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Technology and Policy in Reducing Shark Bycatch: An Overview

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Image courtesy of the Seathos Foundation

> *The portion of a commercial fishing catch that consists of marine animals caught unintentionally* (Definition of bycatch, according to *Merriam-Webster Online*)
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> *Sea creatures caught by accident—except not really 'by accident,' since bycatch has been consciously built into contemporary fishing methods* (Definition of bycatch, according to Jonathan Safran Foer, *Eating Animals*, 2009, p. 49)

Perhaps the ocean's fatal flaw is its size. The ocean is incomparably vast, spanning 71% of the earth's surface. However, this statistic does not do the expanse of the ocean justice. Any visitor to the beach can attest to the seemingly overwhelming and full nature of the sea. It would be difficult for these frequent visitors to the beach to picture the ocean as it is soon likely to be: largely devoid of those flashes of silver that occasionally illuminate the water, or the splashes of color that dart here and there dotting forests of kelp. It would be even more difficult for them to understand that they are probably contributing to this very problem. Yet, this future is precisely the hollow one that modern commercial fishing has brought to bear.

It is estimated that by midcentury, in the absence of change, most commercial fisheries could collapse (World Wildlife Fund, n.d.b). Unless some kind of radical change is made, soon few will have the experiences of eating tuna sashimi, enjoying shrimp with cocktail sauce, or feasting on a bowl of clam chowder. Moreover, according to the Food and Agriculture Organization of the United Nations, the 1 billion people who depend on fish for protein will be deprived of a vital food resource (World Wildlife Fund, n.d.b). If commercial fishing continues at its current rate, fishermen will lose their livelihoods; aquariums will likely just contain relics of a bygone age; multitudes of aquatic ecosystems will probably have collapsed. The oceans will lack the organisms that scientists, fishermen, and beachgoers alike have come to love.

Since commercial fishing took off in the 1950s with the introduction of new fishing technologies like nylon nets, fish freezing, and sonar, large fish stocks have declined by 90% (World Wildlife Fund, n.d.b). Commercial fisheries have the sweeping capacity to deploy 1.4 billion longline hooks per year and to gather 50 tons of ocean wildlife in one fell swoop on just one fishing boat (Foer, 2009). This incredible capacity comes in response to incredible demand. US imports of tuna constituted 7.8% of the global fish market in 2007, and in 2010, 314.863 tons of tuna were brought to the United States, worth a total of 1.304 million dollars (World Wildlife Fund, n.d.a). However, one of the less acknowledged ramifications of such demand for certain valuable fish species is that fishermen will target a species regardless of ecological consequences. One of these consequences, a problem of immense significance, is the “bycatch” problem, wherein species accidentally caught are thrown into the ocean to die. 145 “other species” of marine wildlife die as bycatch in the aforementioned valuable tuna fisheries, including many endangered species (Foer, 2009). This unintentional capture of non-target species in fishing contributes extensively to overfishing. According to Greenpeace, bycatch—which goes entirely to waste—is estimated to account for between 8-25% of the global total catch (Greenpeace, n.d.). 8% may not seem to be a high percentage, but in the context of a fishery that is estimated to run itself into the ground in less than 40 years, this entirely wasted resource is significant indeed, and thus needs to be addressed immediately.

Due partly to lack of information about commercial bycatch, bycatch reduction and mitigation has been largely neglected, with tragic consequences. Measuring the impact of any given activity on fish populations is difficult due to an inherent uncertainty about how many of a given species are actually in the ocean at a given time. Bycatch poses particular difficulties due to the restrictive nature of information on accidental catches. According to Professor Larry Crowder of Stanford University, who is the science director at the Center for Ocean Solutions and studies bycatch extensively, these data are always hindered by confidentiality agreements with fishermen, which incentivize fishermen enough to even reveal the information. Data typically come in two forms. The first is logbook data. These records tend to be available for long periods of time, but—since they are provided by fishermen themselves without being reviewed—logbook data often claim to have a lower incidental catch rate than is actually true. Understandably, the other kind of data available—data taken from trained observers, who go aboard fishing vessels and document the accidental catch—are typically more accurate, but rarely available over a longer time scale or from a large percentage of the fleet. Moreover, high quality data like these are very scarce due to the high cost of training observers. But to formulate a definitive interpretation of a set of data, accurate long-term data is also necessary. Even beyond commercial fisheries, there also exist "pirate" fisheries—the so-called IUU (illegal, unregulated, and unreported) fisheries that are said to account for between 15-20% of fish landings worldwide (Crowder, 2012). Little to nothing is known about how these fisheries operate and what species are being fished, making the issue of bycatch even more uncertain. Greenpeace puts it most bluntly: "no-one [sic] knows how much of a problem [bycatch] really is" (Greenpeace, n.d.). This uncertainty leads to grave difficulties in formulating policy. Professor Crowder says that technology is available to ameliorate the effects of bycatch, but that implementing such technologies is hindered by rampant uncertainty, which keeps adequate policy from being employed to force a technology's adoption. Crowder asserts that policy often "lags" because policymakers "have to be convinced there is a bycatch problem before…[they] do something about the bycatch problem". When studying a volatile population in conjunction with data so rife with uncertainty, convincing policymakers is difficult. Moreover, Crowder specifies that policy changes involving changes in fishing equipment must also come with supporting evidence that the new technology is effective, both in reducing bycatch and in maintaining a large catch of the target species. One example of such difficulty is a study done in the Gulf of California on the use of a BRD (Bycatch Reduction Device) on shrimp trawling. In this study, performed from January to July of 2007, the bycatch reduction device yielded a 40% reduction in bycatch. The scientists involved deduced that the device would save 73,000 "tons of bycatch per year in the Gulf" but lamented that although "with a shrimp-capture loss of 7%, an average shrimp boat will continue to realize profits…opportunity costs could make this type of shrimping financially unattractive" (García-Caudillo, Cisneros-Mata, & Balmori-Ramírez 199, 2000). The fact that, even with a high bycatch reduction and a low cost in target species, bycatch reduction techniques are still often “financially unattractive” is revelatory of the high standards that new technologies must meet in order to be incorporated by fishermen.

Moreover, bycatch data—and, by extension, the national policies it prompts—is complicated by the fact that fish are naturally unaware of territorial boundaries. The large pelagic species whose populations have declined so drastically in recent years tend to also have large ranges, making national data deceiving and migrating populations vulnerable to differing national policies (Lewison, Crowder, Read, & Freeman, 2004). For example, it is illegal to harvest sharks for their fins in the United States Economic Exclusive Zone (which extends 200 miles off the U.S. coastline) but in other areas finning is legal, so migratory shark species are vulnerable to fishing operations as soon as they leave the protective EEZ. Similarly, in the United States the use of a turtle excluder device (TED) to reduce turtle bycatch is mandatory in shrimp trawling operations, but turtles have large ranges and can easily move to areas where this is not the case. Moreover, modern fleets themselves are multinational, so an international approach is logically necessary both in data collection and in policy (Lewison, Crowder, Read, & Freeman, 2004). The multinational nature of these fleets mean that bycatch pressure is high in areas unrelated to nearby countries, i.e. that high levels of bycatch do not correspond necessarily to a neighboring country with high levels of commercial fishing (*Figure 1).* The efforts of individual nations are riddled with problems both relating to data and policy.

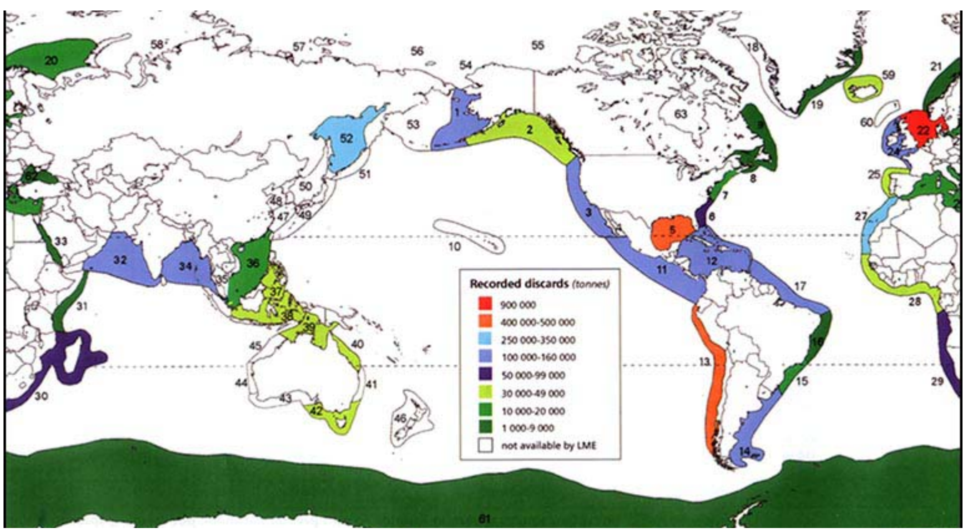

FIGURE 1. The map features a geographical distribution of accidental catches (Kelleher, 2005).

Although bycatch poses an enormous problem to many populations of marine animal, sharks in particular have suffered particular declines due to accidental catches. Shark biology makes intense fishing devastating to their populations. Sharks are slow to reproduce and long-lived, so a short burst of increased fishing pressure can have a devastating impact on their population. And as top predators, they play crucial roles in ecosystems. Dr. Ransom Myers of Dalhousie University and his collaborators found that when numbers of North Atlantic predatory sharks dwindled, their absence led to immense population growth for cownose rays, who then fed extensively on bay scallops, reducing the numbers of scallops substantially. The elimination of sharks from this geographic region brought the bay scallop fishery to a halt, which had previously run for a century without collapse (Myers, Baum, Shepherd, Powers, & Peterson, 2007). Due to these significant and converging factors, insulating shark populations from the negative effects of fishing is particularly important.

Moreover, bycatch is a major contributor to the overall fishing pressure on sharks. Approximately 38 million sharks are intentionally killed for fins each year (Bakalar, 2006). However enormous this number might seem, it pales in comparison to the estimated 100 million sharks killed pointlessly every year as bycatch. Nearly two and a half times as many sharks are caught accidentally as are caught on purpose, making the recent public attention towards shark finning—as evidenced by multitudinous shark finning bills and anti-shark finning campaigns in recent years—seem a bit misplaced. According to the Monterey Bay Aquarium, “nearly 20% of shark species are threatened with extinction, primarily as a result of being caught accidentally on longlines” (Monterey Bay Aquarium, n.d.). Recent declines in shark populations are linked to bycatch, perhaps more than to intentional fishing pressures.

Due to the impact of bycatch on shark populations and their importance in ocean ecosystems, it is important to investigate methods of reducing this bycatch. One of the most obvious strategies to effect change is to modify the fishing gear used. Many technologies have been invented with the aim of reducing shark bycatch. These efforts have had mixed success: some technologies have been shown to reduce shark bycatch substantially without having a major adverse impact on target catches, but are still not implemented due to the difficulties and opportunity costs of making even a small change in gear in a large fishing fleet. Such difficulty highlights the importance of policy in forcing a change in fishing methods. However, the international policy deemed necessary to protect sharks, in their inability to sense territorial boundaries, has met with little success. Both the technology and policy aspects of this issue need further examination to determine how this failing approach can be improved.

I. Technology Remedies for Shark Bycatch

Conservation concerns, along with some economic incentives,[1] have led to a plethora of possible gear changes to reduce shark bycatch. These technological fixes must meet high standards, and must be proven to work without reducing the target catch in order to be accepted by fishermen (Crowder, 2012). However, there are a number of promising options available.

Different fishing technologies have different levels of shark bycatch. Although shrimp trawls are notorious for yielding large quantities of bycatch for all species (Table 1), shrimp trawls are not necessarily the most harmful forms of fishing for sharks. The gear responsible for the greatest quantities of shark bycatch seems likely to be the longline, which typically aims to catch tuna and swordfish but is also responsible for large numbers of discards overall (Monterey Bay Aquarium, n.d.).[2] Part of the challenge of reducing bycatch from longline fisheries stems from the fact that sharks possess remarkably similar biological traits to tuna and swordfish, so fishing techniques that aim to catch these big fish are likely to catch sharks as well (Crowder, 2012). Thus longlines targeting tuna and swordfish are more likely to pose greater threats to sharks than the infamous shrimp trawl.

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[1] The World Wildlife Fund has created a competition to reduce bycatch, with a cash prize that goes to whoever invents the best gear change for bycatch reduction.

[2] These longlines are also occasionally used to catch sharks intentionally for their fins.

TABLE 3
Summary of discards by major types of fishery (tonnes)

Fishery	Landings	Discards[1]	Weighted average discard rate (%)	Range of discard rates (%)
Shrimp trawl	1 126 267	1 865 064	62.3	0-96
Demersal finfish trawl	16 050 978	1 704 107	9.6	0.5-83
Tuna and HMS longline	1 403 591	560 481	28.5	0-40
Midwater (pelagic) trawl	4 133 203	147 126	3.4	0-56
Tuna purse seine	2 673 378	144 152	5.1	0.4-10
Multigear and multispecies	6 023 146	85 436	1.4	n.a.
Mobile trap/pot	240 551	72 472	23.2	0-61
Dredge	165 660	65 373	28.3	9-60
Small pelagics purse seine	3 882 885	48 852	1.2	0-27
Demersal longline	581 560	47 257	7.5	0.5-57
Gillnet (surface/bottom/trammel)[2]	3 350 299	29 004	0.5	0-66
Handline	155 211	3 149	2.0	0-7
Tuna pole and line	818 505	3 121	0.4	0-1
Hand collection	1 134 432	1 671	0.1	0-1
Squid jig	960 432	1 601	0.1	0-1

TABLE 1. Discards listed by fishery (Kelleher, 2005)

Tuna and other longlines account for 560,481 metric tons of yearly discards in comparison to 1,403,591 metric tons of intentional landings yearly (Table 1). Midwater longlines consist of lengths of nylon rope from which drop different lengths of baited hook. Bottom longlines are weighted and left on the bottom, and these different hooks float up from the lines. These lines are up to 40-75 miles long (Crowder, 2012), and are sometimes left in the water for days. Updated and comprehensive data on the precise numbers of shark deaths due to longlines are not widely available, however, since bycatch rates in different fishing locations can be remarkably different (Kelleher, 2005).

A number of technological changes have been proposed to ameliorate the effects of longline fishing on sharks. Perhaps one of the more promising possibilities is a change from wire leaders to nylon leaders. Using nylon leaders instead of wire leaders has been shown to significantly reduce shark bycatch, as sharks can bite through the nylon. A study conducted in September of 2005 through December of 2006 near Australia found that the use of nylon leaders instead of wire leaders nearly halved accidental catch rates. Moreover, in this study, more tuna were caught with nylon leaders than wire leaders, creating an economic incentive to switch to nylon leaders, which was shown to compensate for the economic problems associated with switching (including the issue of increased "gear loss") (Ward, Lawrence, Darbyshire, & Hindmarsh, 2008). Nylon leaders are also safer for fishermen, who can be injured by wire leaders (Crowder, 2012).

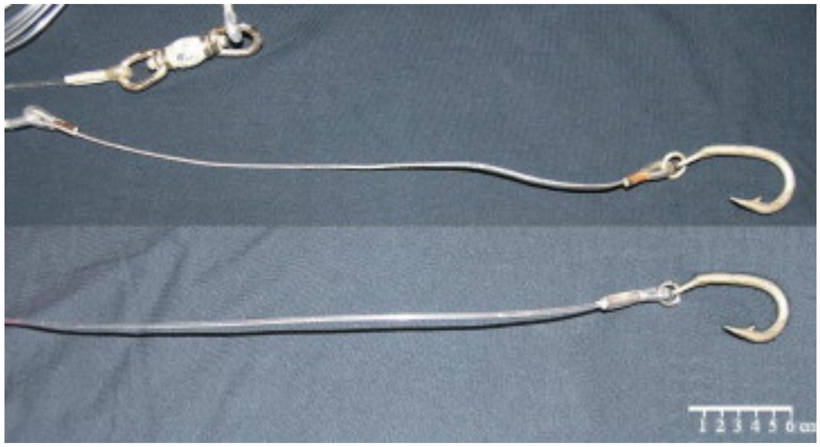


FIGURE 2. The above are wire (above) and nylon (below) leaders (Ward et. al, 2008).

Other ways of ameliorating shark bycatch due to longlines have been proposed as well. The first of these options is the promise of rare earth metals in the reduction of shark bycatch, a recent discovery that holds much potential but has not yet been thoroughly explored. In the laboratory, spiny dogfish (*Squalus acanthius)* have been shown to react negatively to both "cerium mischmetal" (an alloy of different rare earth metals, composed of predominately cerium) and magnets (Stoner & Kaimmer, 2008). This "mischmetal" was shown to have the additional capability of actually deterring dogfish from bait, whereas magnets did not have this level of success. "Mischmetal" was also shown to have no effect on the target species—pacific halibut, *Hippoglossus stenolepis*—in this case. Unfortunately, there are significant drawbacks to the use of "mischmetal." It hydrolyzes in ocean waters, and can be costly, poisonous, and dangerous (Stoner & Kaimmer, 2008). But despite its drawbacks, the potential of incorporating some form of "mischmetal" with longline baits is great, and so further exploration is clearly necessary.

Another possible technology fix to reduce shark bycatch is the circle hook. These modified hooks catch sharks in the corner of the jaw instead of the stomach, reducing mortality and often allowing them to escape. This technology has, however, met with relatively mixed success. A study performed in Hawaii in 2005 and 2006 showed 17.1-27.5% reduction rates in shark bycatch when circle hooks were implemented, without a significant difference in the target species, tuna (Curran & Bigelow, 2011). However, an extremely similar study examined the impact of circle hooks on blue shark catches near Japan, and found that circle hooks "had little impact on catch rate and mortality of blue shark" (Yokota, Kiyota, &

Minami, 2006). Circle hooks are thus far less likely to be implemented than other bycatch reduction technologies for longlines, since the evidence of their success is far lower.

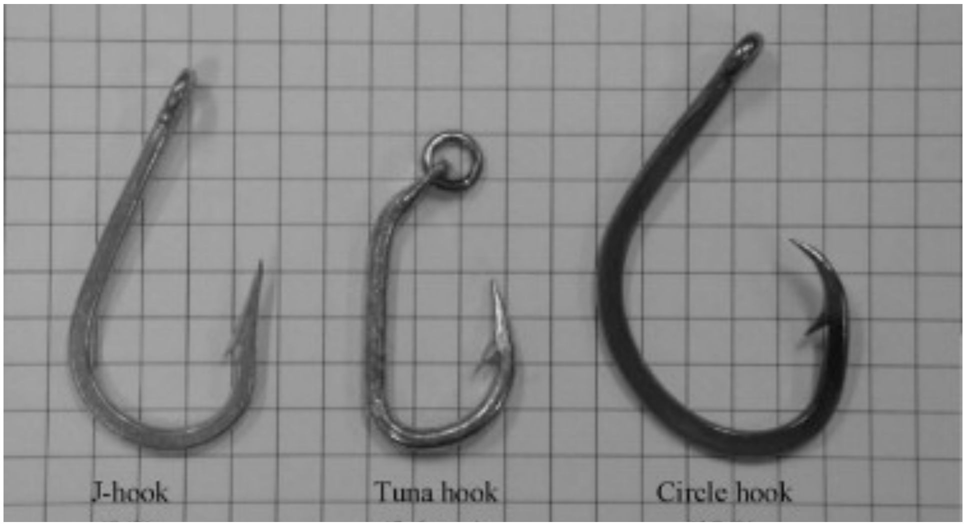


FIGURE 3. Different types of hooks were used in the 2005 study performed in Hawaii. (Curran & Bigelow, 2011)

Devices to reduce bycatch have been suggested for the trawl industry as well. Trawls are large nets that can be dragged through the water column or along the seafloor by a ship. Although this industry does not seem to contribute as much to shark bycatch as longlines do, probably because sharks are usually large pelagic fish that swim in the middle of the water column, it still has enough of an impact to be worth consideration. And there are also a number of promising bycatch solutions for this fishing method. Moreover, technologies proposed for other species to reduce bycatch from this method have been integrated with policy highly successfully, and so can provide a good model for how shark bycatch should be addressed, even if they do not address it directly.

One of the earliest bycatch solutions generated for the trawling industry is a grate that allows large fish to swim up and out of the trawl, while maintaining catch levels of smaller species. One such grate is known as the Nordmore grate (see Figure 4). This device is used mainly for other species, but is a fairly typical BRD (bycatch reduction device) and has provided something of a model for more relevant BRDs.

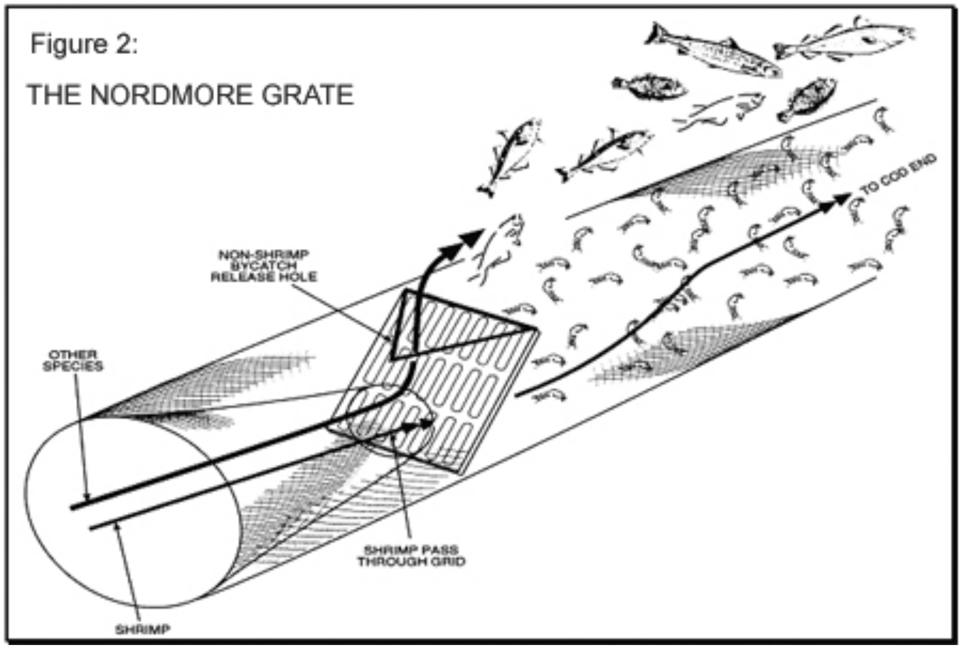
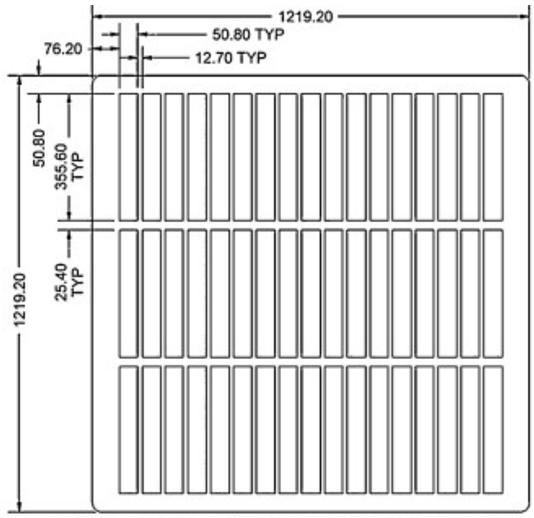


FIGURE 4. The diagram demonstrates the functions of a Nordmore grate. (Fisheries and Oceans Canada, 2009)

A similar type of grate has been used for sharks with some success. A study conducted in Massachusetts Bay in 2008 to 2009 found that integration of a bycatch reduction grate (see Figure 5) cut the bycatch of the shark species *Squalus acanthus* (spiny dogfish) substantially. The increased exclusion of these dogfish led to "increases in the quality of marketable catches, likely reductions in non-target species mortality, and decreases in the codend catch handling times" (Chosid, Pol, Szymanski, Mirarchi, & Mirarchi, 2012). Grates like these could be promising bycatch solutions for smaller sharks suffering the effects of trawl bycatch.



PLASTIC	VOLUME (mm^3)	DENSITY (kg/mm^3)	WEIGHT IN AIR (kg)	DENSITY OF SALT H2O (kg/mm^3)	WEIGHT IN H20 (kg)
HDPE	1.65x10^7	9.69	16.0	9.96	0.45

FIGURE 5. Above are schematics for a bycatch reduction device used for spiny dogfish exclusion. (Chosid et. al, 2012)

Perhaps the greatest success story in the wider issue of bycatch has been the TED (Turtle Excluder Device). Although this technology does not address shark bycatch, its success is revelatory of how bycatch technology and policy can be integrated successfully to make substantial bycatch reductions. TEDs are large grates that—similarly to the Nordmore grate—are placed within shrimp trawls. They allow shrimp to pass through the grate while redirecting turtles out of the shrimp trawl, excluding vast amounts of turtle bycatch. The TED was first developed by the National Marine Fisheries Service (NMFS) in the early 1980s. TEDs were then refined significantly, and in 1983 a much lighter TED was developed—in response to fishermen's complaints about their weight and "cumbersome" nature—that achieved 97% turtle exclusion with "minimal shrimp loss" (Southeast Fisheries Science Center, n.d.). The TED was successful in part because of this ability to adapt to the needs of fishermen. It was also successful because it had a high, proven exclusion rate without compromising the target catch.

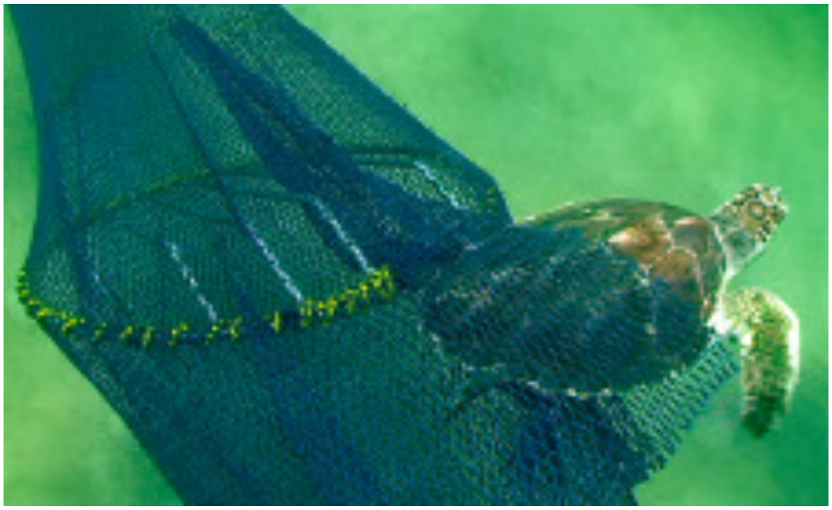


FIGURE 6. A turtle escapes a turtle excluder device. (Southeast Fisheries Science Center, n.d.)

Lastly, and crucially, the TED was integrated well with mandatory national policies. In 1987 the National Oceanic Atmospheric Association (NOAA) began to enforce the use of TEDs on all United States shrimping vessels. The ensuing outcry by fishermen—who still found, occasionally, some declines in target catch and some weaknesses in the devices themselves—led NMFS to make some modifications to the TEDs. The law was then shifted to a more international focus when, in 1989, it was mandated that countries exporting shrimp to the United States be certified as "having a regulatory program comparable to that of the United States for reducing the incidental catch of sea turtles in shrimp trawls" (Southeast Fisheries Science Center, n.d.). A rigorous, internationally focused policy program was implemented alongside the new technology, and policymakers listened to and responded to the needs of fishermen in order to make the implementation of the TED practically feasible and economically viable. For these reasons, the TED has been an outstanding success in the field of bycatch reduction.

II. International Shark Bycatch Reduction Policy

As is evidenced by the success of the TED, to address the problem of shark bycatch on an international level, international policy must be implemented alongside improved technologies for successful bycatch reduction. Unfortunately, international policy faces particular challenges when dealing with the ocean. Regulation of ocean fisheries is divided into two subgroups. The first is the RFMO (Regional Fishery Management Organization), which deals with the management of migratory fish stocks in the open ocean. The problem with these committees is that they were initially established to promote fishing in the open ocean—in the same way that the International Whaling Commission was originally established to promote whaling—and so they have a historical obstacle to overcome. Moreover, there is little enforcement in these areas, so, according to

Professor Larry Crowder, "compliance can still be largely voluntary." RFMOs help assess how many fish are left and make recommendations for policy, but these are voluntary recommendations, not enforced laws (Crowder, 2012).

This kind of voluntary compliance is in fact the overarching theme of international bycatch policy. The one exception, wherein policy is actually actively enforced, is within the Economic Exclusive Zone of a given country. Professor Crowder claims that "the best legal framework is if a fishery happens to be within the EEZ of a nation, then a nation can make it be required…In international waters it's very…difficult because there are best practices…but really no consequences" (Crowder, 2012). This kind of success has been evidenced by the mandated use of technologies like the TED. Moreover, the U.S. does mandate some other best practices to reduce bycatch levels. However, due to the migratory nature of fish stocks, as mentioned earlier, international policy is desperately needed, and enforcement in international areas is lacking.

The international legal framework currently in place is overseen by the Food and Agriculture Organization of the United Nations (the FAO), and is signed by 170 countries. It was first implemented in 1995, as part of the Code of Conduct for Responsible Fisheries. This code outlined a few main goals for countries seeking to manage fisheries responsibly, but again, it was completely voluntary, despite being supposedly based on principles of international law (U.N. Food and Agriculture, 1995). Professor Larry Crowder believes that international normative acts like these have the power to "lead to some improvements in behavior…by some states but not others" (Crowder, 2012). Crowder says that regional requirements to implement bycatch reduction technologies would be more effective.

The actual text of the Code of Conduct is incredibly vague, but its main objectives were to help states implement their own individual frameworks for dealing with fisheries management, while consolidating a list of fundamental concepts to be incorporated into these frameworks. The code did, however, make a few specific points about these concepts. The first was that research into fishing methods should be funded and supported by member countries. This clause is a logical consequence of the fact that accurate bycatch and fishing data are rarely available, and even more rarely are population data known with any certainty. As a consequence of this second problem, the FAO also decided to implement the "precautionary principle," which is a standard environmental regulatory practice that claims that uncertainty—or even a lack of scientific information whatsoever—about a given population should not be used as an excuse not to protect the population. Instead, the most conservative population estimates available should be used at all times in order to protect fishing stocks. The third relevant clause is that fishing technologies that are not effective in excluding bycatch should be gradually replaced with newer technologies that do (U.N. Food and

Agriculture, 1995). The FAO specified that "selective and environmentally safe fishing gear and practices should be further developed and applied…states and users of aquatic ecosystems should minimize…catch of non-target species" (U.N. Food and Agriculture, 1995). All of these principles account for the various problems with past bycatch reduction strategies.

Under the larger umbrella of this policy framework, a second plan was implemented that pertains specifically to shark conservation. This plan was known as the International Plan of Action for the Conservation and Management of Sharks (IPOA-Sharks) and was implemented in 1999 in Rome as a consequence of the Code of Conduct for Responsible Fisheries. This international agreement was again nonbinding, but included both bycatch and intentional catch. Its foundation included the concept of "participation"—that every nation contributing to the fishing pressure on a given species should be involved in the regulation of that industry (U.N. Food and Agriculture, 1999). The plan reinforced the importance of the so-called "precautionary principle" and also detailed that "nutritional and socio-economic" concerns should be addressed in the regulation of the fishing industry (U.N. Food and Agriculture, 1999). The plan then proceeded to order states to formulate individual "shark plans" based on the common set of principles the FAO laid out. It also mandated states to have completed these plans by the 2001 United Nations Conference on Fisheries. The components of the shark plan were diverse, but included regular assessments of local shark populations and the creation of "abundance indices," which could then be reported by individual countries back to the FAO. According to the FAO, "shark plans" were supposed to include this assessment as well as a clear overall objective, and implement strategies such as increased use of sharks caught as bycatch (likely in order to reduce intentional fishing pressure), further research into shark populations, and increased bycatch data collection and "monitoring" (U.N. Food and Agriculture, 1999).

Unsurprisingly, given that no consequences were implemented for countries that did not make changes to their shark policies, the IPOA-Sharks and Code of Conduct were ultimately not very successful. In 2005, the effectiveness of the Code of Conduct and the associated IPOA-Sharks were examined, and found to be remarkably lacking. 30% of FAO member countries declared the need for shark plan, but only 10% of members put a "plan" in place (U.N. Food and Agriculture, 2005). This tiny portion of signatories means that only 11% of nations catching sharks around the world paid any heed to the IPOA-Sharks (U.N. Food and Agriculture, 2005). The 2005 examination also found that the main problems facing its implementation remained "an absence of precise and accurate data relating to all aspects of the fisheries," including documentation of the amount and type of bycatch and population data (U.N. Food and Agriculture, 2005). Other inherent problems with the plan included a lack of funds and enforcement, as well as a sense of apathy towards sharks as a species, as importance was given to other fisheries besides shark fisheries (U.N. Food and Agriculture, 2005). This neglect could have been due to the (inaccurately) perceived unimportance of shark populations to many major commercial fishing operations: as sharks are not typically targeted by major operations, they are perhaps seen to be lower conservation priorities, although they are essential for healthy ocean ecosystems and robust target catch populations. The voluntary nature of the agreement was found to be problematic as well because few countries felt any pressure to react to the agreement. Overall, the program was found to be severely lacking, due to its nonbinding nature and the severe paucity of data it was faced with.

III. Prompting Policy: Methods for Dealing With Scientific Uncertainty

As is evidenced by the failure of the IPOA-sharks, the scarcity of information on catch numbers and shark populations has caused real policy problems. There have, however, been many recent attempts to remedy this problem using different data analysis approaches to the scarce and uncertain data available. Not many of these analyses have been applied to sharks, but they hold much potential for determining more accurately the effect of accidental catches on shark populations.

One of the most direct ways of dealing with uncertainty is simply to acknowledge it in determining the effect of bycatch on a given population. Providing a range of values based on a variety of different bycatch and population models rather than exact values accounts well for the many uncertain factors involved in such a model (Crowder, 2012). Another approach that has been applied to shark populations in particular (by shark conservation biologist Julia Baum) chose to exclude logbook data that did not find any bycatch, and then assumed that if bycatch was recorded it was recorded accurately. "Scenario analys[es]" have also been used, in which uncertainty is accounted for by projecting different population and/or bycatch levels based on distinct levels of certainty (Lewison, Crowder, Read, & Freeman, 2004). Lastly, to study the impacts of bycatch on population, a life history approach can be taken, in which a table is constructed (using the bootstrap method) containing the probability of an animal surviving after a certain age (Lewison, Crowder, Read, & Freeman, 2004). This table is then used to predict the impacts of bycatch on population at each age class (Crowder, 2012). All of these methods present possible solutions to the rampant uncertainty involved in determining the effects of bycatch on shark populations.

IV. Finding A Solution

A solution to the widespread and damaging problems posed by high levels of shark bycatch must address the problem from a policy perspective as well as a technology perspective, and involve much more research, data collection, and uncertainty analysis. As is exemplified by the success of the TED, when technology and policy are integrated along with input from fishermen, they can experience high levels of success. But for these programs to be successful, there must be adequate data, not only revealing the impact of bycatch on a given population, but also focused on the status of that shark population and the ability of the gear change to exclude the non-target species. Thus a more interdisciplinary approach to manage sharks would be most successful, in which technology could be developed in conjunction with policy, supported by adequate research and funding. Moreover, international policy on this front has not been effective, and could be improved by consequences for countries that do not take action. However, to even make such action a possibility, more data is needed. For those aiming to conserve sharks, the next step is further research.

References

Bakalar, N. (2006, October 12). 38 million sharks killed for fins annually, experts estimate. *National Geographic Magazine*. Retrieved from http://news.nationalgeographic.com/news/2006/10/061012-shark-fin.html

Bycatch. (n.d.). In *Merriam-Webster Online*. Retrieved from http://www.merriam-webster.com/dictionary/bycatch

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

Crowder, L. (2012, February 22). [Telephone interview by the author].

Curran, D., & Bigelow, K. (2011). Effects of circle hooks on pelagic catches in the Hawaii-based tuna longline fishery. *Fisheries Research*, *109*(2-3), 265-275.

Fisheries and Oceans Canada. (2009, April). Northern shrimp northeast Newfoundland, Labrador coast and Davis strait-effective 2003. Retrieved from http://www.dfo-mpo.gc.ca/fm-gp/peches-fisheries/ifmp-gmp/shrimp-crevette/shrimp-crevette-2003-eng.htm

Foer, J. S. (2009). *Eating animals*. New York, NY: Back Bay Books.

García-Caudillo, J. M., Cisneros-Mata, M. A., & Balmori-Ramírez, A. (2000). Performance of a bycatch reduction device in the shrimp fishery of the Gulf of California, México. *Biological Conservation*, *92*(2), 199-205.

Greenpeace. Bycatch. (n.d.). Retrieved from http://www.greenpeace.org/international/en/campaigns/oceans/bycatch/

Kelleher, K. (2005). Discards in the world's marine fisheries: An update (Technical Report No. 470). Retrieved from http://www.fao.org/docrep/008/y5936e/y5936e00.htm - Contents

Lewison, R. L., Crowder, L. B., Read, A. J., & Freeman, S. A. (2004). Understanding impacts of fisheries bycatch on marine megafauna. *Trends in Ecology and Evolution*, *19*(11), 598-604. Retrieved from http://atlanticsharks.org/papers/Lewison_et_al_2004.pdf

Monterey Bay Aquarium. (n.d.). Wild seafood issue: Bycatch. Retrieved from http://www.montereybayaquarium.org/cr/cr_seafoodwatch/issues/wildseafood_bycatch.aspx

Myers, R. A., Baum, J. K., Shepherd, T. D., Powers, S. P., & Peterson, C. H. (2007). Cascading effects of the loss of apex predatory sharks from a coastal ocean. *Science*, *315*, 1846-1850. Retrieved from http://www.sciencemag.org/content/315/5820/1846.full.pdf

Seathos Foundation. (n.d.). Shark bycatch. Retrieved from http://www.seathos.org/shark-bycatch

Southeast Fisheries Science Center. (n.d.) History of Turtle Excluder Devices (TEDs). Retrieved from http://www.sefsc.noaa.gov/labs/mississippi/ted/history.htm

Stoner, A. W., & Kaimmer, S. M. (2008). Reducing elasmobranch bycatch: laboratory investigation of rare earth metal and magnetic deterrents with Spiny Dogfish and Pacific Halibut. *Fisheries Research*, *92*(2-3), 162-168.

U.N. Food and Agriculture Organization. (1995). Code of conduct for responsible fisheries. Retrieved from http://www.fao.org/docrep/005/v9878e/v9878e00.HTM

U.N. Food and Agriculture Organization. (1999). International plan of action for the conservation and management of sharks. Retrieved from http://www.fao.org/fishery/ipoa-sharks/en

U.N. Food and Agriculture Organization. (2005, March). Progress in the implementation of the Code of Conduct for Responsible Fisheries and the related International Plans of Action. Retrieved from ftp://ftp.fao.org/docrep/fao/meeting/009/j4176e.pdf

U.N. Food and Agriculture Organization. (2005, December). FAO expert consultation on the implementation of the FAO international plan of action for the conservation and management of sharks. Retrieved from ftp://ftp.fao.org/docrep/fao/009/a0523e/a0523e00.pdf

Ward, P., Lawrence, E., Darbyshire, R., & Hindmarsh, S. (2008). Large-scale experiment shows that nylon leaders reduce shark bycatch and benefit pelagic longline fishers. *Fisheries Research*, *90*(1-3), 100-108.

World Widlife Fund. (n.d.a). Tuna. Retrieved from http://wwf.panda.org/what_we_do/footprint/smart_fishing/target_fisheries/tuna_2/index.cfm

World Widlife Fund. (n.d.b). Unsustainable fishing. Retrieved from http://wwf.panda.org/about_our_earth/blue_planet/problems/problems_fishing/

Yokota, K., Kiyota, M., & Minami, H. (2006). Shark catch in a pelagic longline fishery: Comparison of circle and tuna hooks. *Fisheries Research*, *81*(2-3), 337-341.