Sharks-the state of the science

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Sharks

The State of the Science

Executive Summary

The biological characteristics of sharks make them particularly vulnerable to overfishing. They grow slowly, become sexually mature relatively late and produce few offspring. This vulnerability is reflected in the large number of shark species that are considered to be threatened or endangered.

A review of the current scientific literature on the number of sharks killed per year, the causes of this mortality, the status of shark species worldwide and the impact on ecosystems after large predators are removed provides the following key points:

- Millions of sharks are killed every year to supply the fin trade. In 2000, for example, 26 million to 73 million sharks were killed for fins, corresponding to 1.21 million to 2.29 million tons of shark.
- Commercial fisheries targeting sharks occur throughout the world. Sharks are sought primarily for their fins and meat but also for their cartilage, liver and skin.
- The five countries with the highest numbers of reported shark landings are Indonesia; India; Taiwan, Province of China; Spain; and Mexico.
- Shark bycatch is frequently reported in pelagic longline fisheries targeting tuna and swordfish and can represent as much as 25 percent of the total catch. This bycatch is considered to be a major source of mortality for many shark species worldwide.
- Blue sharks make up an especially large fraction of shark bycatch in pelagic fisheries (47–92 percent).
- The value of shark fins has increased with economic growth in Asia (specifically China), and this increased value is a major factor in the commercial exploitation of sharks worldwide.
- Declines in population sizes of sharks, as much as 70–80 percent, have been reported globally. Some populations, such as the porbeagle sharks in the northwestern Atlantic and spiny dogfish in the northeastern Atlantic, have been reduced by 90 percent or more.
- The removal of large sharks can negatively impact whole ecosystems by, for example, allowing an increase in the abundance of their prey (fewer sharks eat less prey), or influencing prey species through non-lethal means, by causing behavioral changes to prey habitat use, activity level and diet.
- Live sharks have a significant value for marine ecotourism (for example, recreational diving, shark feeding and shark watching) that is typically more sustainable and often more valuable than their individual value to fisheries. Whale shark tourism, for example, is estimated to be worth $47.5 million worldwide.

Sharks: The State of the Science

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Introduction

The current literature identifies dramatic declines in population sizes for several species of sharks worldwide. Sharks are susceptible to overfishing because of their life history characteristics, which include slow growth, slowness to reach maturation and few offspring (Cortés 2002; Heppell et al. 1999). The International Union for Conservation of Nature (IUCN) Red List designates 17 percent of assessed shark and ray species (of a total 1,045 assessed species) to be Threatened (11 percent Vulnerable, 4 percent Endangered and 2 percent Critically Endangered), 13 percent Near Threatened, 23 percent Least Concern and 47 percent Data Deficient (Camhi et al. 2009).

The status of individual shark species is often difficult to determine because of a shortage of long-term data on fishing effort and species-specific catches, landings and discards in commercial fisheries (Anderson 1990; Stevens et al. 2000; Bonfil 2005; Camhi et al. 2009). Sharks are targeted and caught as bycatch throughout the world's oceans and in fisheries that include pelagic and bottom longlines, drift and set gillnets and trawls (Gilman et al. 2008; Camhi et al. 2009; Morgan et al. 2009). Sharks are targeted primarily for their fins but also for their meat, cartilage and oils (Vannuccini 1999). One study of the global shark fin trade estimated that 26 million to 73 million sharks were killed in 2000 to supply the fin trade (Clarke et al. 2006a). Ecosystem models and some field studies suggest that the removal of these top predators has the potential to negatively impact marine ecosystems (Stevens et al. 2000; Bascompte et al. 2005; Myers et al. 2007; Polovina et al. 2009). This document summarizes current scientific literature on the number of sharks killed per year, the forces behind this mortality, the status of shark species worldwide and the impact on ecosystems after large predators are removed.

How many sharks are killed each year?

A recent quantitative study of the Hong Kong shark fin market found that the number of sharks killed to supply the fin trade in 2000 was 26 million to 73 million, which corresponds to 1.21 million to 2.29 million tons (Clarke et al. 2006a). This is the only comprehensive estimate of worldwide shark catches for any period (compared to other estimates that are not based on real data sets) and is three to four times higher than the concurrent estimated shark capture production data (volume of shark landings by country of capture, species and year for all commercial, industrial, recreational and subsistence purposes) compiled by the United Nations Food and Agriculture Organization (FAO) (Clarke et al. 2006a). The disparity between these estimates is probably because the FAO has only landing records (i.e., a shark is offloaded from a fishing vessel to another vessel or shoreside location/facility or to a port, dock, etc.) and has no data related to sharks that are unrecorded, recorded in non-shark categories or discarded at sea (Clarke et al. 2006a). Indeed, Clarke et al. (2006a) note that their paper may have underestimated global catches of sharks because landings by major Asian fishing countries (Japan and Taiwan) and discards of whole sharks at sea may not have been accounted for in the analysis. For example, Bonfil (1995) estimated that around 300,000 tons of sharks were caught annually as bycatch in the late 1980's and early 1990's and are therefore not reported or accounted for in fishing mortality estimates. The five countries with the highest numbers of reported shark landings are Indonesia; India; Taiwan, Province of China; Spain; and Mexico. Combined, they accounted for 42 percent of the landings in 2007 (Camhi et al. 2009).

Blue sharks (*Prionace glauca*) were the most commonly represented species (17 percent) in the Hong Kong fin market and it was estimated that 11 million (5 million-to-16 million range) blue sharks were represented in the shark fin trade in

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Sharks are particularly vulnerable to overfishing because of their slow growth, late sexual maturity, and small number of offspring

2000. (Clarke et al. 2006a). Shortfin mako (*Isurus oxyrinchus*), silky (*Carcharhinus falciformis*), sandbar (*C. plumbeus*), bull (*C. leucas*), hammerhead (*Sphyrna spp.*) and thresher (*Alopias spp.*) sharks represented 2 to 6 percent at that market (Clarke et al. 2006b).

The most significant causes of shark mortality

Commercial shark fishing

Commercial fisheries targeting sharks occur throughout the world. Sharks are targeted primarily for their fins and meat but also for their cartilage, liver and skin (Vannuccini 1999). Well-documented collapses of directed shark fisheries (where sharks are the primary target) include:

- the spiny dogfish (*Squalus acanthias*) off British Columbia (Ketchen 1986) and the North Sea (Hoff and Musick 1990; Holden 1968),
- soupfin (or school) sharks (*Galeorhinus galeus*) off Australia (Olsen 1959) and off California (Ripley 1946),
- porbeagle sharks (*Lamna nasus*) in the North Atlantic Ocean (Campana et al. 2008; Campana et al. 2001; Anderson 1990),
- sandbar and dusky (*C. obscurus*) sharks in the Northwest Atlantic (National Marine Fisheries Service 2006; Cortés et al. 2006).

Directed shark fisheries are typically characterized by a "boom and bust" pattern, wherein high initial catches rapidly diminish and the species is very slow to recover once the fishery is restricted.

In the southeastern United States, the primary gear used to harvest coastal sharks is bottom longline (Morgan et al. 2009; Hale and Carlson 2007). Gillnet fisheries there also target sharks but to a much lesser degree (Passerotti and Carlson 2009). Historically, the bottom longline fishery has primarily targeted sandbar and blacktip sharks (*C. limbatus*), and the gillnet fisheries have targeted blacktip sharks, although many other species of sharks are caught in both fisheries (Morgan et al. 2009; Passerotti and Carlson 2009). However, recent amendments to the Consolidated Atlantic Highly Migratory Species Fishery Management Plan drastically reduced the directed shark fishery in the U.S. Atlantic after the abundance of several species declined severely (National Marine Fisheries Service 2007a).

In the Northeast Atlantic, French and Spanish longline fisheries target porbeagle and other pelagic sharks (Clarke et al. 2008). In the Northwest Atlantic waters of Canada, directed fisheries exist for porbeagles (Campana et al. 2008) and spiny dogfish (Wallace et al. 2009). The Pacific waters of Canada also have a directed longline fishery for spiny dogfish (Wallace et al. 2009). Off the coast of Washington, Oregon and California, thresher (*A. vulpinus*) and shortfin mako sharks are targeted by the drift gillnet fishery (Pacific Fisheries Management Council 2008).

A demersal gillnet fishery in southern Western Australia targets young dusky (Simpfendorfer 1999a and b; Simpfendorfer and Donohue 1998; Heald 1987), sandbar and gummy (*Mustelus antarcticus*) sharks (McAuley and Simpfendorfer 2003; Punt et al. 2000). In New South Wales, large sharks (sandbar, dusky and spinner [*C. brevipinna*], for example) are targeted in the ocean trap-and-line fishery (Macbeth et al. 2009). New Zealand has targeted fisheries for rig (*M. lenticulatus*) and school sharks (New Zealand Ministry of Fisheries 2008).

In Mexico, fishermen use several types of gear, including bottom and surface gillnets and longlines, to target large and small coastal sharks (Holts et al. 1998; Pérez-Jiménz et al. 2005). In the state of Sonora, for example, landings from artisanal shark and ray fisheries using bottom-set gillnets are typically made up of small sharks such as *Mustelus spp.* (Bizzaro et al. 2009). Smooth hammerhead (*S. zygaena*), silky and blue sharks make up the majority of the catch at one fishing village, La Cruz de Huanacaxtle, and scalloped hammerhead (*S. lewini*) and Pacific sharpnose (*Rhizoprionodon longurio*) sharks made up the majority of the catch at Isabel Island in the Central Mexican Pacific (Pérez-Jiménz et al. 2005). Fishermen in these areas use a combination of bottom-fixed longlines and drift and bottom-fixed gillnets (Pérez-Jiménz et al. 2005).

Although these and other target shark fisheries are well-documented, there are many others worldwide about which little is known. Unfortunately, many of these fisheries operate in the Indo-Pacific, where shark biodiversity and endemism is high, which means that many obscure, range-restricted sharks may be in danger of biological extinction. For example, India and Indonesia are two of the top shark-fishing nations by landings, but little is known about the species composition in these fisheries (Camhi et al. 2009). Fishermen in the Maldives use longlines to target sharks, primarily catching silky sharks (Anderson and Waheed 1990). Oman's targeted shark fishery is well-established, but only recently has the fishery been described in a published study (Henderson et al. 2007). Artisanal fishermen in this fishery use bottom longlines, bottom-set gillnets and driftnets to catch a variety of species, including the milk (*R. acutus*), bigeye

A recent study estimates that as 73 million sharks have been killed in a single year to supply the fin trade, actual catches may be much higher

houndshark (*Iago omanensis*) and spottail sharks (*C. sorrah*) (Henderson et al. 2007). McVean et al. (2006) studied the directed shark fisheries of two villages in Madagascar and determined that 13 species of sharks, mostly hammerheads, were represented in their catch. Studies like these on other undocumented directed shark fisheries are needed so scientists and managers can fully understand the impact commercial fishing has on shark populations worldwide.

Shark bycatch fisheries

Bycatch can be defined as part of the catch that is not the targeted species and may be retained and landed for sale. Bycatch is typically discarded at sea dead or released alive. High levels of shark bycatch are a major issue for fishermen because of profit lost through depredation, damage and loss of fishing gear; risk to the crew while handling sharks; and time lost while crews remove shark bycatch from the gear (Gilman et al. 2008).

The amount of shark bycatch varies among fisheries and typically depends on the gear used and where the fishing grounds are (Gilman et al. 2008). High levels of shark bycatch have been reported in several pelagic longline fisheries that target tuna and swordfish (*Xiphias gladius*) (Gilman et al. 2008; Mandelman et al. 2008; Bailey et al. 1996; Herber and McCoy 1997). This type of bycatch is considered to be a major source of mortality for many shark species worldwide (Mandelman et al. 2008; Gilman et al. 2007). In general, shallow-set pelagic longlines and those that use wire leaders or squid for bait have the highest levels of shark bycatch (Gilman et al. 2008). In pelagic longline fisheries, sharks can make up more than a quarter of the total catch (target and bycatch) and of total bycatch. For example, in the Western Pacific Ocean, sharks made up the majority of the bycatch (27 percent) (Bailey et al. 1996), and in the subtropical pelagic longline fisheries, sharks made up 18 percent of the bycatch (Herber and McCoy 1997). Sharks made up a fourth of the bycatch in the U.S. pelagic longline tuna-and-swordfish fishery between 1992 and 2003 (Abercrombie et al. 2005). In the southeastern U.S. pelagic longline fishery, sharks represented 15 percent of the total catch from 1992 to 2000 (Beerkircher et al. 2002). In the Australian longline tuna-and-billfish fishery and the Fiji longline tuna fishery, sharks represented more than 25 percent of the total catch in 1999; in the Hawaii longline swordfish fishery, sharks represented 32 percent of the catch (Gilman et al. 2008). From 1998 to 2005, sharks made up 16 percent of the total catch in the South African longline fishery (Gilman et al. 2008).

A study by Morgan et al. (2010) determined that more than 90 percent of the total bycatch observed in the U.S. bottom longline fishery, targeting large coastal sharks (sandbar and blacktip), was made up of other shark species.

In Portuguese waters, sharks were caught as bycatch in the trawl (Monteiro et al. 2001), pelagic longline hake (Erzini et al. 2001), coastal trammel nets and semi-pelagic longline fisheries (Coelho et al. 2005). Sharks represented 33 percent of the total catch in the semi-pelagic fishery, and of those, 68 percent were discarded at sea (Coelho et al. 2005). Sharks have also been reported to make up a portion of the bycatch in the south Brazilian gillnet monkfish fishery (Perez and Wahrlich 2005), Gulf of Mexico shrimp trawl fishery (Shepherd and Myers 2005; Martinez and Nance 1993), Australia's northern prawn trawl fishery (Stobutzki et al. 2002) and industrial trawl fisheries off Northwest Africa (Zeeberg et al. 2006).

Because blue sharks are globally distributed in the pelagic zone and are very abundant, this species makes up an especially large fraction of shark bycatch in pelagic fisheries (Nakano and Seki 2003). For example, blue sharks represent 50 percent of the Canadian pelagic longline tuna and swordfish fishery bycatch (Smith 2001); 47 percent of the total shark catch in the Australian longline tuna-and-billfish fishery; 82 percent of the total shark catch in the U.S. Hawaii longline tuna fishery; 92 percent of the total shark catch in the U.S. Hawaii longline swordfish fishery; more than 70 percent of the total shark catch in the Japanese longline fishery; and 69 percent of the South African longline tuna-and-swordfish fishery total shark catch (Gilman et al. 2008). In contrast, silky sharks are the numerically dominant (31.4 percent) shark species in the southeastern U.S. pelagic longline fishery, followed by dusky (14.7 percent), night (*C. signatus*) (12.4 percent) and blue (9.4 percent) sharks (Beerkircher et al. 2002).

Recreational targeted fishing

Recreational fisheries that target sharks are also common in many areas, particularly in the United States, Australia, New Zealand and the United Kingdom (Babcock 2008). Blue sharks are a main component of recreational fisheries throughout the North Atlantic, and other pelagic species such as shortfin mako, porbeagle and thresher sharks are also of interest to anglers (Camhi et al. 2009). For example, in Irish waters, blue sharks are considered one of the largest and most valuable marine sportfishes (Fitzmaurice and Green 2000; Crummey et al. 1991) and in Canadian waters represent

99 percent of sharks landed at recreational shark fishing tournaments (Campana et al. 2005). Blue sharks have also been targeted by anglers in southwest England since the 1950s (Clarke et al. 2008). Shortfin mako, blue and thresher sharks are commonly taken in recreational fisheries off the East Coast of the United States (Babcock and Skomal 2008). In the South African province of KwaZulu-Natal, dusky and milk sharks were the most commonly caught species (26 and 18 percent, respectively) in the competitive shore recreational fishery between 1977 and 2000 (Pradervand et al. 2007), and bull (McCord and Lamberth 2009) and sand tiger (*Carcharias taurus*) sharks (Dicken et al. 2006) are also reported to be a component of the recreational shark fisheries in this region. In New Zealand, spiny dogfish, school, rig, mako and blue sharks are caught in the recreational fishery (Francis 1998).

Sharks are killed for their fins and meat, and also for their cartilage, liver and skin

The driving forces behind shark fishing

Meat

Shark meat, which has been used as food in coastal areas for thousands of years (Vannuccini 1999), has become more popular (Gilman et al. 2007) but is less economically valuable than shark fins or meat from other more popular pelagic fish species, such as tuna and swordfish (Anak 2002). For example, U.S. exports of shark fins in 2006 had a value of US$93.68 per kilogram, compared to fresh and frozen shark meat (US$2.09 per kg and US$1.94 per kg, respectively) (National Marine Fisheries Service 2009). Shark meat is more difficult to process than meat from most fish species because of its high urea content (Vannuccini 1999), which also makes it less marketable in many areas. However, shortfin mako, thresher and porbeagle sharks are considered high-value species for meat in the European and U.S. seafood markets and for sashimi in Asia (Vannuccini 1999). Many smaller species such as the spiny dogfish are also commonly utilized for food (Vannuccini 1999; Ketchen 1986). Some shark species, such as blue and hammerhead sharks, are targeted specifically for their fins because of the poor quality of their meat (Vannuccini 1999).

Fins

The value of shark fins has increased in recent years with economic growth in China, and this growth is a major factor in the commercial exploitation of sharks worldwide (Clarke et al. 2007; Clarke et al. 2004a). The shark fin trade in China is driven by economic, traditional and cultural factors (Clarke et al. 2004b). Shark fins can be sold in several forms, including wet, raw, semi-prepared and fully prepared; fin nets; and "ready to eat" (Verlecar et al. 2007). Fins are graded by type, size and color, each of which affects their price (Verlecar et al. 2007). In Hong Kong, fins are placed in 30 to 45 market categories (Xiang et al. 2005). According to Clarke et al. (2006b) and Abercrombie et al. (2005), several of these market categories match individual shark species, suggesting that monitoring trade in these categories could yield species-specific trade data. Chapman et al. (2009) showed that fins from scalloped hammerhead sharks in the Hong Kong market could be traced by their DNA back to their population of origin, a technique that could in the future be used to obtain region and species-specific trade data. From 1985 to 1998, shark fin imports to Hong Kong and Taiwan, Province of China, increased by more than 214 percent and 42 percent, respectively (Food and Agriculture Organization 2001; Vannuccini 1999); and between 1991 and 2000, trade in shark fins in the Chinese market grew by 6 percent a year (Clarke 2004b). Shark fins are considered one of the most valuable food items in the world (Fong and Anderson 2002), reaching prices as high as US$700 per kg (Clarke 2004b). A small number of trading centers in Asia account for the majority of global sourcing of shark fins (Clarke 2004b). The minimum value of the global trade of shark fins has been estimated at $400 million to $550 million a year (Clarke et al. 2007).

"Shark finning"—the practice of cutting off the fins at sea and discarding the rest of the shark—is not synonymous with the shark fin trade. Shark finning is illegal in several countries, including the United States, South Africa, Brazil, Costa Rica and the countries of the European Union (Fowler et al. 2005). Several regional fishery management organizations—including the International Commission for the Conservation of Atlantic Tunas (ICCAT), the Inter-American Tropical Tuna Commission and the Indian Ocean Tuna Commission (Camhi et al. 2008)—have also declared shark finning illegal. Finning is also regulated through administrative measures in Australia and Canada (Clarke et al. 2006a); New Zealand (New Zealand Ministry of Fisheries 2009), and other countries are considering similar bans.

There have been large declines in shark fin imports by Hong Kong from countries with shark finning regulations (Clarke et al. 2007). For example, exports from the European Union dropped by 30 percent after finning was banned, and U.S. exports dropped by 54 percent after Hawaii outlawed shark finning (Clarke et al. 2007). However, Shark bycatch can represent as much as 25% of the total catch in pelagic longline fisheries targeting tuna and swordfish

Shark populations have been reduced by 90% or more in some regions

exports of shark fins from the United States to Hong Kong increased slightly after the ban on finning was put in place in 2002 (Clarke et al. 2007). The effect of shark finning regulations on the entire shark fin trade is not completely understood (Clarke et al. 2007). Factors such as changes in the economy, shifts in trade from Hong Kong to mainland China and the trade going underground due to increased regulations could account for some of these reported changes (Clarke et al. 2007). The unevenness of the regulations complicates the situation. As additional data become available, researchers will have an easier time determining what effect finning regulations have had on the shark fin trade as a whole.

Oil, cartilage and other products

Several parts of sharks, including cartilage and liver oil, are being investigated for their use in combating human illnesses (Walsh et al. 2006; Ostrander et al. 2004) and medicinal and other uses. The liver oil has been studied for anti-cancer effects in mice (Hajimoradi et al. 2009), treatment of conditions resulting from poor immune responses (Lewkowicz et al. 2006), as an adjunct to a vaccine that stimulates the immune system, as a treatment for some types of cancer (Lewkowicz et al. 2006) and for treatment of bacterial, viral and fungal infections (Lewkowicz et al. 2005). Squalene, found in the liver oil of all sharks, has been used in many products, including cosmetics, other health and beauty products and fuel for street lamps, and in the production of vitamin A (Vannuccini 1999). Squalene is an adjuvant that stimulates the immune system and is used in several vaccines, including some for the H1N1 flu virus (Clark et al. 2009), malaria (Saul et al. 2005; Fox 2009) and is being used in clinical trials for hepatitis B, human papilloma virus and tuberculosis (Fox 2009). Additionally, shark liver oil has been shown to deter seabirds from longline fishing gear (Pierre and Norden 2006).

Shark cartilage is used as a dietary supplement to aid in joint ailments (Sim et al. 2006). Gelatin has been extracted from shortfin mako shark cartilage (Kwak et al. 2008), and research has suggested that shark cartilage may be a good candidate for studies on cancer therapy because it inhibits vessel growth (Walsh et al. 2006; Hassan et al. 2005). However, study results have been mixed, with some indicating that shark cartilage has no positive effect in cancer treatment (Loprinzi et al. 2005). It is generally thought that components of shark cartilage may inhibit cancer growth but that unrefined extracts are not effective (Ostrander et al. 2004).

In addition, shark skin is used as leather (Anak 2002) and as food (Vannuccini 1999). Extracts from shark blood have been used in anticoagulants, shark corneas are used in medical treatments (Bonfil 2002), jaws and teeth are sold as souvenirs, dogfish are used as dissection specimens and sharks can be used in fishmeal and/or as fertilizer (Rose 1996).

What is the status of shark populations?

Given high levels of exploitation and the general life history characteristics of sharks (slow growth, late age at maturity and few young), it makes sense that many shark species would be in decline. Dulvy et al. (2008) used the IUCN (International Union for Conservation of Nature) Red List Categories and Criteria (www.iucnredlist.org) to determine the status of 21 pelagic shark and ray species commonly caught in high seas fisheries. Eleven species were considered Globally Threatened (Critically Endangered, Endangered or Vulnerable):

- whale shark (*Rhinodon typus*),
- pelagic thresher (*A. pelagicus*),
- bigeye thresher (*A. superciliosus*),
- thresher,
- basking (*Cetorhinus maximus*),
- great white (*Carcharodon carcharias*),
- shortfin mako,
- longfin mako,
- porbeagle,
- oceanic whitetip.

Five species were considered Near Threatened, two as Least Concern and three as Data Deficient. More generally, the IUCN Red List classifies 17 percent of assessed shark and ray species (of a total 1,045 species) as Threatened (11 percent Vulnerable, 4 percent Endangered and 2 percent Critically Endangered), 13 percent Near Threatened, 23 percent Least Concern and 47 percent Data Deficient (Camhi et al. 2009).

Recent stock assessments and a variety of studies in the Northwest Atlantic Ocean have found declines in many shark species. For example, sandbar sharks have been depleted by 64 to 71 percent from unexploited population levels (National Marine Fisheries Service 2006), and dusky sharks have declined by at least 80 percent from unexploited population levels (Cortés et al. 2006). Both species are considered overfished (National Marine Fisheries Service 2009). Declines in the abundance of hammerhead sharks (*S. lewini*, *S. mokarran* and *S. zygaena*) of about 70 percent since 1981 have also been reported in this region (Jiao et al. 2009). Hayes et al. (2009) determined that there was a high probability that the population of scalloped hammerheads was overfished in 2005 and that the population had declined by 83 percent from 1981 to 2005. The population of blacknose sharks was estimated to be overfished and at about 20 percent of unexploited levels in 2005 (National Marine Fisheries Service 2009; National Marine Fisheries Service 2007b). The population of porbeagle sharks appears to have "crashed" for the second time since 1967—it is at 10 to 20 percent of "virgin" levels (Campana et al. 2008) and is considered overfished (National Marine Fisheries Service 2009). Additionally, North Atlantic shortfin mako shark populations are at about 50 percent of virgin levels (International Commission for the Conservation of Atlantic Tunas 2008) and appear to be approaching an overfished status (National Marine Fisheries Service 2009). In the Northeast Atlantic, the population of spiny dogfish is less than 10 percent of unexploited levels (International Council for the Exploration of the Sea 2006). Large declines in catch rates of several pelagic shark species have also been reported (Baum et al. 2003; Baum et al. 2005; Baum and Myers 2004). These studies suggest severe declines have occurred in hammerheads, silky, oceanic whitetip (*C. longimanus*) and longfin mako (*I. paucus*) sharks among others. Further research indicates that shortfin mako, silky, oceanic whitetip and longfin mako sharks are highly susceptible to overexploitation by pelagic longlines (Cortés et al. 2008; Simpfendorfer et al. 2008).

In the Indian Ocean, analysis of data collected from the protective gillnet program off KwaZulu-Natal beaches in South Africa from 1978 to 2003 revealed significant declines in catch rates for bull, blacktip and scalloped and great (*S. mokarran*) hammerheads (Dudley and Simpfendorfer 2006). The biomass of sandbar sharks caught in the northern shark fisheries off Western Australia is considered depleted and is estimated to be about 35 percent of virgin levels (McAuley 2008a). The status of gummy sharks in the Western Australia demersal gillnet and longline fishery is considered to be acceptable, while the populations of dusky and sandbar sharks caught in this fishery are considered depleted and the whiskery shark (*Furgaleus macki*) population is recovering (McAuley 2008b). In the Pacific Ocean, research on coral reef atolls in the northern Line Islands found that areas uninhabited by humans (Kingman Reef and Palmyra Atoll, for instance) had reef systems dominated by top predators such as sharks, while populated areas (such as Tabuaeran and Kiritimati) were dominated by small planktivorous fish (Sandin et al. 2008). Robbins et al. (2006) and Heupel et al. (2009) show that reef shark populations inside areas with high fishing pressure are diminished relative to protected areas on the Great Barrier Reef.

Although the population status of some shark species is well understood, there are still a large number of species about which little information on population status is available. This lack of information is largely due to deficiencies in long-term time-series data on fishing effort, catches, landings and discards in commercial fisheries (Anderson 1990; Stevens et al. 2000; Bonfil 2005; Camhi et al. 2009) and highlights the need for the continued collection of these data on a species and region-specific basis.

Removing sharks can negatively impact entire ecosystems and marine foodwebs

The fate of an ecosystem when top predators such as sharks are lost

The loss of top predators has been shown to cause dramatic shifts in ecosystems and communities in the marine and terrestrial realms. Sharks are top predators and thus ecologically important in most marine ecosystems (Libralato et al. 2005), where they are thought to play a major role in maintaining ecosystem structure and function (Piraino et al. 2002; Stevens et al. 2000). The removal of sharks may drive an increase in prey abundance, which can cause a cascade of indirect effects, including changes to the abundance of other organisms (Baum and Worm 2009; Myers et al. 2007; Duffy 2003; Schindler et al. 2002).

The ecological effects of shark removal can be difficult to research and quantify. Several studies have attempted to do so through quantitative ecosystem modeling.

For example, modeling of Caribbean coral reef ecosystems suggests that the loss of large predatory sharks may reduce large piscivorous fish, which then leads to the decline of herbivorous fish (Bascompte et al. 2005). In the North Pacific, an increase in short-lived and fast-growing species—mahimahi *(Coryphaena hippurus)*, sickle pomfret *(Taractichthys steindachneri)*, escolar *(Lepidocybium flavobrunneum)* and snake mackerel *(Gempylus serpens)*—occurred after longline fishing caused a decline in several top predators (blue sharks and tunas *[Thunnus spp.]*) (Polovina et al. 2009). Modeling of an ecosystem in the French Frigate Shoals showed that the removal of tiger sharks caused reef shark, sea turtle and seabird abundance to increase, while tuna and jack abundance decreased (Stevens et al. 2000).

Other modeling studies have examined concurrent time-series of abundance for sharks and other ecosystem components to infer the effects of shark

Live sharks have a significant value for marine ecotourism

Whale shark tourism, mainly through diving, is estimated to be worth $47.5 million globally

removal. Myers et al. (2007) correlated declines in the abundance of sharks in the coastal Northwest Atlantic with increases in several ray species. They implicated one of these, the cownose ray *(Rhinoptera bonasus)* in the decline of the bay scallop due to increased predation rates (Myers et al. 2007). They further suggested that this cascading effect may also eventually inhibit the recovery of hard clams, soft-shell clams and oysters in the region. In a similar analysis for the northern Gulf of Mexico, shrimp trawling appears to have removed large sharks, which resulted in an increase in deeper-water sharks (Atlantic angel *[Squatina dumeril]* and smooth dogfish *[M. canis]*) (Shepherd and Myers 2005). Schindler et al. (2002) determined that removing blue sharks through commercial fishing had a large impact on the food web structure of the pelagic Pacific Ocean.

Predators such as sharks can also influence the populations of prey by causing behavioral changes (Creel and Christianson 2008), including modified activity level, diet and habitat use (Heithaus et al. 2007). These behavioral changes can affect how prey utilize resources within an ecosystem (Heithaus et al. 2007). Field research has been conducted on what effect nonlethal changes have on habitat use, activity level or diet caused by the presence and absence of sharks (Heithaus et al. 2007). For example, in Australia's Shark Bay, dugongs *(Dugong dugon)* optimize foraging tactics and habitat use based on the abundance of tiger sharks. When the sharks are not abundant, dugongs spend more time foraging on seagrass and stay closer to the interior of the bay (Wirsing et al. 2007a; Wirsing et al. 2007b). Green sea turtles *(Chelonia mydas)* in this area move to safer habitats that have nutrient-poor seagrass when tiger sharks are abundant (Heithaus et al. 2007). Removing tiger sharks from this ecosystem would therefore change the distribution of grazing species and their foraging behavior, which could in turn change the distribution and abundance of sea grass. Nonlethal effects of sharks on their prey are likely to be important and widespread, and as such, shark removals may have large effects on ecosystems and communities beyond those that stem from trophic cascades (the cascading effect that a change in the size of one population has on the populations below it in the food web).

Combined, these findings illustrate the intricate relationship between predatory sharks, their prey and the ecosystems they share. Changes in shark abundance can impact ecosystems in significant ways that at this time are unpredictable and often difficult to document. It is therefore important that shark populations be managed to reduce the possibility of lethal and nonlethal effects of shark removal on organisms, communities and ecosystems (Heithaus et al. 2008).

How do sharks economically benefit sectors other than fisheries?

Live sharks have a significant value for marine ecotourism (for example, recreational diving, shark feeding and shark watching from boats) that is typically more sustainable and often higher than their individual value to fisheries (Rodriguez-Dowdell et al. 2007; Newman et al. 2002). Among the places where shark ecotourism can be found are the Bahia de los Angeles conservation area in Mexico (Cheng 2009; Rodriguez-Dowdell et al. 2007), the Seychelles off East Africa (Rowat and Engelhardt 2007; Cheng 2009), South Africa (Hara et al. 2003), the Philippines (Newman et al. 2002), Phuket, Thailand (Bennett et al. 2003), Maldives (Anderson and Ahmed 1993), Belize (Graham 2004) and Ningaloo Marine Park in Western Australia (Newman et al. 2002). Indeed, Carwardine and Watterson (2002) document more than 200 shark dive tourism operations around the world.

Although many shark species are the focus of marine ecotourism (Carwardine and Waterson 2003), large charismatic species yield the highest revenue. It has been estimated that whale shark tourism, mainly through recreational diving, is worth about $47.5 million worldwide (Graham 2004). In the Ningaloo Marine Park, participants paid about AU$3,198 apiece in 1995 to participate in whale shark tours, and it was estimated that the industry value of these tours was between AU$6.4 million and $12.8 million from 1995 to 2000 (Newman et al. 2002). Another study found that in 2006, participants spent AU$6 million on whale shark tours at the park, which added about AU$2 million to $5 million to the regional economy (Jones et al. 2009). The value of whale shark encounters in the Seychelles was about US$5 million during a 14-week season (Rowat and Engelhardt 2007). In Phuket, Bennett et al. (2003) estimated that whale sharks were a US$110 million resource and were reported to be the third most important reason divers visited the area. In Gansbaai, South Africa, shark-diving tourists typically spend R$1000/day and shark-diving operators brought in R$30 million annually in 2000/2001 (Hara et al. 2003), and Belize reported an economic return of US$3.7 million annually from whale shark ecotourism

(Graham 2003). In Australia, the value of each living whale shark was estimated at AU$282,000 (Norman and Catlin 2007), and in Belize the worth was US$2.09 million over a shark's lifetime, or $34,906 a year (Graham 2004). In the Maldives, individual grey reef sharks (*C. amblyrhynchos*) were estimated to have an annual value of US$33,500 in 1993 (Anderson and Ahmed 1993). In 2005, whale shark ecotourism created 300 jobs, an increase in annual income and an economic return of about US$623,000 in Donsal, Philippines (Quiros 2005). Despite the large economic incentive associated with shark ecotourism, there are potentially several long-term risks to the sharks that can occur without proper management and visitor guidelines, including mortality, injury, stress, disruption of feeding patterns and mating behaviors, and changes to migratory pathways (Mau 2008; Quiros 2006).

Conclusion

The exploitation of sharks in commercial fisheries for their fins, meat, liver oil, cartilage and other parts has led to large declines in the population sizes of many species of sharks worldwide. Although the Asian fin market has increased the monetary value of sharks in commercial fisheries, shark ecotourism has increased the value of live sharks in many areas of the world. Removing sharks from the ocean has been shown to have a variety of effects on an ecosystem, including increasing the abundance of prey species or causing behavioral changes. The overall effects of these losses are not well known, however, because of difficulties associated with this type of research. This report has provided an overview of the literature bearing on these and other issues and highlights the need for continued research on the effects of commercial exploitation of shark populations worldwide.

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