ELSEVIER

Shark interactions in pelagic longline fisheries

Eric Gilman[a,b,c,*], Shelley Clarke[d], Nigel Brothers[e], Joanna Alfaro-Shigueto[f],
John Mandelman[g], Jeff Mangel[f], Samantha Petersen[h], Susanna Piovano[i], Nicola Thomson[j],
Paul Dalzell[k], Miguel Donoso[l], Meidad Goren[h], Tim Werner[g]

[a]Blue Ocean Institute, USA
[b]School of Geography and Environmental Studies, University of Tasmania, Australia
[c]2718 Napuaa Place, Honolulu, Hawaii 96822, USA
[d]Imperial College London, Silwood Park Campus, Manor House, Buckhurst Road, Ascot SL5 7PY, UK
[e]178 South Arm Drive, Wonga Beach, Queensland 4873, Australia
[f]Pro Delphinus, Octavio Bernal 572-5, Lima 11, Peru
[g]New England Aquarium, Central Wharf, Boston, MA 02110, USA
[h]BirdLife South Africa, P.O. Box 52026, Waterfront, Cape Town 8002, South Africa
[i]Dipartimento di Biologia Animale e dell'Uomo, Università di Torino, Via Accademia Albertina 13, I-10123 Torino, Italy
[j]Environment Consultants Fiji, Box 2041, Government Buildings, Suva, Fiji
[k]Western Pacific Regional Fishery Management Council, 1164 Bishop Suite, Suite 1400, Honolulu, HI 96813, USA
[l]Instituto de Fomento Pesquero, Blanco 839, Valparaiso, V Region, Chile

Abstract

Substantial ecological, economic and social problems result from shark interactions in pelagic longline fisheries. Improved understanding of industry attitudes and practices towards shark interactions assists with managing these problems. Information on fisher knowledge and new strategies for shark avoidance may benefit sharks and fishers. A study of 12 pelagic longline fisheries from eight countries shows that incentives to avoid sharks vary along a continuum, based on whether sharks represent an economic disadvantage or advantage. Shark avoidance practices are limited, including avoiding certain areas, moving when shark interaction rates are high, using fish instead of squid for bait and deeper setting. Some conventionally employed fishing gear and methods used to target non-shark species contribute to shark avoidance. Shark repellents hold promise; more research and development is needed. Development of specifically designed equipment to discard sharks could improve shark post release survival prospects, reduce gear loss and improve crew safety. With expanding exploitation of sharks for fins and meat, improved data collection, monitoring and precautionary shark management measures are needed to ensure that shark fishing mortality levels are sustainable.
© 2007 Elsevier Ltd. All rights reserved.

Keywords: Bycatch; Depredation; Finning; Fishery; Pelagic longline; Shark

1. Introduction

Bycatch[1] in marine fisheries is an increasingly prominent international issue [1–16]. Bycatch raises ecological concerns, as some bycatch species of cetaceans, seabirds, sea

*Corresponding author. Tel.: +1 808 722 5424; fax: +1 808 988 1440.

E-mail addresses: egilman@blueocean.org (E. Gilman), scclarke@biznetvigator.com (S. Clarke), brothersbone@yahoo.com.au (N. Brothers), prodelphinus@prodelphinus.org (J. Alfaro-Shigueto), jmandelman@neaq.org (J. Mandelman), Seabirds@birdlife.org.za (S. Petersen), susanna.piovano@unito.it (S. Piovano), watling@connect.com.fj (N. Thomson), paul.dalzell@noaa.gov (P. Dalzell), mdonoso@ifop.cl (M. Donoso), twerner@neaq.org (T. Werner).

[1]"Bycatch" is the retained catch of non-targeted species or "incidental catch", plus all discards [1, 17]. "Target" catch is the catch of a species or species assemblage primarily sought in a fishery, while "non-target" catch is the catch of a species or species assemblage not primarily sought. "Incidental" catch is the portion of non-target catch that is retained, while "discards" is the portion of non-target catch that is not retained [1, 17].
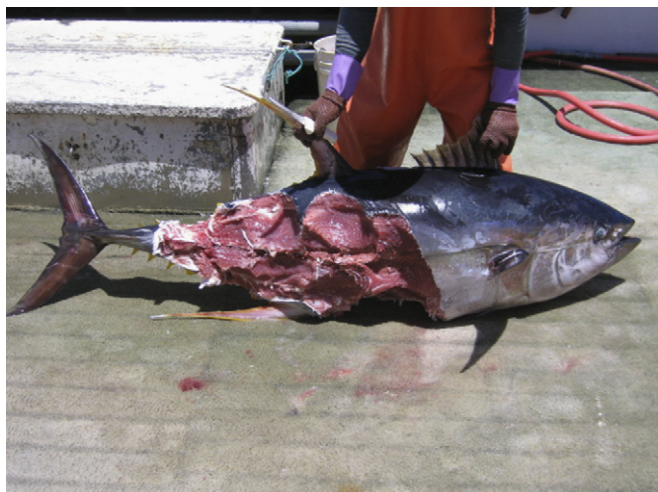
Fig. 1. Shark-damaged yellowfin tuna caught in the Hawaii pelagic longline fisheries (photo courtesy of US National Marine Fisheries Service Hawaii Pelagic Longline Observer Program).

turtles, sharks[2] and other fish species are particularly sensitive to increased mortality above natural levels due to their life history traits, including being long-lived, having delayed maturity and having low reproductive rates [9,12,18,19]. Bycatch can alter biodiversity by removing top predators and prey species at unsustainable levels. It also alters foraging habits of species that learn to take advantage of discards [11,13]. Economic effects on fisheries from bycatch include the imposition of a range of restrictions, closed areas, embargos, and possible closures; fishery interactions, where bycatch in one fishery reduces target catch in another, and bycatch of juvenile and undersized individuals of a commercial species, can adversely affect future catch levels [13]. Discarded bycatch is a social issue over waste [1, 4].

Depredation, the partial or complete removal of hooked fish and bait from fishing gear, is conducted primarily by cetaceans and sharks in pelagic longline fisheries (Fig. 1). Economic losses from depredation can be substantial [20, 21]. Depredation also raises ecological concerns as these interactions may change cetacean and shark foraging behavior and distribution, increase fishing effort, and confound fish stock assessments as well as result in deliberate injury and mortality of cetaceans and sharks by fishers to discourage depredation and avoid future interactions [11].

Much progress has been made to identify effective, commercially viable, and even operationally beneficial methods to significantly reduce seabird and sea turtle bycatch in longline fisheries [8, 12, 22–24]. Relatively little progress has been made to reduce cetacean [11] and shark interactions in longline fisheries.

In some pelagic longline fisheries, shark interactions pose substantial ecological, economic and social problems. As

demonstrated in some fisheries to address seabird and sea turtle bycatch [8, 9, 12, 24, 25], collaborative approaches, which tap fishers' large repository of knowledge, may likewise successfully reduce unwanted shark interactions. We collect information from longline industries ranging from small-scale artisanal fisheries to large-scale industrial distant water fleets to obtain a more complete understanding of shark-pelagic longline interactions, current fisher attitudes and practices employed in response to shark interactions, identify methods to avoid shark interactions, identify research priorities and assess the effects of legislation that affect longline practices in catching and processing sharks. Information on existing fisher knowledge and new strategies for shark avoidance may benefit sharks and fishers wanting to reduce shark interactions. Improving the understanding of longline industry attitudes and practices towards shark interactions provides industry and management authorities with better information to address these problems. A detailed project report from this study has been produced by Gilman et al. [26].

2. Methods and overview of fisheries

Information was collected from the following 12 pelagic longline fisheries from eight countries: (i) Australia longline tuna (*Thunnus* spp) and billfish (*Istiorphoridae* spp) fishery, (ii) Chile artisanal mahi mahi (dolphinfish) (*Coryphaena* spp) and shark fishery, (iii) Chile swordfish (*Xiphias gladius*) fishery, (iv) Fiji longline tuna fishery, (v) Italy Mediterranean industrial longline swordfish fishery, (vi) Japan distant water longline fishery, (vii) Japan offshore longline fishery, (viii) Japan nearshore longline fishery, (ix) Peru artisanal mahi mahi and shark fishery, (x) South Africa longline tuna and swordfish fishery, (xi) US Hawaii longline tuna fishery, and (xii) US Hawaii longline swordfish fishery. From January to December 2006, 149 vessel captains, fishing masters, crew, vessel and company owners, fishing cooperative staff and port officials from these 12 fisheries were interviewed at 24 fishing seaports (nine seaports in Australia, including the main port of Mooloolabah; Arica, Iquique and Valparaiso, Chile; Suva, Fiji; Sicily, Italy; Kesennuma, Kii-Katsuura, Yaizu and Misaki, Japan; Ilo, Paita and Salaverry, Peru; Cape Town Harbour, Hout Bay Harbour and Richards Bay Harbour, South Africa; and Honolulu, USA).

Information from the interviews, analyses of available logbook and observer data, and a review of the literature were collected and analyzed to:

- Determine shark catch rates, disposition of caught sharks and costs and benefits from shark interactions to better understand longline industry interest in reducing shark interactions;
- Describe the range of longline industry attitudes towards shark capture and depredation to understand the degree of interest in shark avoidance;

---

[2]The term 'sharks' refers to the Chondrichthyan fishes, which comprise elasmobranchs (sharks, skates and rays) and holocephalans (chimaeroids).

- Identify practices employed by longline fishers in response to shark interactions;
- Identify promising concepts not currently practiced to reduce shark capture, reduce depredation and gear damage, improve discard methods, and determine what obstacles must be overcome to implement these concepts;
- Identify priority research and development, monitoring and management measures; and
- Identify economic, social and ecological effects of legislation affecting shark practices, assess if the legislation has resulted in reduced interest in capturing and retaining sharks, and discuss how these laws may have affected shark fishing mortality levels.

The 12 fisheries range from small-scale domestic artisanal fisheries to modern mechanized industrial fleets of distant water fishing nations. Distant water vessel fishing grounds range throughout the world's oceans on trips lasting two to three months, while smaller vessels fish in nearshore waters on trips lasting a few days. The number of vessels in each fleet also varies, from the South Africa longline fleet with about 17 vessels, to the Japanese and Peruvian fleets with about 1500 vessels each. Some of these fisheries never target and rarely retain sharks, while in other fisheries sharks are an important target species.

There are several fishing gear designs and operational characteristics that are likely to affect shark interactions, including the location of fishing grounds, depth of baited hooks, timing of gear deployment and retrieval, use of wire leaders and lightsticks on branch lines and type and size of bait. For example, Peru artisanal longline vessels, which are about 15 m in length, target mahi mahi during the austral summer and target sharks from autumn to spring. Baited hooks are set at depths between 10 and 16 m. Wire leaders are not typically used during the mahi mahi season but are always used during the shark season to maximize shark retention and reduce gear loss. Giant squid, mackerel and flying fish are used for bait. Lightsticks are not used. Gear soaks during the daytime. Hawaii longline tuna vessels are a bit larger, between 15 and 31 m in length, set baited hooks deeper at depths between 35 and 224 m, use a wire trace, use fish for bait, do not use lightsticks, and gear soaks during the day. However, there may be large variability in fishing gear and methods between vessels in a fleet and even for an individual vessel. For instance, some vessels in the Fiji longline tuna fleet fish at grounds within the Fiji Exclusive Economic Zone (EEZ), while larger vessels fish at grounds much more distant from their home port, on the high seas and in other nation's EEZs, and these two categories of vessels have substantially different gear characteristics. In some fisheries, vessels will substantially alter their gear seasonally when they change their primary target species (e.g., Chile and Peru artisanal longline mahi mahi and shark fisheries, Japan offshore and nearshore pelagic longline tuna fisheries). Gear characteristics may also vary substantially between seaports within a fishery.

Table 1
Shark catch rate and disposition in 12 pelagic longline fisheries for the most current year for which data are available

Pelagic longline fishery	Shark catch rate (number per 1000 hooks)	Shark retention (fins and/or carcass) (% of total number caught sharks)
Australia tuna and billfish longline fishery	5.5[a]	Not available
Chile artisanal mahi mahi and shark longline fishery	24[b]	> 99[b]
Chile longline swordfish fishery	8[b]	> 99[b]
Fiji longline tuna fishery	1.1	78–90
Italy mediterranean industrial longline swordfish fishery	0.74	Not available
Japan distant water longline tuna fishery	0.021[c]	Not available
Japan offshore longline fishery	0.175[c]	Not available
Japan nearshore longline fishery	0.020[c]	Not available
Peru artisanal longline mahi mahi and shark fishery during mahi season	0.99	84
South Africa longline tuna and swordfish fishery	4.0	80
USA-Hawaii tuna	2.2	2.1
USA-Hawaii swordfish	16.7	0.2

[a]Rough estimate based on Australian Commonwealth Scientific and Research Organization, unpublished data from a subset of the fleet and time period, possibly not representative.
[b]Rough estimate based on interview responses.
[c]Based on number of sharks recorded in vessel logbooks [27].

3. Shark catch rates and disposition

Table 1 summarizes the catch rates and retention of caught sharks, where available. Several of these entries are based on limited data from small sample sizes. For the Japan distant water, offshore and nearshore longline fisheries, the shark catch rates reported in Table 1 are based on logbook data. These figures' relationship to the actual number of sharks caught and retained is expected to vary with logbook recording behavior [27]. The Italy Mediterranean large-scale longline swordfish fishery is the only fishery included in this study where there is a lack of a local market for shark fins, and as a result, fishers do not fin sharks. The shark catch rates for the two Chile fisheries are estimated from fisher interviews. Shark catch rates for the Chile longline swordfish fishery and artisanal longline mahi mahi and shark fishery are available only in units of weight per unit of effort (0.36 and 0.28 kg/hk, respectively [28]), and not as number of sharks per unit of effort. Information on the Fiji longline tuna fishery is based on observer data

from 1999 and 2002 to 2005 (Secretariat of the Pacific Community, unpublished data). Statistics for the Peru artisanal longline mahi mahi and shark fishery are based on 2004–2006 onboard observer data taken only during the mahi mahi season from four ports for a total of 27 trips and 197 sets.

The large number of "not available" entries and entries based on rough estimates in Table 1 suggests either that there is insufficient data collection and management measures for shark species or that relevant data are collected but have not been analyzed. For fisheries where there is high confidence in available shark catch rates, these range from 0.7 to 17 sharks per 1000 hooks. The location of fishing grounds and characteristics of fishing gear and methods are likely primary factors determining a fleet's shark catch rate. Certain gear designs (e.g., use of a wire leader, use of squid for bait, use of lightsticks, and setting baited hooks at shallow depths) contribute to high shark catch rates.

The proportion of total catch comprised of sharks by number varies widely for the fisheries. In the Australia fishery, sharks comprise about 27% of the total catch. Sharks comprised > 25% of the total number of fish caught by Fiji longline tuna vessels based on observer data from 1999 [29], while Secretariat of the Pacific Community observer program data for 1999 and 2002–2005 found that sharks comprised only 5.5% of the total number of caught fish. From 1998 to 1999, sharks comprised about 18% of the total catch in the Italian longline swordfish fishery [30]. In the Peru artisanal longline fishery, during the mahi mahi season in the port of Ilo for 2005–2006, sharks comprise less than 1% of the total catch by number. In the South Africa longline fishery, from 1998 to 2005, sharks comprised 16.2% of the total number of caught fish. In 2001, pelagic sharks comprised about 50% of the catch composition of swordfish sets and 16% for tuna sets in the Hawaii longline fishery [31]. However, since 2004 the shark catch rate in the swordfish fishery dropped 36% when the fishery was required to switch from using J hooks with squid bait to wider circle hooks with fish bait [8].

Results are generally consistent with the literature, which shows that a large quantity of pelagic sharks is taken as bycatch in pelagic longline fisheries with tuna and swordfish as their primary target species [29, 32–36]. For example, in the western Pacific, shark species account for the highest category of bycatch in tropical fisheries, where sharks comprise 27% of total bycatch, and in subtropical fisheries, where sharks are 18% of total bycatch [32, 37]. In the US Atlantic longline swordfish and tuna fisheries, sharks and rays constituted 25% of total catch between 1992 and 2003 [38]. Beerkircher et al. [33] found that sharks comprised 15% of the total catch in the southeastern US pelagic longine swordfish and tuna fisheries. Bonfil [18] found that the same numbers of sharks are caught in directed fisheries as are caught as bycatch mostly in longline tuna fisheries. However, the recent development of longline directed shark fisheries, especially in the Pacific, may mean that directed shark fisheries are now catching more sharks [39–42].

For fisheries where information on shark catch composition is available, blue sharks comprise the largest proportion of shark catch. Blue sharks comprise 47% of total shark catch by number of fish in the Australia longline tuna and billfish fishery; 49% in the Fiji longline tuna fishery; ⩾70% in Japan longline fisheries; 57% for the Peru artisanal mahi mahi and shark longline fishery (Pro Delphinus, unpublished data); 69% for the South Africa longline tuna and swordfish fishery; and 82% and 92% for the US Hawaii longline tuna and swordfish longline fisheries, respectively.

Identifying effective and commercially viable methods to reduce unwanted shark bycatch in longline fisheries would contribute to reducing shark fishing mortality. Increasing the proportion of caught blue sharks that are discarded in pelagic longline fisheries would likely reduce fishing mortality of this species, as blue sharks are usually alive when hauled to the vessel. Beerkircher et al. [33] found that the condition of sharks caught in pelagic longline gear (dead versus alive when hauled to the vessel) varied widely by species, where, for example, blue sharks had a relatively low 12.2% mortality, while silky sharks (the most dominant species of shark by number caught in the observed southeastern US pelagic longline swordfish and tuna fisheries, 31.4% of elasmobranch catch) had a 66.3% mortality. Over 89% of sharks caught in the Hawaii-based longline swordfish fishery and over 93% of sharks caught in the Hawaii-based longline tuna fishery are alive when the gear is retrieved. Eighty-seven percent of sharks caught in the Peru artisanal mahi mahi and shark longline fishery were alive when gear was retrieved. An analysis of Secretariat of the Pacific Community observer program data from 2002 to 2005 for the Fiji longline tuna fishery indicates that over 94% of blue sharks and over 84% of combined species of sharks were alive when hauled to the vessel.

4. Summary and effects of national/EC legislation on shark interactions

Table 2 summarizes legally binding measures that influence longline industry practices and attitudes towards shark bycatch and depredation. The two Chile longline fisheries, Fiji longline fishery, and three Japan longline tuna fisheries are not subject to legally binding measures that manage shark interactions, and are not included in Table 2. Japan and Fiji distant water vessels may comply with voluntary measures adopted by Regional Fishery Management Organizations, and vessels operating in EEZs of other nations through foreign license access agreements may be required to comply with restrictions on shark catch, retention and use under these agreements.

Legislation prohibiting the removal of shark fins and tail and discarding the remainder of the shark at sea in pelagic longline fisheries exists in four of the eight countries included in this study (Australia, Italy, South Africa, and USA) [43–46]. In the Australia longline tuna and billfish

Table 2
Legal framework that influence practices and attitudes towards shark bycatch and depredation in six pelagic longline fisheries [43–46]

Pelagic longline fisheries by flag state	Legal constraints[a]				
	Retention of fins requires retention of corresponding carcass[b]	Shark retention limit[c]	Prohibit wire trace	Prohibit retention of specified shark species	Size Limit
Australia tuna and billfish	X	X	X	X	
Italy Mediterranean industrial swordfish	X				
Peru artisanal mahi mahi and shark					X
South Africa tuna and swordfish	X	X	X		
USA-Hawaii tuna	X				
USA-Hawaii swordfish	X				

[a]Japan and Fiji distant water longline tuna vessels may comply with voluntary measures adopted by Regional Fishery Management Organizations, and vessels operating in EEZs of other nations through foreign license access agreements may be required to comply with restrictions on shark catch, retention and use under these access agreements.

[b]USA, Italy (European Union), and South Africa require the total weight of retained shark fins to be ≤5% of the total dressed "live" weight of shark carcasses. Australia requires fins to be attached to the shark carcass when landed.

[c]Australia has a 20 shark carcass per trip retention limit for longline tuna and billfish fisheries. South Africa has a shark landing limit of 10% of the total swordfish and tuna catch.

fishery, a rule that disallows possession, carrying and landing of shark fins unless attached to the trunk of the shark has likely substantially reduced shark fishing mortality, as finning was a widespread practice before this measure was instituted, while about 75% of caught sharks are now released alive [47, 48]. In the Hawaii longline tuna and swordfish fisheries, observer data indicate that the restriction on shark finning, which requires the retention of shark carcasses for corresponding retained fins, has likewise substantially reduced shark fishing mortality. As many as 76% and 64% of caught sharks were finned in the Hawaii tuna and swordfish fisheries, respectively, prior to this rule, while in 2006, 91% and 93% of caught sharks were released alive in the tuna and swordfish fisheries, respectively. Revenue from shark fins had comprised 10–11% of Hawaii longline crew salaries [49]. In the South Africa longline tuna and swordfish fishery, all interviewed fishers stated that prior to the finning restriction, they would fin and discard the carcass of all caught sharks excluding makos, which were retained for the sale of both fins and meat. Thus, the restriction on finning in South Africa has also substantially reduced shark retention and increased discards. In these fisheries, shark finning restrictions have caused substantial reductions in revenue to industry.

All 17 interviewed owner–operators from the Italy Mediterranean industrial longline swordfish fishery were unaware of a restriction on shark finning practices: the legislation does not affect their practices. However, no shark finning is reported to occur in the fishery due to the lack of a local market for fins.

Japan does not have legislation restricting shark finning practices, however, the distant-water fleet fishes in EEZs of nations that do have finning restrictions (e.g., South Africa, Brazil, Costa Rica). Vessels in the Japan distant-water longline tuna fishery will likely fin caught sharks and discard the carcass unless they are fishing in the EEZ of a nation that prohibits this practice, in which case the vessel may choose to retain the whole shark carcass and land the carcass in ports where there are markets for shark meat. Thus, Japanese longline fishermen have adapted to finning regulations applicable in some areas by landing sharks in recently developed local markets. In waters without finning regulations, including Japanese waters and the North Pacific, sharks are either finned or landed whole, and in either case the ability to sell shark products has contributed to a lack of interest in reducing shark bycatch.

A 20 shark carcass per trip limit for the retention of sharks in the Australia East coast longline tuna and billfish fishery has not altered the number of sharks retained by fishers, as fewer than 20 sharks are typically caught during an average length trip, and only a small proportion of the sharks caught on a trip are of species (makos and threshers) for which there is sufficient value for their meat. Furthermore, many operators only retain a shark of a marketable species if it is dead or dying when hauled to the vessel, which can be safely and easily landed.

The South Africa longline tuna and swordfish fishery is subject to a shark landing limit of 10% of the total swordfish and tuna catch. In theory, this has been economically detrimental to the industry. From 1998 to 2005, the total number of caught sharks was 18% of the total number of caught swordfish and tunas. Thus, vessels would need to discard about 44% of caught sharks to comply with the shark limit. Because only about 18% of caught blue sharks and 10% of makos have been observed to be released alive in this fishery, and the literature demonstrates that a much larger proportion of these shark

species (> 85%) are likely alive when hauled to the vessel (e.g., [33]), it is likely that fishers are not complying with this measure.

A prohibition on the use of a wire trace in the Australian longline tuna and billfish fishery and South Africa longline tuna and swordfish fishery has likely resulted in an increased economic cost from shark interactions as this has likely caused an increase in the loss of terminal tackle to sharks. A substantially larger number of hooks, bait and line are likely now bitten off of branch lines compared to when wire trace was used. However, fishers generally do not consider this to be a large concern. It is not known how the injury to sharks from retaining hook and trailing monofilament line affects their survival prospects. This is a research priority. This may be an improvement to their previous fate when caught on lines with wire trace when they would soak on the gear for hours, be gaffed and hauled onboard the vessel and then have hooks removed by cutting with a knife or pulled out by force. Available but limited information indicates that a large proportion of sharks caught in longline gear that are released after removal of the hook will survive (Section 7.4; [50]). In fisheries where a large proportion of caught sharks are killed either for retention or discarding, prohibiting the use of wire leaders will reduce shark fishing mortality. Prohibiting wire leaders may exacerbate seabird bycatch problems. Fishers will be less likely to attach weights close to hooks on branch lines lacking a wire leader due to safety concerns, thus, reducing the baited hook sink rate, and increasing seabird catch rates.

Shark fisheries in Peru are regulated by the Ministry of Fishery through size limits for certain elasmobranch species. However, there is little enforcement of these regulations and few fishers are aware of the regulations. Of the few interviewed fishers who reported that they were aware of the regulations (5%), all report that they still retain sharks that are under the minimum size limit.

5. Economic, practical, ecological and social problems from shark–longline interactions

5.1. Economic and practical concerns

Shark interactions in pelagic longline fisheries result in substantial inconveniences and adverse economic effects, including:

(i) *Depredation*: Lost revenue from shark damage to target species can amount to several thousand US dollars in a single set in some fisheries.
(ii) *Damage and loss of gear*: Sharks bite off terminal tackle (e.g., baited hook, leader, weighted swivel, and line) from branch lines, stretch and chafe branch lines, break the main line, and some shark species will pull the gear down causing branch lines to entangle.
(iii) *Reduced catch of marketable species*: When baited hooks are occupied or removed by sharks, fewer

hooks are available to catch marketable non-shark species.
(iv) *Risk of injury*: It is dangerous to handle caught sharks and there is a risk of being hit by weights when branch lines containing sharks break during gear retrieval.
(v) *Expenditure of time*: Substantial time is spent removing sharks from gear, retrieving terminal tackle and repairing and replacing gear due to shark interactions.

In fisheries with a demand for shark products, where vessels continuously or periodically target sharks, fishermen generally perceive these costs to be a minor inconvenience and are not problematic enough to create an incentive to avoid sharks. However, in fisheries with restrictions on finning, a lack of market for shark meat or a per-trip limit on shark retention, where shark catch rates are relatively high, shark interactions are perceived to be a major inconvenience and can represent a substantial economic cost.

In the Australia longline tuna and billfish fishery, fishermen estimate that they lose 20% of their catch of target species due to shark damage, while damage and loss of gear from shark interactions amount to a loss of about AUD 100 per set. Considerable time is also expended to discard caught sharks. The average catch rate of sharks is about 5.5 sharks per 1000 hooks compared to the catch rate of target and incidental fish of about 20.5 fish per 1000 hooks. However, on a given set, the shark catch can be extremely high (hundreds of sharks).

Fishers in the Chile mahi mahi and shark fishery and swordfish fishery report that sharks are an important target or incidental catch species. Fishers perceive that revenue from catching sharks exceeds costs from shark interactions. In a typical mahi mahi set, costs from the loss and damage to gear is about USD 18.5 and in the swordfish fishery 50–100 branch lines are damaged from shark interactions on a typical set. Fishermen reported having an average of six mahi mahi and three swordfish damaged from shark depredation on a typical set in the artisanal mahi mahi fishery and swordfish fishery, respectively. This represents a loss of about USD 146 per mahi mahi set and USD 1063 per swordfish set.

In the Fiji longline tuna fishery, almost all caught sharks are finned (Table 1) and carcasses are usually discarded due to the low value of shark meat. Fishers generally perceive that costs from shark interactions, including economic costs and time spent to deal with the interactions, exceed the benefit from revenue to crew from fins.

In the Italian Mediterranean industrial longline swordfish fishery, where the shark catch rate is low and sharks are occasionally retained for the sale of meat, fishermen find the costs of shark interactions to be a minor inconvenience. Few (0–10) branch lines are damaged or lost to sharks on a typical set, and very rarely is a target species damaged by sharks. At most, two target species are damaged by sharks per set. However, despite the perceived low frequency of shark interactions and nominal economic

cost from shark interactions, fishermen perceive that the revenue from catching sharks is exceeded by costs from shark interactions, and there is concern over the safety risk of handling caught sharks. As a result, fishers are interested in reducing shark interactions as long as this does not adversely affect their catch rate of target species.

In Japanese longline fisheries, where fins are retained from the majority of caught sharks and in some cases carcasses are retained for their meat, costs of shark interactions are perceived to be minor. Gear damage and loss from shark interactions are considered a much less important problem than shark damage to hooked tunas and billfishes, which can result in the damage of as many as three fish per set, where shark depredation of one fish every 3–5 sets is more typical.

Fishers in the Peru artisanal mahi mahi and shark longline fishery report that the revenue from catching sharks exceeds costs from shark interactions. Sharks are an important incidental catch species during the mahi mahi season and the main target species during the remainder of the year. Fishers estimate that they incur a cost of USD 11 per set due to damage and loss of gear, and incur a loss of about USD 30 from 7 to 8 mahi mahi being damaged from sharks on a typical set during the mahi mahi season.

In the South Africa longline tuna and swordfish fishery, fishers are concerned over shark damage to their gear and the loss of bait from shark interactions. On average, they lose the terminal tackle of 10–30 branch lines, although this is highly variable from set to set. On typical sets, 2–5 marketable fish are damaged or lost to sharks.

In the US Hawaii longline swordfish fishery, > 99% of caught sharks were discarded in 2006 when the shark catch rate was 16.7 sharks per 1000 hooks and the catch rate of retained fish was 23 fish per 1000 hooks. In the Hawaii longline tuna fishery, > 97% of caught sharks were discarded in 2006 when the shark catch rate was 2.2 sharks per 1000 hooks and the catch rate of retained fish was 13 fish per 1000 hooks [9]. In these fisheries, fishers perceive the time required to remove sharks from gear and to rebuild damaged and lost gear to be a substantial inconvenience. Risk of injury from caught sharks is also a substantial concern. Economic costs from the damage and loss of gear are nominal, costing an estimated USD 19 and USD 50 per typical tuna and swordfish set, respectively. Fishers report having an average of three marketable fish species damaged from sharks on a typical longline tuna set and five damaged on a typical swordfish set. This can represent a loss of several thousand dollars. This is a much higher rate of depredation of caught fish than reported by Lawson [20] for Western and Central Pacific Ocean pelagic longline tuna fisheries, where 1.8% (46 of 2555) of caught tunas were discarded due to shark damage. On an especially bad set, as many as 50% of target species may be damaged to a degree that they cannot be sold.

Many pelagic longline fisheries targeting species other than sharks, when not prevented by regulation, will retain the fins of captured sharks, which fetch a high value in the Asian dried seafood trade, and occasionally will retain meat and other parts (cartilage, liver oil, skin) from marketable species of sharks when markets for these products are available (e.g., [34, 36, 49, 51]. High demand for shark fins in Asia means that few sharks caught in pelagic longline fisheries, where finning is not prohibited or resources for enforcement are scarce, are released alive [34, 36]. For instance, from 1995 to 1999, before restrictions on shark finning were instituted, the Hawaii-based longline swordfish fishery finned 65% of caught sharks, when about 50% of the catch by number was elasmobranch bycatch. In the Fiji longline tuna fishery, 78–90% of caught sharks are finned (Secretariat of the Pacific Community, unpublished data). Francis et al. [34] found that about half of the catch by number on New Zealand tuna longlines was elasmobranch bycatch, from which usually only the fins were retained. Williams [36] found that in western and central Pacific longline tuna fisheries, the fate of shark bycatch was species-specific: Certain species, such as pelagic stingray, were always discarded, trunks of silky and blue shark were occasionally retained (45.8% and 5.4% of the time, respectively), fins of blue sharks were retained 84.1% of the time, and fins of silky sharks were retained 47.5% of the time. Crew in many pelagic longline fisheries have a strong economic incentive to catch sharks and fin as many of the sharks that are caught as possible as they receive the proceeds from shark fins [36, 49]. For instance, Williams [36] reported that crew of some longline tuna vessels operating in the western and central Pacific obtain half of their wage from shark fin revenue. McCoy and Ishihara [49] estimated that Hawaii longline crew had obtained over 10% of their annual wage from shark fin sales, prior to the promulgation of rules restricting finning practices. In some fisheries, shark discarding and retention practices are also a result of the value of the species of caught shark, whether the shark is caught at the beginning or end of a fishing trip, how much hold space remains, whether or not the shark is alive or dead when hauled to the vessel and the size of the shark.

However, to address the social concern that shark finning is wasteful when a large portion of the shark is discarded, and ecological concerns over the sustainability of shark exploitation in fisheries, there have been several recent international initiatives[3] and adoption of national legislation addressing shark finning (Section 4 Table 2). Fisheries that are required to retain and land entire shark carcasses if they wish to retain the fins have a high economic incentive to avoid shark bycatch in areas where there is a lack of markets for shark meat. Some fisheries may lack access to markets for shark products, as documented in Italy, creating an incentive to avoid catching sharks.

---

[3] For instance, the International Commission for the Conservation of Atlantic Tunas, Inter-American Tropical Tuna Commission and North Atlantic Fisheries Organization have adopted legally binding measures to prohibit shark finning practices.

There are pelagic longline fisheries where revenue from sharks exceeds costs from shark interactions, a large proportion of caught sharks are retained, and sharks are either always an important target species, are targeted seasonally or at certain fishing grounds proximate to ports where there is demand for shark fins and meat, or are an important incidental catch species. For instance, sharks comprised 70% of landings by the Spanish North Atlantic and Mediterranean longline swordfish fishery in 1991–1992 based on sampling at the Algeciras fish market in southern Spain [52]. While the majority of pelagic longline fisheries target tunas and billfishes [53], as documented in this study (Chile, Peru, Japan) there are a growing number of pelagic longline fisheries where the main target species are pelagic or coastal sharks [19, 39, 40–42]. While some directed shark fisheries are large industrial practices, the majority of shark catches comes from small-scale primarily gillnet fisheries [19, 54]. Chondrichthyan fisheries have substantially grown in developing countries over the past several decades. Developing countries' shark catches increased from 76,000 to 575,031 metric tons from 1950 to 2000 for a value in the year 2000 of USD 515 million [39, 41]. From 1985 to 2000, elasmobranch catches reported to the Food and Agriculture Organization of the United Nations increased annually by an average of 2% [55]. However, actual elasmobranch catches are likely much higher than reported due to a lack of accurate data collection programs and to purposeful underreporting [51, 56].

Results from this study reveal that there has been a large increase in the demand for shark fins and meat and catch of sharks over the past several decades [36, 41, 49]. For instance, shark catch by weight in Chile fisheries has increased an order of magnitude from about 1000 ton in 1950 to over 10,000 ton in 2005 [41]. Also, the shark catch in Peruvian fisheries and export market for frozen shark meat have grown, where the revenue from shark meat exceeds revenue from fins on a per-trip basis for a vessel in the Peru artisanal mahi mahi and shark longline fishery. From 2000 to 2005, exports of shark meat from Peru tripled, with main export markets including Uruguay, Spain, Brazil and Colombia [57]. The Japan component of this study has identified a trend in expanding demand for shark meat in a few regions in Japan where offshore and nearshore vessels land their catch as well as at several foreign seaports where distant water longline vessels land their catch, including Cape Town (South Africa), Callao (Peru), Las Palmas (Spain), Balboa (Panama), Cartagena (Venezuela) and Port Louis (Mauritius), and a concomitant increase in retention and landing of shark carcasses by Japan longline fisheries. The shark meat landed in Callao, Cape Town and Las Palmas may be exported to European markets in Italy and Spain.

5.2. Ecological concerns

There is an ecological basis for concern over shark interactions in pelagic longline fisheries. In the last decade, as elasmobranch catches have increased in both directed and incidental fisheries, there has been increasing concern about the status of some shark stocks, the sustainability of their exploitation in world fisheries, and ecosystem-level effects from shark population declines [4, 19, 58–60].[4] Most shark species are predators at the top of the food chain and characterized by relatively late maturity, long life, slow growth, low fecundity and productivity (small and infrequent litters), long gestation periods, high natural survivorship for all age classes, and low abundance (K-selected life history strategies) relative to bony fish such as tunas and billfishes and to organisms at lower trophic levels [66]. Some shark species may also aggregate by sex, age and reproductive stage [37, 67]. These life history characteristics make sharks particularly vulnerable to overexploitation and slow to recover from large population declines [19, 67]. Directed shark fisheries in North America provide examples of overfishing and population declines, such as occurred in directed fisheries for the porbeagle (*Lamna nasus*) [68], soupfin shark (*Galeorhinus zyopterus*) [69], and spiny dogfish (*Squalus acanthias*) [70]. Also, for example, the lack of monitoring of primarily discarded bycatch of the barndoor skate (*Dipturus laevis*) in the western North Atlantic bottom trawl fisheries resulted in a large population decline [71].

The main threats faced by chondrichthyans are various fishing activities and habitat degradation and loss [72]. Reviews of assessments of the threatened status of sharks and related taxa undertaken to date indicate that the taxa at highest risk include commercially exploited species of deepwater sharks, species restricted to freshwater and brackish water habitats and coastal endemics whose entire range overlaps with fishing effort [73]. However, a lack of both fundamental biological information and fishery-dependent data for most shark species [67, 71] means that there is a high degree of uncertainty in the status of these species. The biology of the chondrichthyan fishes is the least understood of all the major marine vertebrate groups, where detailed information on life history and reproductive dynamics is not available for all but a few of species important for directed fisheries [67]. There is a general lack of reliable and sufficiently detailed fishery-dependent data on shark species to enable sustainable management [71, 74]. Pelagic longline fisheries operating on the high seas are not likely interacting with these shark species identified as highest-risk, while some

---

[4]Atlantic blue sharks are among those reported to have undergone considerable population declines [58]. Consistent with previous arguments against treating CPUE as an index of abundance [61], the reported blue shark decline (∼60% since 1986) postulated by Baum et al. [58] has been questioned by several authors (e.g. [62–64] on the basis that potential reasons for drops in CPUE aside from abundance declines were not accounted for, such as underreporting, changes in fishing grounds and changes in fishing gear such as not using wire leaders [65]. It is acknowledged, however, that the species has likely endured some level of decline in recent years [64, 65].

coastal pelagic longline fleets could be catching at-risk coastal endemics. In particular, blue sharks (*Prionace glauca*), the dominant species of shark caught in most pelagic longline fisheries operating on the high seas (e.g., [34, 36]), are less vulnerable to overfishing relative to other shark species due to their being relatively prolific and resilient [75, 76]. Blue sharks comprise the largest proportion of shark species caught in all 12 of the fisheries included in this study, ranging from 47% to 92% of shark catch in fisheries where this information is available. Kleiber et al. [77] conducted a stock assessment of blue sharks in the North Pacific and concluded that blue sharks are not being overfished in the North Pacific. However, more recent research by Clarke et al. [51] suggests that blue sharks globally are being captured at levels close to or possibly exceeding maximum sustainable yield. Clarke et al. [51] estimated global shark catches using shark fin trade records, and found that shark biomass in the fin trade is three to four times higher than shark catch figures reported by the Food and Agriculture Organization of the United Nations, which is the sole existing global database. Additional stock assessments for other pelagic sharks have been conducted only by the International Commission for the Conservation of Atlantic Tunas for blue and shortfin mako sharks in the North and South Atlantic.

5.3. Social concerns

Shark finning, where fins from caught sharks are retained and the remainder of the carcass is discarded, raises the social issue of waste. This has received recent international and national attention (Section 4). Concern has also been raised that finning practices are cruel to sharks based on the presumption that fishers remove fins and discard sharks alive. However, results from this study document that, in all fisheries where shark finning occurs, to avoid injury and increase efficiency, crew first kill the fish before removing fins, and do not remove fins from live sharks. Also, discarded bycatch in general raises the social issue of waste [1, 4], however, in the case of shark discards, available information suggests that in pelagic longline fisheries, shark post release survival prospects are high [50] and most sharks caught in pelagic longline fisheries are alive when hauled to the vessel [36].

6. Industry attitudes

Table 3 summarizes predominant attitudes related to shark interactions held by fishers of 12 pelagic longline fisheries. The existence of restrictions on shark finning and shark retention limits (Table 2) has a large influence on industry attitudes towards shark interactions in the Australia, South Africa and Hawaii longline fisheries, where legal constraints have caused shark interactions to be an economic disadvantage. In these fisheries, fishers

have a large incentive to avoid shark interactions. In the Italy longline fishery, despite a lack of market for shark products, low shark interaction rates result in low incentive to reduce shark interactions. The predominant attitude in the Fiji longline fishery towards shark interactions is unexpected. In this fishery, where almost all caught sharks are finned and carcasses discarded, fishers perceive that costs from shark interactions exceed the economic benefit. In the Chile, Japan and Peru longline fisheries, where restrictions on shark finning and retention are lacking, there is no incentive to reduce shark interactions, as revenue from sharks exceeds costs.

7. Industry shark avoidance and discarding practices

Table 4 identifies practices in use by longline fishers in response to shark interactions with longline gear. A practice is checked for a fishery only when it is employed predominantly for the purpose of addressing shark interactions, and not if the practice is employed primarily as a normal part of fishing operations to maximize catch rates of non-shark target species.

Fishers identified numerous fishing methods and gear characteristics that they employ to maximize catch rates of non-shark target species, which may contribute to reducing shark catch rates. For instance, the depth of baited hooks, timing of gear setting, soak and hauling, location of fishing grounds in relation to topographic and oceanographic features as well as sea surface temperature, type and size of bait and hook, selection of material for the leader on branch lines, use of lightsticks, and other fishing methods and gear designs selected to maximize non-shark target species catch rates may be effective shark avoidance strategies. More research is needed to improve the understanding of the shark avoidance efficacy of many of these practices.

7.1. Avoid peak areas and periods of shark abundance

In fisheries where there is an incentive to avoid shark interactions, common practices are to avoid areas known to have high shark abundance and move position when shark interaction rates are high and the non-shark target species catch rates are not particularly high. Because there is high spatial and temporal variability in shark catch rates (e.g., [78, 79]), in addition to fishing gear characteristics, the location of fishing grounds to target non-shark species and perhaps the capability of a vessel captain to avoid areas where sharks are abundant appear to be important factors determining a vessel's shark catch rate.

Fishing position in relation to (i) certain sea surface temperatures, (ii) topographic features such as shelf breaks and sea mounts, and (iii) oceanographic features such as currents, fronts, and gyres, may affect shark interaction rates. Australian fishermen identified setting on the colder side of fronts in order to reduce shark catch levels.

Table 3
Industry attitudes towards shark bycatch and depredation prevalent in each of 12 pelagic longline fisheries

Pelagic longline fishery	Longline industry attitude								
	Want to minimize shark interactions due to time required to repair gear and discard sharks	Want to minimize shark interactions because revenue from catching sharks is exceeded by costs from shark interactions	Little incentive to reduce shark interactions because they are infrequent and result in nominal costs	Want to maximize shark catch because revenue exceeds economic costs from shark interactions	Want to minimize shark catch to avoid injuring crew when landing sharks from projectile swivels and shark bites	Want to minimize shark fishing mortality because are concerned with overfishing	Want to minimize shark catch to make more baited hooks available to more valuable fish species	Shark interactions are an expected and unavoidable part of longline fishing	No incentive to reduce shark interactions because revenue from sharks exceeds costs from shark interactions
Australia tuna and billfish fishery	X	X			X		X	X	
Chile artisanal mahi mahi and shark fishery				X					X
Chile swordfish fishery									X
Fiji tuna fishery	X	X							
Italy mediterranean industrial swordfish fishery			X						
Japan distant water, offshore and nearshore tuna fisheries			X					X	X
Peru artisanal mahi mahi and shark fishery				X					X
South africa tuna and swordfish fishery	X	X					X	X	
US hawaii tuna fishery	X	X			X		X	X	
US hawaii swordfish fishery	X	X			X		X	X	

Catch rates of blue sharks have been found to decline by 9.7–11.4% in response to only a 0.6 °C increase in sea surface temperature [24]. Not surprisingly, it has also been shown that blue sharks tend to prefer sub-surface depths that possess cooler temperatures (e.g. [80]). However, more comprehensive studies on blue shark distribution according to full water column temperature profiles and thermocline dynamics are necessary before amending fishing practices in accordance with patterns in sea-surface temperatures.

7.2. Reduce shark detection of baited hooks

Very few interviewed fishers believe that refraining from chumming during the set and refraining from discarding offal and spent bait during the haul will affect shark interactions. Chumming during setting is not a common practice. Offal and spent bait are typically discarded during hauling operations. Many respondents explained that it would be impractical to retain spent bait and offal to discard at the end of hauling due to limited space. Some

Table 4
Prevalent industry practices employed to address shark interactions in 12 pelagic longline fisheries

Practice	Pelagic longline fishery									
	Australia tuna and billfish fishery	Chile artisanal mahi mahi and shark fishery	Chile swordfish fishery	Fiji tuna fishery	Italy Mediterranean industrial swordfish fishery	Japan distant water, offshore and nearshore fisheries	Peru artisanal mahi mahi and shark fishery	South Africa tuna and swordfish fishery	US Hawaii tuna fishery	US Hawaii swordfish fishery
Move position if shark interactions are high and target species CPUE is low	X		X	X			X	X	X	X
Avoid fishing grounds with high shark abundance from past experience or communication from other vessels	X		X		X			X	X	
Reduce shark detection of baited hooks										
Set gear deeper	X									
Use or avoid type of bait or hook	X									
To discard sharks, cut branch line or remove hook by making cut in shark mouth	X			X			X	X	X	
No wire trace to reduce retention of sharks	X									
Do not use lightsticks	X									
Avoid setting in specific sea surface temperature	X									
Set during daytime	X									
Minimize gear soak time	X									
Kill sharks before discarding to avoid re-catching	X									
Do nothing to reduce shark catch because shark catch is desirable or shark interactions are rare		X			X		X			

Australian fishers avoid using lightsticks because they believe lightsticks increase shark catch rates.

7.3. Reduce shark catch rate through deeper setting, leader material and type of bait or hook

Some fishers avoid using certain types of bait to reduce shark interactions, or perceive that avoiding certain bait types will reduce shark capture rates (e.g., Italy and Japan, avoid squid; Australia, avoid oily pilchard and squid). Few fishers believe that hook shape has a large effect on shark catch rates. Furthermore, some fishers indicated that they set their gear at a certain depth or perceive that setting deeper would contribute to reducing shark interactions.

Most fishers believe that the depth of baited hooks and timing of the gear soak influence shark catch rates. The deployment depth of hooks and timing of the soak and haul (day versus night) can have an influence on fish species CPUE, including sharks, perhaps due to different water temperature preferences by each species [36, 81, 82]. For example, Rey and Munoz-Chapuli [82] found higher mako

shark (*Isurus oxyrinchus*) CPUE on shallower set hooks, and no mako capture on the three deepest hooks in a basket, which were estimated to be set to between 370 and 460 m deep, in a Spanish tropical eastern Atlantic surface longline swordfish and mako shark fishery. Williams [36] found that main pelagic shark species, with the main exception being the mako sharks, tend to be taken at a higher rate in more shallow-set gear than vessels setting gear deeper in central and western Pacific pelagic longine tuna fisheries. Blue shark, silky shark, pelagic stingray, and oceanic whitetip CPUE were 2.7, 6.4, 1.1, and 2.8 times higher, respectively, in shallow versus deep set gear. Setting baited hooks below a threshold depth may reduce bycatch and depredation by certain species of sharks in certain areas, but shark interaction rates may also depend on when it is that the hooks are at these depths.

One fisher in the Hawaii-based longline tuna fishery tried various types of artificial baits to determine their ability to catch target species and to reduce shark capture. He found that the artificial baits did not catch tuna well and that they were not durable enough as he lost about 90% of the artificial baits after one trip. One fisher in the Peru artisanal mahi mahi and shark longline fishery tried artificial bait, which did not reduce shark interactions. An artificial bait was tested in the Alaska demersal longline sablefish (*Anoplopoma fimbria*) and Pacific halibut (*Hippoglossus stenolepis*) fishery. Results indicated that the artificial bait caught as many or more target species and reduced bycatch of spiny dogfish shark (*Squalus acanthias*), skate (*Raja* spp.), arrowtooth flounder (*Atheresthes stomias*), and Pacific cod (*Gadus macrocephalus*) by more than ten times compared to a control of fishing with herring bait, the conventional bait used in this fishery [83].

The type of hook and natural bait used might affect shark CPUE and depredation rates [8, 36]. Results from controlled experiments in the Azores and US North Atlantic longline fisheries indicate that fishing with fish instead of squid for bait causes a significant decrease in shark CPUE, while using a wider circle hook instead of a narrower J hook may cause a significant but small increase in shark CPUE. Research in the Azores longline swordfish and blue shark fishery, during a year when blue sharks were not being targeted due to low market demand, found that non-offset 16/0 circle hooks had a significantly higher blue shark CPUE than a non-offset 9/0 J hook [84]. In another study in the Azores fishery, during a year when blue sharks were being targeted, non-offset 16/0 and non-offset 18/0 circle hooks caught significantly more blue sharks than a non-offset 9/0 J hook [85]. A study conducted in the US North Atlantic longline swordfish fishery found that a non-offset and 10° offset 18/0 circle hook with squid bait resulted in a small but significant increase in blue shark CPUE (8% and 9% increases, respectively) compared to a 9/0 J hook with squid [24]. Watson et al. [24] also found that a 10° offset 18/0 circle hook with mackerel bait and a 9/0 J hook with mackerel bait resulted in a significant and large reduction in blue

shark CPUE by 31% and 40%, respectively, compared to a 9/0 J hook with squid. Research in an experimental Japanese North Pacific longline fishery found no difference in the capture rate of blue sharks between a circle and Japan tuna hook [86, 87].

An assessment of observer data from the Hawaii-based longline swordfish fishery is consistent with results from these controlled experiments [8]. Shark combined species CPUE was significantly lower by 36% after regulations came into effect, which required the fishery to switch from using a 9/0 J hook with squid bait to using a 10° offset 18/0 circle hook with fish bait [8].

Retention of sharks on branch lines with wire leaders or other durable material is substantially higher than in gear where nylon monofilament is connected directly to the hook (Section 4 (e.g., [36])). Several fishermen who target sharks seasonally use a wire leader when they wish to maximize their shark catch rates and do not use a wire leader when they are targeting non-shark species. Avoiding certain material for branch lines could also reduce shark depredation and catch rates. For instance, the use of rope/steel ("Yankee") gangions resulted in lower juvenile sandbar shark catch rates than when using monofilament gangions [88]. In another study, percent-capture of blue shark with the use of monofilament gangions (66%) exceeded that when employing multifilament gangions (34%) [89]. Shortfin mako shark catches adhered to the same pattern (60% and 40%) for "mono" and "multi" line, respectively. Stone and Dixon [89] hypothesized that the aversion to the multifilament gangion was a function of strong visual acuity.

7.4. Shark discard practices

A large proportion of pelagic shark species are alive when gear is retrieved (Section 3), suggesting that improved shark handling and release methods may reduce fishing mortality of discarded sharks. While some fishers report routinely killing caught sharks to retrieve terminal tackle and to avoid the inconvenience of recapture, empirical information from Australia, Hawaii and Peru shows that a very small proportion of caught sharks that are alive when hauled to the vessel are killed before discarding. When a caught shark is discarded, the majority of fishers indicate that most of the time they cut branch lines, cut the hook out of the shark's mouth with a knife or pull the hook out by force in order to retrieve the terminal tackle before discarding the shark. It is uncommon for fishers to kill a shark to retrieve terminal tackle or to prevent future shark interactions.

The survival of sharks that are not finned, that are deeply hooked (where the shark has swallowed the hook) and have hooks removed by fishers pulling the hook out likely depends on where they were hooked and how much damage is done by pulling out the hook. For deeply hooked sharks, as is believed to be the case for sea turtles [8, 9, 24], prospects for post release survival might be

improved by having fishers cut the line as close to the shark as safely possible. A large proportion of sharks caught in longline gear that is released after removal of the hook from the mouth are expected to survive. Research using pop-up satellite archival tags found that 97.5% of pelagic sharks released after capture in longline gear survived (1 of 40 captured sharks died), while another study found that 94% of 17 tagged shorfin mako sharks survived beyond two months after release from being caught in longline gear [50]. While shark post-release survival prospects are high, and while many fishers do not see a need for new hook removal methods, development of especially designed equipment to discard sharks could improve shark post release survival prospects, reduce the loss of terminal tackle and improve crew safety.

None of the interviewed pelagic longline fishermen use dehookers to discard live sharks. Only two fishers, one from the Chile artisanal mahi mahi and shark longline fishery and one from the Peru artisanal mahi mahi and shark longline fishery, report that they use a dehooker to recover hooks from sharks when these are onboard and already dead. Most fishers perceive commercially available dehooker devices to be impractical and potentially dangerous for use with sharks. Some caught sharks will twist and spin when hauled to the vessel, which could cause the dehooker to be lost overboard and be a hazard for crew to handle before being lost overboard. Because sharks may be on the sea surface when being hauled, some fishers were concerned that the incidence of having branch lines break if a shark pulls the line would increase with use of a dehooker because use of a dehooker requires bringing the shark close to the vessel.

8. Promising new strategies for shark avoidance

8.1. Shark repellents

For fisheries with an incentive to reduce shark interactions, chemical, magnetic, electropositive rare earth metal and electrical repellents are promising shark deterrents. Some of these strategies are concepts requiring substantial investment to develop the technology for application in longline gear. Research and commercial demonstrations are needed to assess their efficacy at repelling sharks and effects on target and incidental species. Research and development is also needed to reduce the per-unit cost of these repellents to make them economically viable for use in pelagic longline fisheries.

Chemical deterrents, including a protein extract called "pardaxin" from an excretion from the moses sole (*Pardachirus marmoratus*), sodium and lithium lauryl sulfate (components of common soap and shampoo) and sodium dodecyl sulfate, a related compound, have been found to repel some species of sharks under certain conditions [90]. Some fishers from Peru artisanal mahi mahi and shark fishery report retain all shark offal until the end of a haul because they believe that discharging offal

during the haul would repel sharks and reduce their shark catch rate. The US-based company Shark Defense LLC has identified a semiochemical-based shark repellent, which in preliminary trials caused six shark species to leave an area after the chemical was disbursed without repelling teleost fish [91]. Presumably, this can be ascribed to an apparent aversion in sharks to certain chemicals, including ammonium acetate (a major component in decaying shark flesh) and other semiochemicals emitted from predators [92]. When mixtures of semiochemicals were introduced into feeding aggregations of sharks and teleost fish in reef habitat, sharks quickly left the feeding area while bony fish stayed in the area and continued feeding [50].

A preliminary study was conducted by the US National Marine Fisheries Service Pacific Islands Fisheries Science Center in Hawaii in early 2005 to compare the catch of target species and sharks in sets using bait injected with synthetic shark semiochemicals produced by Shark Defense LLC to catch rates in sets using untreated bait. Results were inconclusive, in part, because the research design prevents conclusions to be drawn on the single factor effect of the presence or absence of semiochemicals in the bait, and because it was not possible to confirm that bait injected with semiochemicals retained the chemical throughout the gear soak [50].

Since conducting this 2005 trial in Hawaii, the chemical is now available in a hydroxypropyl cellulose and glycol ether ester gel matrix [91]. In current ongoing trials the gel is placed in biodegradable, porous muslin bags filled with 100 ml of the gel at 30.5 cm above the bait. The gel has been observed to dissolve evenly over an 8-h period while the fishing gear soaks. The gel could also be syringed directly into a bait or a bag of the gel could be stuffed into a bait [91]. One bag filled with 100 ml of the gel matrix would cost about USD 1.05. Pre-treated baits may be a less expensive option.

Shark Defense is also conducting preliminary trials of neodymium-iron-boride ($Nd_2Fe_{14}B$) magnets as a possible shark deterrent in longline gear. It is hypothesized that a 10 cm × 4 cm NdFeB magnet's field would be effectively detected by sharks up to a 0.3-m range. Preliminary research conducted in 2005 on the effect of $Nd_2Fe_{14}B$ magnets by the Inter-American Tropical Tuna Commission on captive yellowfin tuna and by the University of Miami on cobia indicates that the presence of the magnet versus a control produced no significant difference in feeding behavior [91]. Preliminary research in a demersal longline fishery in the Bahamas is underway. A 2.5 cm × 2.5 cm $Nd_2Fe_{14}B$ nickel-coated cylinder with a center bore costs about USD 300 for 100 magnets.

Shark Defense is also exploring the shark deterrent efficacy of electropositive metals (e.g. neodymium, praseodymium, early lanthanide metals, mischmetal, and magnesium). These metals, which are also present in rare earth magnets, may be responsible for some of the repellency effect seen with permanent magnets and present a more

practical alternative to the magnets. A correlation has been found between standard oxidation potential of these metals and their behavioral response using immobilized sharks [91].

An electrical shark avoidance device was tested in a coastal midwater trawl fishery in the Sea of Japan (Ishikawa Prefecture) in 2004. The purpose of the device was to deter predation by sharks on the cod end of the trawl during hauling. The device, mounted on the fishing vessel, emitted an electrical pulse into the waters in the immediate vicinity. It was believed by fishermen to be effective based on qualitative observations of sharks suddenly moving away from the cod end and the vessel once the electrical pulse was emitted.

The Shark Protective Ocean Device is a device designed to be worn by scuba-divers that emits an electrical field with a radius of 4–6 m to repel sharks from divers. The device costs about USD 700. This technology theoretically could be modified to deter sharks from foraging on bait and catch on longline hooks.

Acoustic deterrents may reduce shark–longline interactions, but have not been tested in longline fisheries for any shark species.

8.2. Hotspot avoidance through fleet communication and protected areas

The distribution of sharks, as well as other species groups such as seabirds, sea turtles and cetaceans, is often unpredictable, and may be spatially contagious or aggregated. Consequently, fleet communication programs may be employed by a fishing industry to report near real-time observations of hotspots to substantially reduce fleet-wide depredation and bycatch of sharks [11]. In addition, fleet coordination of daily fishing positions and times, a current practice in many fleets, may minimize per vessel shark interaction levels relative to vessels that fish in isolation [10].

Area and seasonal closures can also contribute to reducing shark–longline interactions. Establishing protected areas within a nation's EEZ is potentially an expedient method to reduce shark–longline interactions. However, establishing and managing high seas marine protected areas to protect sharks, which would require extensive and dynamic boundaries and extensive buffers, may not be a viable short-term solution. This is due in part to the extensive time anticipated to (i) resolve legal complications with international treaties, including creating legally binding mechanisms for multilateral designation and management of high seas protected areas;[5] (ii) achieve

international consensus and political will; (iii) provide requisite extensive resources for surveillance and enforcement, in part, to control illegal, unreported and unregulated fishing activities; and (iv) improve the scientific basis for designing high seas marine protected areas, which can be effective at reducing shark interactions only where the location and times of occurrence of shark hotspots are known and predictable. However, establishing and managing a representative system of protected area networks on the high seas to contribute to the management of interactions between marine capture fisheries and highly migratory sensitive species groups, including sharks, may eventually be realized.

Consequences of establishing a protected area need to be carefully considered, as resource use restrictions of a marine protected area may displace effort to adjacent and potentially more sensitive and valuable areas, where weaker management frameworks may be in place [58, 93]. Also, measures adopted by regional fishery management organizations and other international bodies are only binding to parties to the Convention that established the organization, and will not control activities by non-party States. Thus, another consideration for employing high seas marine protected areas to manage problematic fisheries bycatch is that closing areas to fisheries only of party States could result in increased effort in this area by fleets from non-party States with fewer or no control to manage bycatch, exacerbating the problem for which the MPA was established to address.

9. Conclusions

Incentives for pelagic longline fishers to reduce shark interactions vary along a continuum, based on whether sharks represent an economic disadvantage or advantage. On one extreme, there are pelagic longline fisheries with a regulatory framework limiting shark catches or placing restrictions on shark handling, or lack of markets for shark products, resulting in negligible retention of sharks. In these fisheries, the costs from shark interactions exceed benefits from revenue from sharks. On the other extreme, there are pelagic longline fisheries where revenue from sharks exceeds costs from shark interactions, a large proportion of caught sharks are retained, and sharks are either always an important target species, are targeted seasonally or at certain fishing grounds proximate to ports where there is demand for shark products, or are an important incidental catch species.

In fisheries where there is an incentive to avoid shark interactions, predominant shark avoidance practices are to:

(i) Avoid fishing in areas known to have high shark interactions; and

---

[5]It is already possible to establish high seas MPAs for discrete areas by agreement by individual countries. However, there remains a need for an international framework with specific language to identify the criteria to establish a representative system of high seas MPA networks, and management and enforcement measures for the individual MPAs. Several RFMOs are updating their scope and legal mandate to include ecosystem-based management and biodiversity conservation under the auspices of

(footnote continued)

the Fish Stocks Agreement. The Commission for the Conservation of Antarctic Marine Living Resources has made some preliminary progress toward establishing a system of MPAs in the Southern Ocean.

(ii) Change fishing grounds when shark interactions are high but the target species catch rate is low.

Longline fishers identified numerous fishing methods and gear characteristics that they conventionally employ to maximize catch rates of non-shark target species, which may contribute to reducing shark catch rates. For instance, experimental trials have shown that using fish instead of squid as bait results in a significant and large decrease in shark catch rates [8, 24, 84, 85]. Also, deeper setting helps reduce catch rates of most pelagic shark species [36]. Research is needed to improve the understanding of the shark avoidance efficacy of some of these other practices.

Beyond these strategies, the state of knowledge for shark avoidance in pelagic longline fisheries is poor. Chemical, magnetic, electropositive rare earth metals and electrical shark deterrents hold promise. Research is needed to assess their efficacy at repelling sharks, effect on target species catch rates and reduce the cost for commercially viable employment in longline fisheries. Fleet communication programs and marine protected areas also hold promise to reduce unwanted shark–longline interactions.

A large proportion of pelagic shark species are alive when gear is retrieved. Most sharks that are alive when hauled to the vessel and will be discarded are released alive. When a caught shark is discarded, most of the time fishers either cut branch lines, cut the hook out of the shark's mouth or pull the hook out by force in order to retrieve the terminal tackle before discarding the shark. It is uncommon for fishers to kill a shark to retrieve terminal tackle or to prevent future shark interactions. Most fishers perceive commercially available dehooker devices to be impractical and potentially dangerous for use with sharks. Development of especially designed equipment to discard sharks could improve shark post release survival prospects, reduce the loss of terminal tackle and improve crew safety. In fisheries where shark finning occurs, to avoid injury and increase efficiency, crew first kill the fish before removing fins, and do not remove fins from live sharks.

The Japan, Chile and Peru components of this study documented growing markets for shark meat at several ports worldwide. This trend toward more utilization of shark meat may be beneficial in the short term in that fully utilized sharks are more likely to be reported in logbooks and landings statistics than are the retention and landing of just shark fins. However, if the shark meat market continues to grow, this could increase shark catch rates and fishing mortality. This study shows that fishers possess the knowledge to modify their fishing gear and methods to maximize shark catch. There are few fisheries with measures to manage shark catch levels. Thus, to prepare for a possible increase in demand for shark meat fishery management authorities are encouraged to institute data collection, monitoring and precautionary management measures to ensure that shark catches are sustainable.

Most national fishery management authorities of the 12 fisheries included in this study demonstrate a low priority for monitoring and managing chondrichthyan fishes, consistent with the results of a global review by Shotton [74]. Few regional fishery management organizations are using fishery-dependent data to conduct shark stock assessments (only the International Commission for the Conservation of Atlantic Tunas, for blue and shortfin mako sharks in the North and South Atlantic). Sustainable management of chondrichthyan populations is hampered by this general lack of fishery-dependent data and management measures for sharks [71]. The expanding exploitation of sharks, for their fins as well as meat, largely in the absence of management frameworks and the lack of reliable fishery-dependent data and fundamental understanding of the biology of most shark species warrant concern for the health of shark populations as well as ecosystem-level effects from population declines. Approaches to sustainably managed cartilaginous fishes will necessarily differ from traditional fishery management methods for teleosts due to cartilaginous fishes' relatively low reproductive potential [72].

Acknowledgments

References

[1] Alverson DL, Freeberg MH, Murawski SA, Pope JG. A global assessment of fisheries bycatch and discards. Fisheries Technical Paper No. 339. Food and Agriculture Organization of the United Nations, Rome, Italy; 1994.

[2] FAO. International plan of action for reducing incidental catch of seabirds in longline fisheries. Rome, Italy: Food and Agriculture Organization of the United Nations; 1999.

[3] FAO. International plan of action for the conservation and management of sharks. Rome, Italy: Food and Agriculture Organization of the United Nations; 1999.

[4] FAO. The state of world fisheries and aquaculture. Rome, Italy: Food and Agriculture Organization of the United Nations; 1999.

[5] FAO. Technical consultation on sea turtles conservation and fisheries, Bangkok, Thailand, 29 November–2 December 2004. Sea

turtle conservation concerns and fisheries management challenges and options. Food and Agriculture Organization of the United Nations, Rome, Italy; 2004.

[6] FAO. Expert consultation on interactions between sea turtles and fisheries within an ecosystem context. FAO Fisheries Report No. 738. Food and Agriculture Organization of the United Nations, Rome, Italy; 2004.

[7] Gilman E. Integrated management approach to address incidental mortality of seabirds in longline fisheries. Aquatic Conservation 2001;11:391–414.

[8] Gilman E, Kobayashi D, Swenarton T, Brothers N, Dalzell P, Kinan I. Reducing sea turtle interactions in the Hawaii-based longline swordfish fishery. Biological Conservation, in press.

[9] Gilman E, Zollett E, Beverly S, Nakano H, Shiode D, Davis K, et al. Reducing sea turtle bycatch in pelagic longline gear. Fish and Fisheries 2006;7(1):2–23.

[10] Gilman E, Dalzell P, Martin S. Fleet communication to abate fisheries bycatch. Marine Policy 2006;30(4):360–6.

[11] Gilman E, Brothers N, McPherson G, Dalzell P. Review of cetacean interactions with longline gear. Journal of Cetacean Research and Management 2006;8(2):215–23.

[12] Gilman E, Brothers N, Kobayashi D. Principles and approaches to abate seabird bycatch in longline fisheries. Fish and Fisheries 2005; 6(1):35–49.

[13] Hall MA, Alverson DL, Metuzals KI. By-catch: problems and solutions. Marine Pollution Bulletin 2000;41(1–6):204–19.

[14] IUCN. Fisheries by-catch, Resolution 1.16. Adopted at the First World Conservation Congress, Montreal, Canada, October 13–23, 1996. World Conservation Congress, International Union for the Conservation of Nature (IUCN), Gland, Switzerland; 1996.

[15] IUCN. Incidental mortality of seabirds in longline fisheries, Resolution 1.15. Adopted at the First World Conservation Congress, Montreal, Canada, October 13–23, 1996. World Conservation Congress, International Union for the Conservation of Nature (IUCN), Gland, Switzerland; 1996.

[16] IUCN. Incidental capture of marine turtles by pelagic longline fisheries, Resolution 2.65. Adopted at the Second World Conservation Congress, Amman, Jordan, 4–11 October 2000. World Conservation Congress, International Union for the Conservation of Nature (IUCN), Gland, Switzerland; 2000.

[17] McCaughran DA. Standardized nomenclature and methods of defining bycatch levels and implications. Proceedings of the national industry bycatch workshop, Newport, Oregon, February 4–6, 1992. Seattle, WA: Natural Resources Consultants; 1992.

[18] Bonfil R. Trends and patterns in world and Asian elasmobranch fisheries. In: Fowler SL, Reed TM, Dipper FA, editors. Elasmobranch biodiversity, conservation and management. Occasional Paper of the IUCN Species Survival Commission, vol. 25. International Union for Conservation of Nature and Natural Resources, Gland, Switzerland; 2002. p. 15–24.

[19] Musick JA, Burgess GH, Camhi M, Cailliet G, Fordham S. Management of sharks and their relatives (*Elasmobranchii*). Fisheries 2000;25(3):9–13.

[20] Lawson T. Predation of tuna by whales and sharks in the Western and Central Pacific Ocean. 14th meeting of the standing committee on tuna and billfish. Working Paper SWG-6. Secretariat of the Pacific Community, Noumea, New Caledonia; 2001.

[21] Nishida T, Shiba Y. Report of the predation survey by the Japanese commercial tuna longline fisheries (September, 2000–November, 2001). Technical Document (IOTC/WPTT/02/14) submitted to the Fourth working party on the tropical tuna meeting, 4–11 June, Shanghai, China. Indian Ocean Tuna Commission, Victoria, Seychelles; 2002.

[22] Gilman E, Boggs C, Brothers N. Performance assessment of an underwater setting chute to mitigate seabird bycatch in the Hawaii pelagic longline tuna fishery. Ocean and Coastal Management 2003; 46(11–12):985–1010.

[23] Gilman E, Brothers N, Kobayashi D. Comparison of the efficacy of three seabird bycatch avoidance methods in Hawaii pelagic longline fisheries. Fisheries Science 2007;73(1):208–12.

[24] Watson J, Foster D, Epperly S, Shah A. Fishing methods to reduce sea turtle mortality associated with pelagic longlines. Canadian Journal of Fisheries and Aquatic Sciences 2005;62(5):965–81.

[25] Martin S, Gilman E, Dalzell P. Meeting Hawaii longline industry needs to reduce fisheries bycatch through cooperative research. In: Read AN, Hartley TW, editors. Partnerships for a common purpose: cooperative fisheries research and management. Proceedings of the American fisheries society/sea grant symposium 52. American Fisheries Society 135th annual meeting, 11–15 September 2005, Anchorage, Alaska. Bethesda, Maryland, USA: American Fisheries Society; 2006. p. 197–203.

[26] Gilman E, Clarke S, Brothers N, Alfaro-Shigueto J, Mandelman J, Mangel J, et al. Shark depredation and unwanted bycatch in pelagic longline fisheries: industry practices and attitudes, and shark avoidance strategies. Western Pacific Regional Fishery Management Council, and Regional Seas Programme of the United Nations Environment Programme, Honolulu and Nairobi; 2007. ISBN:1-934061-06-9.

[27] Nakano H, Clarke S. Filtering method for obtaining stock indices by shark species from species-combined logbook data in tuna longline fisheries. Fisheries Science 2006;72:322–32.

[28] Barria M, Donoso P. Seguimiento del Estado de Situación de las principales pesquerías nacionales. Pesquería Recursos Altamente Migratorios, 2005. Informe Final, BIP 30033825-0; 2006.

[29] Swamy K. Shark fisheries in Fiji: their management and issues for future concern. IN FAO. Case studies of the management of Elasmobranch fisheries. FAO Fisheries Technical Paper, No. 378, part 1. Food and Agriculture Organization of the United Nations, Rome, Italy; 1999.

[30] Megalofonou P, Yannopoulos C, Damalas D, De Metrio G, Deflorio M, de la Serna JM, et al. Incidental catch and estimated discards of pelagic sharks from the swordfish and tuna fisheries in the Mediterranean Sea. Fishery Bulletin 2005;103(4):620–34.

[31] Ito R, Machado W. Annual report of the Hawaii-based longline fishery for 1998. Administrative Report H-99-06. US National Marine Fisheries Service Southwest Fisheries Science Center, Honolulu, HI, USA; 1999.

[32] Bailey K, Williams PG, Itano D. By-catch and discards in western pacific tuna fisheries: a review of SPC data holdings and literature. Oceanic Fisheries Technical Paper no. 341. South Pacific Commission, Noumean, New Caledonia; 1996.

[33] Beerkircher LR, Cortes E, Shivji M. Characteristics of shark bycatch observed on pelagic longlines off the Southeastern United States, 1992–2000. Marine Fisheries Review 2002;64(4):40–9.

[34] Francis MP, Griggs LH, Baird SJ. Pelagic shark bycatch in the New Zealand tuna longline fishery. Marine and Freshwater Research 2001;52:165–78.

[35] Matsunaga H, Nakano H. Species composition and CPUE of pelagic sharks caught by Japanese longline research and training vessels in the Pacific Ocean. Fisheries Science 1999;65:16–22.

[36] Williams PG. Shark and related species catch in tuna fisheries of the tropical Western and Central Pacific Ocean. Prepared for the Food and Agricultural Organisation of the United Nations for the 23–27 April 1998 meeting of the Technical Working Group on Sharks. Noumea, New Caledonia: South Pacific Commission; 1997.

[37] Heberer CF, McCoy MA. Overview of pacific fishing agencies and institutions collecting shark catch data. Honolulu: Western Pacific Regional Fishery Management Council; 1997.

[38] Abercrombie DL, Balchowsky HA, Paine AL. 2002 and 2003 Annual summary: large pelagic species. NOAA Technical Memorandum NMFS SEFSC-529. Pascagoula, Mississippi: Southeast Fisheries Science Center, US National Marine Fisheries Service; 2005.

[39] Catarci C. World markets and industry of selected commercially-exploited aquatic species with an international conservation profile.

FAO Fisheries Circular. No. 990. Rome, Italy: Food and Agriculture Organization of the United Nations; 2004.

[40] Chen C, Liu K, Joung S, Phipps M. Taiwan's shark fishery. An overview. In: Fowler S, Reed T, Dipper F, editors. Elasmobranch biodiversity, conservation and management. Gland, Switzerland: IUCN, Species Survival Commission; 2002. p. 95–103.

[41] FAO. Fisheries commodities production and trade 1976–2004. FISHSTAT Plus-Universal software for fishery statistical time series. Rome, Italy: Fishery Information, Data and Statistics Unit, Food and Agriculture Organization of the United Nations; 2006.

[42] Stevens J. A review of Australian Elasmobranch fisheries. In: Fowler S, Reed T, Dipper F, editors. Elasmobranch biodiversity, conservation and management. Gland, Switzerland: IUCN, Species Survival Commission; 2002. p. 122–6.

[43] Commonwealth of Australia. Fisheries Management Act 1991. Act no. 162 of 1991 as amended; 1991.

[44] Council of the European Union. Council Regulation (EC) no. 1185/2003 of 26 June 2003. On the removal of fins of sharks on board vessels. Official Journal of the European Union 2003; L167: 1–3.

[45] Republic of South Africa. South Africa marine living resource act of 1998. Cape Town: Republic of South Africa; 1998.

[46] US Congress. Shark Finning Prohibition Act. 16 USC 1822, Public Law 106–557. US Government, Washington, DC; 2000.

[47] Hobday A, Stobutzki I, Webb H. Draft ecological risk assessment of effects of fishing: eastern tuna and billfish fishery (V7). In: Hobday A, Smith ADM, Stobutzki I, editors. Ecological risk assessment for Australian commonwealth fisheries. Final Report-Stage 1. Hazard identification and preliminary risk assessment. Canberra, Australia: Australian Fisheries Management Authority; 2004.

[48] Rose C, McLaughlin K. Review of shark finning in Australian fisheries. Canberra, Australia: Bureau of Rural Sciences; 2001.

[49] McCoy M, Ishihara H. The socioeconomic importance of sharks in the US Flag Areas of the Western and Central Pacific. Administrative Report AR-SWR-00-01. US National Marine Fisheries Service Southwest Region, La Jolla, CA, USA; 1999.

[50] US National Marine Fisheries Service. 2005 Report to Congress Pursuant to the Shark Finning Prohibition Act of 2000 (Public Law 106–557). US National Oceanic and Atmospheric Administration, US Department of Commerce, Washington, DC; 2005.

[51] Clarke SC, McAllister M, Milner-Gulland E, Kirkwood G, Michielsens C, Agnew D, et al. Global estimates of shark catches using trade records from commercial markets. Ecology Letters 2006;9:1115–26.

[52] Buencuerpo V, Rios S, Moron J. Pelagic sharks associated with the swordfish, *Xiphias gladius*, fishery in the eastern North Atlantic Ocean and Strait of Gibraltar. Fishery Bulletin 1998;96:667–85.

[53] Brothers NP, Cooper J, Lokkeborg S. The incidental catch of seabirds by longline fisheries: worldwide review and technical guidelines for mitigation. FAO Fisheries Circular No. 937. Food and Agriculture Organization of the United Nations, Rome, Italy; 1999.

[54] Reyes JC. Reintroduction of longlines in the peruvian shark fishery: an alternative to reduce small cetacean mortality. Cetacean Specialist Group, Species Survival Commission of the International Union for the Conservation of Nature and Natural Resources (IUCN), Gland, Switzerland, and Whale and Dolphin Conservation Society, Wiltshire, UK; 1993.

[55] FAO. FISHSTAT Plus (V. 2.30), Capture production database 1970–2000, and commodities trade and production database 1976–2000. Food and Agriculture Organization of the United Nations, Rome, Italy; 2002.

[56] Clarke SC, Burgess G, Cavanagh R, Crow G, Fordham S, McDavitt M, et al. Socio-economic significance of chondrichthyan fishes. In: Fowler S, Cavanagh R, Camhi M, Burgess G, Cailliet G, Fordham S, Simpfendorfer C, Musick J, editors. Sharks, rays and chimaeras: the status of the chondrichthyan fishes. Gland, Switzerland: The World Conservation Union (IUCN); 2005. p. 19–47.

[57] PROMPEX, Comision para la Promocion de Exportaciones. On-line information, May 2006. 〈www.prompex.gob.pe〉.

[58] Baum JK, Myers RA, Kehler DG, Worm B, Harley SJ, Doherty PA. Collapse and conservation of shark populations in the northwest Atlantic. Science 2003;299:389–92.

[59] Baum JK, Myers RA. Shifting baselines and the decline of pelagic sharks in the Gulf of Mexico. Ecology Letters 2004;7:135–45.

[60] Ward P, Meyers RA. Shifts in open-ocean fish communities coinciding with the commencement of commercial fishing. Ecology 2005;86:835–47.

[61] Cooke JG, Beddington JR. The relationship between catch rates and abundance in fisheries. IMA Journal of Mathematics Applied in Medicine and Biology 1984;1:391–405.

[62] Burgess G, Beerkircher L, Cailliet G, Carlson J, Cortes E, Goldman K, et al. Is the collapse of shark populations in the Northwest Atlantic Ocean and Gulf of Mexico real? Fisheries 2005;30(10):19–26.

[63] Burgess G, Beerkircher L, Cailliet G, Carlson J, Cortes E, Goldman K, et al. Reply to robust estimates of decline for pelagic shark populations in the Northwest Atlantic and Gulf of Mexico. Fisheries 2005;30(10):30–1.

[64] Campana SE, Marks L, Joyce W, Kohler N. Effects of recreational and commercial fishing on blue sharks (*Prionace glauca*) in Atlantic Canada, with inferences on the North Atlantic population. Canadian Journal of Fisheries and Aquatic Sciences 2006;63:670–82.

[65] Brooks EN, Ortiz M, Beerkircher L, Apostolaki P, Scott G. Standardized catch rates for blue shark and shortfin mako shark from the US pelagic logbook and US pelagic observer program, and US weightout landings. Col. Vol. Sci. Pap. ICCAT 2005;58(3):1054–72.

[66] Fowler S, Cavanagh R, Camhi M, Burgess G, Cailliet G, Fordham S, Simpfendorfer C, Musick J, editors. Sharks, rays and chimaeras: the status of the chondrichthyan fishes. Gland, Switzerland: The World Conservation Union (IUCN); 2005.

[67] Cailliet M, Musick J, Simpfendorfer C, Stevens J. Ecology and life history characteristics of chondrichthyan fish. In: Fowler S, Cavanagh R, Camhi M, Burgess G, Cailliet G, Fordham S, Simpfendorfer C, Musick J, editors. Sharks, rays and chimaeras: the status of the chondrichthyan fishes. Gland, Switzerland: The World Conservation Union (IUCN); 2005. p. 12–8.

[68] Casey JG, Mather FJ, Mason JM, Hoenig J. Offshore fisheries of the Middle Atlantic Bight. Marine Recreational Fisheries 1978;3:107–29.

[69] Ripley WE. The soupfin shark and the fishery. California Department of Fish and Game Fisheries Bulletin 1946;64:7–37.

[70] Rago PJ, Sosebee KA, Brodziak JKT, Murawski SA, Anderson ED. Implications of recent increases in catches on the dynamics of northeast Atlantic spiny dogfish (*Squalus acanthias*). Fisheries Research 1998;39(2):165–81.

[71] Musick JA. Introduction. In: Fowler S, Cavanagh R, Camhi M, Burgess G, Cailliet G, Fordham S, Simpfendorfer C, Musick J, editors. Sharks, rays and chimaeras: the status of the chondrichthyan fishes. Gland, Switzerland: The World Conservation Union (IUCN); 2005. p. 1–3.

[72] Stevens JD, Walker T, Cook S, Fordham S. Threats faced by chondrichthyan fish. In: Fowler S, Cavanagh R, Camhi M, Burgess G, Cailliet G, Fordham S, Simpfendorfer C, Musick J, editors. Sharks, rays and chimaeras: the status of the chondrichthyan fishes. Gland, Switzerland: The World Conservation Union (IUCN); 2005. p. 48–57.

[73] CITES. Progress made by the IUCN species survival commission's shark specialist group in assessing the threatened status of sharks and related taxa. Nineteenth meeting of the Animals Committee, Geneva, Switzerland, 18–21 August 2003. Convention on International Trade in Endangered Species of Wild Fauna and Flora, Geneva, Switzerland; 2003.

[74] Shotton R. Species identification practices of countries reported landings of chnodrichthyan fishes in the FAO nominal catches and landings database. In: Shotton R, editor. Case studies of the management of elasmobranch fisheries. FAO Fisheries Technical

Paper no. 378, Part 2. Food and Agriculture Organization of the United Nations, Rome, Italy; 1999. p. 904–20.

[75] Cortes E. Incorporating uncertainty into demographic modeling: application to shark populations and their conservation. Conservation Biology 2002;16:1048–62.

[76] Smith SE, Au D, Snow C. Intrinsic rebound potentials of 26 species of Pacific sharks. Marine and Freshwater Research 1998;49: 663–78.

[77] Kleiber P, Takeuchi Y, Nakano H. Calculation of plausible maximum sustainable yield (MSY) for blue sharks (Prionace glauca) in the North Pacific. Administrative Report H-01-02. US National Marine Fisheries Service Southwest Fisheries Science Center, La Jolla, California, USA; 2001.

[78] Matsushita Y, Matsunaga H. Species composition and CPUE of pelagic sharks observed by Japanese observers for tuna longline fisheries in the Atlantic Ocean. International Commission for the Conservation of Atlantic Tunas. ICCAT Collective Volume of Scientific Papers 2001;54:1371–80.

[79] Neves dos Santos M, Garcia A, Pereira JG. A historical review of the by-catch from the Portuguese surface long-line swordfish fishery: observations on blue shark (Prionace glauca) and short-fin mako (Isurus oxyrinchus). International Commission for the Conservation of Atlantic Tunas. ICCAT Collective Volume of Scientific Papers 2001;54:1333–40.

[80] Simpfendorfer CA, Hueter RE, Bergman U, Connett SMH. Results of a fishery-independent survey for pelagic sharks in the western North Atlantic, 1977–1994. Fisheries Research 2002;55:175–92.

[81] Sciarrotta TC, Nelson DN. Diel behavior of the blue shark, Prionace glauca, near Santa Catalina Island, Californa. Fishery Bulletin 1977;75:519–28.

[82] Rey JC, Munoz-Chapuli R. Relation between hook depth and fish efficiency in surface longline gear. Fishery Bulletin 1991;89(4):729–32.

[83] Erickson DL, Goldhor S, Giurca R. Efficiency and species selectivity of fabricated baits used in Alaska demersal longline fisheries. Copenhagen: ICES; 2000.

[84] Bolten A, Bjorndal K. Experiment to evaluate gear modification on rates of sea turtle bycatch in the swordfish longline fishery in the azores. Final Project Report submitted to the US National Marine Fisheries Service. Archie Carr Center for Sea Turtle Research, University of Florida, Gainesville, Florida, USA; 2002.

[85] Bolten A, Bjorndal K. Experiment to evaluate gear modification on rates of sea turtle bycatch in the swordfish longline fishery in the azores–phase 2. Final Project Report submitted to the US National Marine Fisheries Service. Archie Carr Center for Sea Turtle Research, University of Florida, Gainesville, Florida, USA; 2003.

[86] Yokota K, Minami H, Kiyota M. Measurement-points examination of circle hooks for pelagic longline fishery to evaluate effects of hook design. Bulletin of the Fisheries Research Agency 2006;17:83–102.

[87] Yokota K, Kiyota M, Minami H. Shark catch in a pelagic longline fishery: comparison of circle and tuna hooks. Fisheries Research 2006;81:337–41.

[88] Branstetter S, Musick JA. Comparisons of shark catch rates on longlines using rope/steel (Yankee) and monofilament gangions. Marine Fisheries Review 1993;55:4–9.

[89] Stone HH, Dixon LK. A comparison of catches of swordfish, Xiphias gladius, and other pelagic species from Canadian longline gear configured with alternating monofilament and multifilament nylon gangions. Fishery Bulletin 2001;99:210–6.

[90] Smith Jr LJ. The effectiveness of sodium lauryl sulphate as a shark repellent in a laboratory test situation. Journal of Fish Biology 1991;38(1):105–13.

[91] Stround E. Personal communication, Shark Defense LLC, 3 April 2006.

[92] Sisneros JA, Nelson DR. Surfactants as chemical repellants: past, present, and future. Environmental Biology of Fishes 2001;60: 117–29.

[93] Murray KT, Read AJ, Solow AR. The use of time/area closures to reduce bycatches of harbour porpoises: lessons from the Gulf of Maine sink gillnet fishery. Journal of Cetacean Research and Management 2000;2:135–41.