing plausible gear changes are promising because they create a new market for jobs and get fishers involved (Campbell and Cornwell 2008).

For longlines, a number of gear modifications have proved effective. While studies have disagreed on whether circle hooks reduce or increase bycatch of sharks, all agree that circle hooks increase shark survival rate upon release (Yokota et al. 2006; Kerstetter and Graves 2006; Kerstetter et al. 2006; Kaplan et al. 2007; Campana et al. 2009; Campana et al. 2009; Cosandey-Godin and Morgan 2011; Jordan et al. 2013; Amorim et al. 2014; Favaro and Coté 2015, Gilman et al. 2016). Using mono- and multi-filament lines and gangions instead of wire leaders allow sharks to bite through them to escape (Branstetter and Musick 1993; Stone and Dixon 2001; Jordan et al. 2013; Favaro and Coté 2015). Nylon leaders proved effective at reducing shark bycatch compared to wire leaders (Ward et al. 2008; Campana et al. 2009; Favaro and Coté 2015). Favaro and Coté (2015) found that monofilament and nylon leaders reduced shark bycatch by 58%. The addition of chemical and/or electromagnetic shark repellents to the gear has also been suggested, although the numerous studies done have yet to demonstrate significant success using these gear modifications (Cosandey-Godin and Morgan 2011; Cosandey-Godin et al. 2013; Favaro and Coté 2015).

Most trawls use bycatch reduction devices (BRDs), which were originally designed to reduce the bycatch of sea turtles but are now more widely used for a number of non-target species (Jordan et al. 2013). BRDs are effective in allowing large sharks to escape the trawl net, but do not prevent smaller sharks, including juveniles, from being caught (Brewer et a. 1998; Stobutzki et al. 2002; Watson et al. 2005; Blaber et al. 2009; Favaro and Coté 2015). In fact, trawls catch more juvenile sharks than any other fishery type, which may be attributed to the use of a type of BRD called turtle excluder devices (TEDs) (Kotas et al. 2012). However, using smaller spacing between the bars on the TEDs may aid in reducing juvenile and small shark bycatch (Fennessy and Isaksen 2007; Belcher and Jennings 2011). Adding lights to excluder devices on the trawls have reduced spiny dogfish bycatch, and may be useful where this species is caught in large numbers (Jordan et al. 2013).

There are different types of BRDs being developed to reduce small shark bycatch without affecting the target catch. One promising BRD is a spiny dogfish reduction device that showed significant results (Chosid et al. 2012). The BRD was a grate that allowed the target catch to pass through while keeping the spiny dogfish out. There were drawbacks such as the grate becoming blocked if the tows lasted too long, but this type of BRD is worth further study and modification (Chosid et al. 2012). Other than the bycatch reduction devices, there is some evidence that adding LED lights to the nets and small jets to bottom trawls may reduce shark bycatch (Jordan et al. 2013). The jets would alert benthic sharks to the incoming trawls and allow them time to escape (Jordan et al. 2013). Finally, "tickler" chains are a common attachment to trawls that are used to stir up fish from the bottom as the trawl passes by (Kynoch et al. 2015). Banning the use of this chain reduces shark bycatch significantly (Kynoch et al. 2015).

Gillnets have limited possibilities for gear alterations. Recent studies have found promising results in creating more tension in the net (Thorpe and Frierson 2009; Cosandey-Godin and Morgan 2011; Jordan et al. 2013). This is accomplished by having more weights and buoys on each end of the nets (Thorpe and Frierson 2009). Studies show that this reduced the number of sharks wound up in the net, which can cause the sharks stress and ultimately death (Thorpe and Frierson 2009; Hyatt et al. 2012). Net mesh size is important when considering shark bycatch (Trent et al. 1997; Walker et al. 2005; Jordan et al. 2013). Studies show smaller mesh sizes result in higher catches of sharks, therefore limitations on the minimum size of gillnet mesh can help reduce shark bycatch (Trent et al. 1997; Walker et al. 2005; Cosandey-Godin and Morgan 2011; Jordan et al. 2013).

Although purse seines catch a comparatively small amount of sharks as bycatch, the high mortality rates make reducing the catch a priority. The use of fish aggregating devices (FADs) as is commonly done in purse-seine fisheries increase shark bycatch significantly (Torres-Irineo et al. 2014; Hutchinson et al. 2015). While outlawing these FAD devices is improbable, there are ways to modify them to reduce bycatch (Jordan et al. 2013). For example, European fleets use non-entangling FADs to reduce shark bycatch (Poisson et al. 2014). To reduce mortality of sharks caught in the seine nets, conducting quick release of sharks from the net increases post-release survival significantly (Cosandey-Godin and Morgan 2011; Poisson et al. 2014; Hutchinson et al. 2015; Tolotti et al. 2015). It is suggested that fishers quickly sort through the catch before putting the catch in the hold, shortening the time between capture and release of the sharks (Poisson et al. 2014).

There are a number of ways to reduce the bycatch of sharks without modifying fishing gear, although the effectiveness of these options varies. For longlines, reduced soak times and changing bait from squid to mackerel have proven effective at reducing shark bycatch and post-release mortality (Ward et al. 2004; Campana et al. 2009; Campana et al. 2009; Cosandey-Godin and Morgan 2011; Dapp et al. 2013; Jordan et al. 2013; Amorim et al. 2014). Fishers could also adjust the location of the lines depending on the type of sharks they are catching; lifting the line off the floor to avoid benthic sharks, or sinking it closer to the floor to avoid pelagic sharks (Jordan et al. 2013; Favaro and Coté 2015; Tolotti et al. 2015). The U.S. swordfish longline fishery sets lines relatively shallow and catches primarily blue sharks as bycatch while the U.S. tuna longline fishery sets lines deeper and catches more tiger sharks (Dapp et al. 2017). Communication between fishers can help warn others of "hotspots" where sharks are gathered to help reduce interactions (Barker and Schluessel 2005; Mandelman et al. 2008; Gilman et al. 2008; Cosandey-Godin et al. 2015).

In addition to these fishing gear and fishing method changes, educating the fishers is an important component of reducing bycatch. The FAO found that less than 15% of chondricthyans were identified to species in 1998, demonstrating an ignorance of shark species by fishers (Barker and Schluessel 2005; Baeta et al. 2010). Educating fishers to identify shark species, as well as to recognize shark "hotspots" can be useful in gathering fisheries data such as more accurate bycatch records, species specific data, and potential ecologically important areas to sharks such as nursery areas (Stobutzki et al. 2002; Barker and Schluessel 2005; Campbell and Cornwell 2008; Blaber et al. 2009; Benjamins et al. 2010; Cosandey-Godin et al. 2015). Requiring classes with every fishing license and/or creating shark identification pamphlets for use onboard may be helpful ways to improve shark fisheries records and track bycatch to aid in downstream bycatch reduction efforts (Campbell and Cornwell 2008; Dapp et al. 2017).

All the options for bycatch reduction thus far have been at the fisher level, however, there are also changes to be made at the management level such as enforcing quotas, trade restrictions, and area closures (Barker and Schluessel 2005; Mandelman et al. 2008; Campbell and Cornwell 2008; Blaber et al. 2009; Benjamins et al. 2010; Cosandey-Godin and Morgan 2011; Bustamante and Bennett 2013; Tolotti et al. 2015). Creating bycatch quotas with fines for those who catch more than the set quota and incentives for those who manage to stay under the quota may encourage fishers to avoid shark interactions as often as possible (Hall et al. 2000; Barker and Schluessel 2005; Campbell and Cornwell 2008; Blaber et al. 2009; Benjamins et al. 2010). Some nations have a required fin-to-carcass ratio for fishers, which reduces finning practices. Since shark carcasses take up more room than shark fins, the regulation entices fishers to avoid shark interactions and release sharks alive rather than have to take up additional room on the ship by keeping shark carcasses. This fin-to-carcass ratio regulation has proved effective at reducing bycatch for many shark species, especially larger sharks. Tiger shark bycatch was reduced more so by this regulation than the use of circle hooks in U.S. pelagic longline fisheries (Dapp et al. 2017). In the US, recent regulations now require all landed fins to be attached to the sharks, further incentivizing swordfish and tuna fishers to avoid sharks as bycatch as much as possible. Trade restrictions on shark fins or shark meat can make it difficult for fishers to make money off the shark bycatch, which will also encourage them to avoid shark catches (Blaber et al. 2009; Worm et al. 2013; Passantino 2014; Tolotti et al. 2015). Occasionally, trade restrictions are not enough to deter fishers, and a market closure may be necessary (Hall et al. 2000; Kirby and Ward 2014). This was done in the 1990s in response to dolphin bycatch and proved successful in creating change to avoid all bycatch including sharks (Hall et al. 2000; Kirby and Ward 2014). The key to its success was public support: thus, public awareness and education is important as part of the overall effort to entice shark bycatch reduction.

For overfished or endangered shark species, area closures to fishing may be necessary to reduce bycatch. To do so, scientists need to determine which areas are ecologically important to sharks such as nurseries. The area must also be a viable option for closure, where the regulations can be enforced and provide suitable protection for the sharks. The area must be large enough to provide adequate protection while not taking too much fishing grounds away from the fishers. Closing areas to fishing are complicated and difficult to obtain approval for, but may be necessary for ecologically important areas for endangered species (Hall et al. 2000; Stobutzki et al. 2002; Barker and Schluessel 2005;

Campbell and Cornwell 2008; Mandelman et al. 2008; Blaber et al. 2009; Cosandey-Godin and Morgan 2011; Dapp et al. 2013; Worm et al. 2013; Tolotti et al. 2015).

All of the options listed above are a good start for reducing bycatch, but will not eliminate shark bycatch. Biologists need to continue to gain information on both shark biology and shark population statistics to close the gaps in data to help fisheries managers determine the best course of action for reducing shark bycatch (Hall et al. 2000; Carbonell et al. 2003; Baum et al. 2003; Barker and Schluessel 2005; Dulvy et al. 2008; Blaber et al. 2009; Benjamins et al. 2010; Gilman 2011; Molina and Cooke 2012; Kirby and Ward 2014; Tolotti et al. 2015). Additional scientific observer coverage is vital to gain bycatch data by species (Cosandey-Godin and Morgan 2011; Dapp et al. 2013; Kirby and Ward 2014). Unfortunately, observer coverage across fisheries varies but is generally minimal. In the United States Monterey Bay gillnet fishery, observer coverage was between 25% and 35%, while the Hawaiian longline fishery observer coverage was only at 6.5% (NOAA 2000; Lawson 2011). Between 1992 and 2009, observer coverage for the Japanese tuna longline fishery in Australian waters was only 5.1% and the New Zealand longline fishery had 3.6% coverage (Lawson 2011). Pacific Ocean tuna purse seine fisheries tend to have higher coverage, reaching percentages as high as 11.05% between 1995 and 2010 (Lawson 2011). South African fisheries observer coverage varies between fisheries. The observer coverage for the South African demersal trawl fishery is nearly nonexistent at between 0.49%-0.62% (Walmsley 2004). However, the tuna and swordfish longline fisheries off the southern coast of Africa have higher observer coverage at 9.8% between 1998 and 2005 (Petersen et al. 2009). The South African inshore trawl fishery observer program covered 2.9-4.4% between 2003 and 2006 (Attwood et al. 2011). The Adriatic Sea pair trawl fishery observer coverage ranges between 0.9% and 6.3% (Fortuna et al. 2010). It is suggested that observer coverage be at least 5-10% of fishing effort to estimate bycatch across the fishery with accuracy (Walmsley 2004).

Reducing interactions with sharks in teleost targeted fisheries has economic incentives to many fishers, as incidental catch of sharks is often economically deleterious to the fishers in terms of effort needed to remove the sharks and gear damage (Hall et al. 2000;

Campbell and Cornwell 2008; Jordan et al. 2013; Cosandey-Godin et al. 2013; Torres-Irineo et al. 2014; Favaro and Coté 2015). There are also other economic incentives for decreasing shark bycatch including reduced drag, uninterrupted fishing access, eco-friendly marketing, and a decreased number of trips (Campbell and Cornwell 2008).

### *Conclusions*

Bycatch is widely recognized as one of the largest contributors to shark population declines worldwide, and there is considerable need for more target efficient fishing methods to drastically reduce this bycatch. With sharks having key functional roles in ocean ecosystems, their large-scale removal can alter food webs via top down trophic cascades, causing concomitant declines in commercially important species. These trophic cascades could also occur if sharks continue to decline in average size due to fishing pressures. Smaller sized sharks are unlikely to function as apex predators, causing food web disruptions similar to if they were removed completely. In addition to ecological impacts, shark bycatch can cause economic problems for fishers through destroyed gear, extra time and effort, and less vessel storage space for target species.

While a lot of research is being done to try to find ways to reduce shark bycatch, the current gear modifications recommended have yet to be globally applied in fisheries. As a result they have not yet demonstrated significant reductions in bycatch levels overall to reduce concerns about shark population declines. Recent studies also suggest improvements in bycatch reduction efforts need to be made not only at the fishing level but also at the management level. Standardization of bycatch nomenclature, education requirements for fishers, expanded observer programs, area closures, and ecosystem-based management regimes are just a few of these management-level suggestions that could help with shark bycatch reduction.

The following are some important steps that need to be taken to reduce shark bycatch and improve future research on bycatch assessment and monitoring:

1. The word “bycatch” must be universally defined for nations to compare shark capture numbers more easily. Since mortality rates of many shark species tend to be high once they are caught, I suggest standardizing the term bycatch to

encompass all non-target shark species caught, both discarded and retained. By incorporating sharks that are discarded in the definition of bycatch, we can account for mortality and better predict impacts on shark populations. A universal definition of the term may also encourage collaboration between national management regimes.

2. Immediately instituting management regimes in areas where shark bycatch is high is necessary. For example, most United States longline fisheries require circle hooks be used over J-hooks. Although there is currently no study that demonstrates significant results in effectiveness of circle hooks in reducing shark bycatch, circle hooks reduce post-release mortality for sharks over J-hooks. Circle hooks more frequently hook sharks in the mouth rather than the gut, which causes less harm to the sharks and increases their survival rate upon release. Requiring circle hooks in fisheries may not reduce shark bycatch, but it will reduce their mortality and have a smaller impact on the local shark populations.
3. Shark bycatch data needs to be made public by all fishing nations, both to gain public support for shark conservation and to aid scientists and managers in improving stock assessments. Currently, not many nations release fisheries data, making it difficult for scientists and fisheries managers to determine how many sharks are being caught worldwide. Fish stocks are often assessed using fisheries data, thus if nations released shark catch and bycatch data, managers and scientists would be able to better assess global shark stocks.
4. Expanding coverage of national scientific observer programs is vital. For those nations that have scientific observers in place, priority needs to be placed on identifying and recording sharks by species. Most European nations do not include sharks in their bycatch reports, and many of the fisheries in the United States do not identify sharks to species (NOAA 2014; ICES 2015). Increasing scientific observer coverage is also important to ensure the fisheries spatial scales of effort are well represented. For nations without scientific observers in place, a program should be created.
5. Closing ecologically important areas to fishing can help overfished populations recover.

6. Continuing to research and develop improved methods for bycatch reduction, as well as learning as much as possible about sharks and their biology can help scientists make the best suggestions to fisheries managers.

Overall, my review of the shark bycatch literature strongly indicates that increased investment by the fishing industry and management agencies in shark bycatch reduction methods will be critical to reverse the drastic declines in shark populations occurring worldwide.

## Literature Cited

Amandé, M., E. Chassot, P. Chavance, and R. Planet. 2008. Silky shark (*Carcharhinus falciformes*) bycatch in the French tuna purse-seine fishery of the Indian Ocean. IOTC WPEB – 2008/016 Indian Ocean Tuna Commission, Mahe, Seychelles.

Amandé, M., J. Ariz, E. Chassot, A. Delgado de Molina, D. Gaertner, H. Murua, R. Pianat, J. Ruiz, and P. Cherance. 2010. Bycatch of the European purse seine tuna fishery in the Atlantic Ocean for the 2003 – 2007 period.

Amorim, S., M. Santos, R. Coelho and J. Fernanzed-Carvalho. 2014. Effects of 17/0 circle hooks and bait on fish catches in a Southern Atlantic Swordfish longline fishery. Aquatic Conservation: Marine and Freshwater Ecosystems 25: 518 – 533.

Anderson, O.F. 2013. Fish and invertebrate bycatch and discards in New Zealand arrow squid fisheries from 1990-91 until 2010-11. New Zealand Aquatic Environment and Biodiversity Report No. 112.

Arocha, F., O. Arocha, and L. MArcano. 2002. Observed shark bycatch from the Venezuelan tuna and swordfish fishery from 1994 through 2000. ICCAT Collective Volume of Scientific Papers 54: 1123 – 1131.

Attwood, C.; S. Peterson, and S. Kerwath. 2011. Bycatch in South Africa’s inshore trawl fishery as determined from observer records. ICES Journal of Marine Science 68: 2163 – 2174.

Baeta, F., M. Batista, A. Main, M. Costa and H. Cabral. 2010. Elasmobranch bycatch in a trammel net fishery in Portuguese west coast. Fisheries Research 102: 123 – 129.

Barker, S. and V. Schluessel. 2005. Managing global shark fisheries: suggesting for prioritizing management strategies. Aquatic Conservation 15: 325 – 347.

Baum, J. and R. Myers. 2004. Shifting baselines and the decline of pelagic sharks in the Gulf of Mexico. Ecology Letters 7: 135 – 145.

Baum, J. and W. Blanchard. 2010. Inferring shark population trends from generalized linear mixed models of pelagic longline catch and effort data. Fisheries Research 102: 229 - 239.

Baum, J., R. Myers, D. Kehler, B. Worm, S. Harley and P. Doherty. 2003. Collapse and conservation of shark populations in the Northwest Atlantic. Science 299: 389-392.

Beerkircher, L., E. Cortés and M. Shivji. 2002. Characteristics of shark bycatch observed on pelagic longlines off of the Southeastern United States, 1992 – 2000. Marine Fisheries Review 64: 40 – 49.

Belcher, C. and C. Jennings. 2011. Identification and evaluation of shark bycatch in Georgia's commercial shrimp trawl fishery with implications for management. Fisheries Management and Ecology 18: 104 – 112.

Benjamins, S., D. Kulka and J. Lawson. 2010. Recent incidental catch of sharks in gillnet fisheries of Newfoundland and Labrador, Canada. Endangered Species Research 11: 133 – 146.

Blaber, S., C. Dichmont, W. White, R. Buckworth, L. Sadiyah, B. Iskandsr, S. Nurhakim, R. Pillans and R. Andamari. 2009. Elasmobranchs in Southern Indonesian fisheries: the fisheries, the status of the stocks and management options. Reviews in Fish Biology and Fisheries 19: 367 – 391.

Branstetter, S. and J. Musick. 1993. Comparisons of shark catch rates on longline using rope/steel (Yankee) and monofilament gangions. Marine Fisheries Review 55: 4-9.

Brewer, D.; N. Rawlinson, S. Eayrs and C. Burridge. 1998. An assessment of Bycatch Reduction Devices in a tropical Australian prawn trawl fishery. Fisheries Research 36: 195 – 215.

Brodziak, J. and W. Walsh. 2013. Model selection and multimodel inference for standardizing catch rates of bycatch species: a case study of oceanic whitetip shark in the Hawaii based longline fishery. Canadian Journal of Fisheries and Aquatic Sciences 70: 1723 - 1740.

Brooks, E., J. Mandelman, K. Sloman, S. Liss, A. Danylchuck, S. Cooke, G. Skomal, D. Phillipp, D. Sims and C. Suski. 2012. The physiological response of the Caribbean reef shark (*Carcharhinus perezi*) to longline capture. Comparative Biochemistry and Physiology Part A: Molecular and Integrative Physiology 162: 94 – 100.

Bustamante, C. and M. Bennett. 2013. Insights into the reproductive biology and fisheries of two commercially exploited species, shortfin mako (*Isurus oxyrinchus*) and blue shark (*Prionace glauca*), in the south-east Pacific Ocean. Fisheries Research 143: 174 – 183.

Campana, S., L. Marks, W. Joyce, and N. Kohler. 2005. Catch, by-catch, and indices of population status of blue shark (*Prioncace glauca*) in the Canadian Atlantic. ICCAT Collective Volumes of Scientific Papers 58: 891 – 934.

Campana, S., W. Joyce and M. Mannis. 2009. Bycatch and discard mortality in commercially caught blue sharks *Prionace glauca* assessed using archival satellite pop-up tags. Marine Ecology Progress Series 387: 241 – 253.

Campana, S., W. Joyce, M. Francis and M. Mannis. 2009. Comparability of blue shark mortality estimates for the Atlantic and Pacific longline fisheries. Marine Ecology Progress Series 396: 161 – 164.

Campbell, L. and M. Cornwell. 2008. Human dimensions of bycatch reduction technology: current assumptions and directions for future research. Endangered Species Research 5: 325 – 334.

Carbonell, A., F. Alemany, P. Merella, A. Quelglas and E. Román. 2003. The by-catch of sharks in the western Mediterranean (Balearic Islands) trawl fishery. Fisheries Research 61: 7 - 18.

Cedrola, P., A. González, G. Chiaramonte and A. Pettovello. 2012. Bycatch of sharks (Elasmobranchii) in the Patagonian red shrimp *Pleoticus muelleri* (Bate, 1888) fishery. Revista del Museo Argentino de Ciencias Naturales, n.s. 14: 349 – 356.

Chosid, D., M. Pol, M. Szymanski, F. Mirarchi, and A. Mirarchi. 2012. Development and observations of a spiny dogfish *Squalus acanthias* reduction device in a raised footrope hake *Merluccius bilinearis* trawl. Fisheries Research 114: 66 – 75.

Clarke, S., M. McAllister, E. Milner-Gulland, G. Kirkwood, C. Michielsens, D. Agnew, E. Pikitch, H. Nakano, and M. Shivji. 2006. Global estimates of shark catches using trade records from commercial markets. Ecology Letters 9: 1115 – 1126.

Coelho, R. and K. Erzini. 2008. Effects of fishing methods on deep water shark species caught as by-catch off southern Portugal. Hydrobiologia 606: 187 – 193.

Cosandey-Godin, A. and A. Morgan. 2011. Fisheries bycatch of sharks: options for mitigations. PEW Ocean-Science Division, Pew Environmental Group, Washington D.C.

Cosandey-Godin, A., E. Krainski, B. Worm and J. Flemming. 2015. Applying Bayesian spatiotemporal models to fisheries bycatch in the Canadian Arctic. Canadian Journal of Fisheries and Aquatic Sciences 72: 186 – 197.

Cosandey-Godin, A., T. Wimmer, J. Wang and B. Worm. 2013. No effect from rare-earth metal deterrent on shark bycatch in a commercial pelagic longline trial. Fisheries Research 143: 131 – 135.

Dai, X., Y. Zheng, R. Jiang, and L. Xu. 2009. Shark by-catch observation in ICCAT waters by the Chinese longline observers in 2007. Collection volume scientific papers ICCAT 64: 1741 - 1745.

Damalas, D. and V. Vassilopoulou. 2011. Chondricthyan by-catch and discards in the demersal trawl fishery of the central Aegan Sea (Eastern Mediterranean). Fisheries Research 108: 142 – 152.

Dapp, R., C. Huveneers, T. Walker, J. Mandelman, D. Kerstetter, and R. Reina. 2017. Using logbook data to determine the immediate mortality of blue sharks (*Prionace glauca*) and tiger sharks (*Galeocerdo cuvier*) caught in the commercial U.S. pelagic longline fishery. Fishery Bulletin 115: 27-41.

Dapp, D., J. Spotila and M. O’Connor. 2013. Impact of Costa Rican longline fishery on its bycatch of sharks, stingrays, bony fish, and olive ridley turtles (*Lepidochelys olivacea*). Journal of Experimental Marine Biology and Ecology 448: 228 – 239.

Davies, R., S. Cripps, A. Nickson, and G. Porter. 2009. Defining and estimating global marine fisheries bycatch. Marine Policy 33: 661 – 672.

Dudley, S. and C. Simpfendorfer. 2006. Population status of 14 shark species caught in the protective gillnets off KwaZulu-Natal beaches, South Africa, 1978 – 2003. Marine and Freshwater Research 57: 225 – 240.

Dulvy, N., J. Baum, S. Clarke, L. Compagno, E. Cortés, A. Domingo, S. Fordham, S. Fowter, M. Francis, C. Gibson, J. Martínez, J. Musick, A. Soldo, J. Stevens and S. Valenti. 2008. You can swim but you can’t hide: the global status and conservation of oceanic pelagic sharks and rays. Aquatic Conservation: Marine and Freshwater Ecosystems 18: 459- 482.

Eddy, F., R. Brill and D. Bernal. 2016. Rates of at-vessel mortality and post-release survival of pelagic sharks captured with tuna purse seines around drifting fish aggregating devices (FADs) in the equatorial eastern Pacific Ocean. Fisheries Research 174: 109 – 117. Available online 9/26/2015 at http://www.sciencedirect.com.ezproxylocal.library.nova.edu/science/article/pii/S0165783615300849?np=y.

Favaro, B. and I. Coté. 2015. Do by-catch reduction devices in longline fisheries reduce capture of sharks and rays? A global meta-analysis. Fish and Fisheries 16: 300-309.

Fennessy, S. and B. Isaksen. 2007. Can bycatch reduction devices be implemented successfully on prawn trawlers in the Western Indian Ocean? African Journal of Marine Science 29: 453 – 463.

Ferretti, F., B. Worm, G. Britten, M. Heithaus, and H. Lotze. 2010. Patterns and ecosystem consequences of shark declines in the ocean. Ecology Letters 13: 1055 – 1071.

Field, I., M. Meekan, R. Buckworth, and C. Bradshaw. 2009. Chapter 4 Susceptibility of sharks, rays, and chimaeras to global extinction. Advances in Marine Biology 56: 275 – 363.

Filmalter, J., M. Capello, J. Deneubourg, P. Cowley, and L. Dagorn. 2013. Looking behind the curtain: quantifying massive shark mortality in fish aggregating devices. Frontiers in Ecology and the Environment 11: 291 – 296.

Fortuna, C., C. Vallini, E. Filidei Jr., M. Ruffino, I. Consalvo, S. Muccio, C. Gion, U. Scacco, E. Tarulli, O. Giovanardi, and A. Mazzola. 2010. By-catch of cetaceans and other species of conservation concern during pair trawl fishing operations in the Adriatic Sea (Italy). Chemistry and Ecology 26: 65 – 76.

Francis, M., L. Griggs and S. Baird. 2001. Pelagic shark bycatch in the New Zealand tuna longline fishery. Marine and Freshwater Research 52: 167 – 178.

Gallagher, A.J., E.S. Orbesen, N. Hammerschlag, and J.E. Serafy. 2014. Vulnerability of oceanic sharks as pelagic longline bycatch. Global Ecology and Conservation 1: 50 – 59.

Gilman, E., M. Chaloupka, Y. Swimmer, S. Piovano. 2016. A cross-taxa assessment of pelagic longline by-catch mitigation measures: conflicts and mutual benefits to elasmobranchs. Fish and Fisheries 17: 748-784.

Gilman, E. 2011. Bycatch governance and best practice mitigation technology in global tuna fisheries. Marine Policy 35: 590 – 609.

Gilman, E., S. Clarke, N. Brothers, J. Alfero-Shigweto, J. Mandelman, J. Mongel, S. Peterson, S. Piovano, N. Thomson, P. Dalzell, M. Donose, M. Gorem and T. Werner. 2008. Shark interactions in pelagic longline fisheries. Marine Policy 32: 1 – 18.

Grubbs, R., J. Carlson, J. Romine, T. Curtis, W. McElroy, C. McCandless, C. Cotton, and J. Musick. 2016. Critical assessment and ramifications of a purported marine trophic cascade. Scientific Reports 6: 20970

Hall, M. and M. Roman. 2013. Bycatch and non-tuna catch in the tropical tuna purse seine fisheries of the world. FAO fisheries and aquaculture technical paper pp. 137 – 167.

Hall, M., D. Alverson and K. Metuzals. 2000. By-catch: Problems and solutions. Marine Pollution Bulletin 41: 204 – 219.

Huang, H. and K. Liu. 2010. Bycatch and discards by Taiwanese large-scale tuna longline fleets in Indian Ocean. Fisheries Research 106: 261 – 270.

Hutchinson, M., D. Itano, J. Muir and K. Holland. 2015. Post-release survival of juvenile silky sharks captured in a tropical tuna purse seine fishery. Marine Ecology Progress Series 521: 143 – 154.

Hyatt, M., P. Anderson, P. O’Donnell and I. Berzins. 2012. Assessment of acid-base derangements among bonnethead (*Sphyrna tiburo*), bull (*Carcharhinus leucas*), and lemon (*Negaprion brevirostris*) sharks from gill-net and longline capture and handling methods. Comparative Biochemistry and Physiology Part A: Molecular and Integrative Physiology 162: 113 – 120.

ICES. 2015. Report of the Working Group on Bycatch of Protected Species (WGBYC), 2-6 February 2015, ICES Headquarters, Copenhagen, Denmark. ICES CM 2015\ACOM:26. 82 pp.

Jordan, L., J. Mandelman, D. McComb, S. Fordhan, J. Carlson and T. Werner. 2013. Linking sensory biology and fisheries bycatch reduction in elasmobranch fishes: a review with new directions for research. Conservation Physiology 1: 1 – 20.

Kaplan, I., S. Cox and J. Kitchell. 2007. Circle hooks for pelagic longliners: not a panacea for marlin and shark bycatch, but part of the solution. Transactions of the American Fisheries Society 136: 392 – 401.

Kerstetter, D. and J. Graves. 2006. Effects of circle versus J-style hooks on target and non-target species in a pelagic longline fishery. Fisheries Research 80: 239 – 250.

Kerstetter, D., J. Pacheco, F. Hazin, D. Travassos and J. Graves. 2006. Preliminary results of circle versus J-style hook comparisons in the Brazilian pelagic longline fishery. Collective Volume of Scientific Papers ICCAT 60: 2140 – 2147.

Kirby, D. and P. Ward. 2014. Standards for the effective management of fisheries bycatch. Marine Policy 44: 419 – 426.

Kotas, J., M. Petrere Jr., R. Santos, A. Bustamante, C. Lin, A. Menezes and E. Mitchelletti. 2012. The horizontal migration of hammerhead sharks along the southern Brazilian coast, based on their exploitation pattern and considerations about the impact of anchored gillnets activities on those species. Revista CEPSUL – Biodiversidade a Conservacăo Marinha 3: 45 – 68.

Kynoch, R., R. Fryer and F. Neat. 2015. A simple technical measure to reduce bycatch and discard of skates and sharks in mixed-species bottom-trawl fisheries. ICES Journal of Marine Science. URL: http://icesjms.oxfordjournals.org.ezproxylocal.library.nova.edu/content/early/2015/03/11/icesjms.fsv037.full.pdf+html.

Lam, V. and Y. Mitcheson. 2011. The sharks of South East Asia – unknown, unmonitored, and unmanaged. Fish and Fisheries 12: 51 – 74.

Lawson, T. 2011. Estimation of catch rates and catches of key shark species in tuna fisheries of the Western and Central Pacific Ocean using observer data. Information Paper EB IP-02. Seventh Regular Session of the Scientific Committee of the WCPFC. Pohnpei, FSM 9th- 17th August.

Le Manach, F., C. Gough, A. Harris, H. Frances, S. Harper and D. Zeller. 2012. Unreported fishing, hungry people and political turmoil: the recipe for a food security crisis in Madagascar? Marine Policy 36: 218 – 225.

Lewison, R., L. Crowder, A. Read and S. Freeman. 2004. Understanding impacts of fisheries bycatch on marine megafauna. Trends in Ecology and Evolution 19: 598 – 604.

Lyons, K., E. Jarvis, S. Jorgenson, K. Weng, J. O'Sullivan, C. Winkler and C. Lowe. 2013. The degree and result of gillnet fishery interactions with juvenile white sharks in southern California assessed by fishery-independent and –dependent methods. Fisheries Research 147: 370 – 380.

Mandelman, J., P. Cooper, J. Werner and K. Lagueux. 2008. Shark bycatch and depredation in the U.S. Atlantic pelagic longline fishery. Reviews in Fish Biology and Fisheries 18: 427 - 442.

Murua, H., M.N. Santos, P. Chavance, J. Amanda, F.J. Abascal, J. Ariz, P. Bach, M. Korta, F. Poisson, R. Coelho and B. Seret. 2013. EU Project for the Provision of Scientific Advice for the purpose of the implementation of the EUPOA sharks: a brief overview of the results for the Indian Ocean. Ninth Session of the IOTC Working Party on Ecosystems and Bycatch La Réunion, France 12 – 16 September 2013. URL: http://archimer.ifremer.fr/doc/00160/27160/25359.pdf.

McKinnell, S. and M. Seki. 1998. Shark bycatch in the Japanese high seas squid driftnet fishery in the North Pacific Ocean. Fisheries Research 39: 127 – 138.

Molina, J. and S. Cooke. 2012. Trends in shark bycatch research: current status and research needs. Reviews in Fish Biology and Fisheries 22: 719 – 737.

Morgan, A. and H. Burgess. 2007. At-vessel fishing mortality for six species of sharks caught in the northwest Atlantic and Gulf of Mexico. Gulf of Caribbean Research 19: 123 – 129.

Musick, J., G. Burgess, G. Cailliet, M. Camhi, and S. Fordham. 2000. Management of sharks and their relatives (Elasmobranchii). Fisheries 25: 9 – 13.

Myers, R., J. Baum, T. Shepherd, S. Powers, and C. Peterson. 2007. Cascading effects of the loss of apex predatory sharks from a coastal ocean. Science 315: 1846 – 1850.

NOAA Office of Science and Technology. 2014. National Bycatch Report, First Edition Update 1URL: http://www.st.nmfs.noaa.gov/observer-home/first-edition-update-1.

NOAA Office of Science and Technology. 2000. Management control review of national marine fisheries service observer programs/service delivery models. URL: http://www.st.nmfs.noaa.gov/Assets/Observer-Program/pdf/MCR.pdf

Oliver, S., M. Braccini, S. Newnan and E. Harvey. 2015. Global patterns in the bycatch of sharks and rays. Marine Policy 54: 86 – 97.

Passantino, A. 2014. The EU shark finning ban at the beginning of the new millennium: the legal framework. ICES Journal of Marine Science 71: 429 – 434.

Perez, J. and R. Wahrlich. 2005. A bycatch assessment of the gillnet monkfish *Lophius gastrophygus* fishery off southern Brazil. Fisheries Research 72: 81 – 95.

Petersen, S., M. Honig, P. Ryan, L. Underhill, and L. Compagno. 2009. Pelagic shark bycatch in the tuna- and swordfish-directed longline fishery off southern Africa. African Journal of Marine Science 31: 215 – 225.

Poisson, F., J. Filmalter, A. Vernet and L. Dragorn. 2014. Mortality rate of silky sharks (*Carcharhinus falciformis*) caught in tropical tuna purse seine fishery in the Indian Ocean. Canadian Journal of Fisheries and Aquatic Sciences 71: 795 – 798.

Raborn, S., B. Gallaway, J. Cole, W. Gazey and K. Andrews. 2012. Effects of turtle excluder devices (TEDs) on the bycatch of three small coastal sharks in the Gulf of Mexico Penaeid shrimp fishery. North American Journal of Fisheries Management 32: 333 – 345.

Ramos-Cartelle, A., B. Garcia-Cortés, and J. Mejuto. 2008. Scientific estimates of bycatch landed by the Spanish surface longline fleet targeting swordfish (*Xiphias gladius*) in the Indian Ocean with special reference to the 2004-2006 period. IOTC-008-WPEB-03.

Rogan, E. and M. Mackey. 2007. Megafauna bycatch in the drift nets for albacore tuna (*Thunnus alalunga*) in the NE Atlantic. Fisheries Research 86: 6 – 14.

Romanov, E. 2002. Bycatch in the tuna purse-seine fisheries of the western Indian Ocean. Fisheries Bulletin 100: 90 – 105.

Román-Verdesoto, M. and M. Orozco-Zöllen. 2005. Bycatches of sharks in the tuna purse-seine fishery of the Eastern Pacific Ocean reported by observers of the inter-American tropical tuna commission 1993-2004. Inter-American Tropical Tuna Commission Data Report 11.

Shester, G. and F. Micheli. 2011. Conservation challenges for small-scale fisheries: bycatch and habitat impacts of traps and gillnets. Biological Conservation 144: 1673 – 1681.

Simpfendorfer, C. and P. Kyne. 2009. Limited potential to recover from overfishing raises concerns for deep-sea sharks, rays, and chimaeras. Environmental Conservation 36: 97 - 103.

Stobutzki, I., M. Miller, D. Heales and D. Brewer. 2002. Sustainability of elasmobranchs caught as bycatch in a tropical prawn (shrimp) trawl fishery. Fisheries Bulletin 100: 800 – 821.

Stone, H. and L. Dixon. 2001. A comparison of catches of swordfish, *Xiphias gladius*, and other pelagic species from Canadian longline gear configured with alternating monofilament and monofilament nylon gangions. Fishery Bulletin 99: 210 – 216.

Thorpe, T. and D. Frierson. 2009. Bycatch mitigation assessment for sharks caught in coastal anchored gillnets. Fisheries Research 98: 102 – 112.

Tolotti, M., J. Filmalter, P. Bach, P. Travassos, B. Seret, and L. Dagorn. 2015. Banning is not enough: The complexities of oceanic shark management by tuna region fisheries management organizations. Global Ecology and Conservation 2: 1 – 7.

Torres-Irineo, E., M. Amandè, D. Gaertner, A. Delgado de Molina, H. Murua, P. Chavance, J. Ariz, J. Ruiz and N. Lezama-Ochoa. 2014. Bycatch species composition over time by tuna purse-seine fishery in the Eastern tropical Atlantic Ocean. Biodiversity and Conservation 23: 1157 – 1173.

Trent, L., D. Parshley and J. Carlson. 1997. Catch and bycatch in the shark drift gillnet fishery off Georgia and East Florida. Marine Fisheries Review 59: 19 – 28.

Walker, T., R. Hudson, and A. Gason. 2005. Catch evaluation of target, by-product, and by catch species taken by gillnets and longlines in the shark fishery of South Eastern Australia. Journal of Northwest Atlantic Fisheries Science 35: 505 – 530.

Walmsley, S. 2004. The assessment and management of bycatch and discards in the South African demersal trawl fishery. Doctor of Philosophy, Rhodes University 275 pages.

Ward, P., E. Lawrence, R. Darbyshire and S. Hindmarsh. 2008. Large-scale experiment shows that nylon leaders reduce shark bycatch and benefit pelagic longline fishers. Fisheries Research 90: 100 – 108.

Ward, P., R. Myers and W. Blanchard. 2004. A fish lost at sea: the effect of soak times on pelagic longline catches. Fishery Bulletin 102: 179 – 195.

Watson, J., S. Epperly, A. Shak and D. Foster. 2005. Fishing methods to reduce sea turtle mortality associated with pelagic longlines. Canadian Journal of Fisheries and Aquatic Sciences 62: 965 – 981.

Worm, B., B. Davis, L. Kettemar, C. Ward-Paige, D. Chapman, M. Heithaus, S. Kessel and S. Gruber. 2013. Global catches, exploitation rates, and rebuilding options for sharks. Marine Policy 40: 194 – 204.

Yokota, K., M. Koyota and H. Minami. 2006. Shark catch in a pelagic longline fishery: comparison of circle and tuna hooks. Fisheries Research 81: 337 – 341.