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Shark Catch in Pelagic Longline Fisheries: A Review of Mitigation Measures

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Introduction:

Pelagic longline gear is used throughout the world's oceans to capture tuna and tuna-like species. Longline gear is typically deployed from a single vessel across many miles of ocean. The vessel deploys a single mainline that is periodically buoyed with floatation devices and thinner branchlines (with baited hooks) are then attached to the mainline between the floats (Fig. 1 – Beverly et al. 2009). Within this simple framework, a variety of configurations and operational practices can be employed to specifically target different depths and species of fish (Beverly et al. 2003).

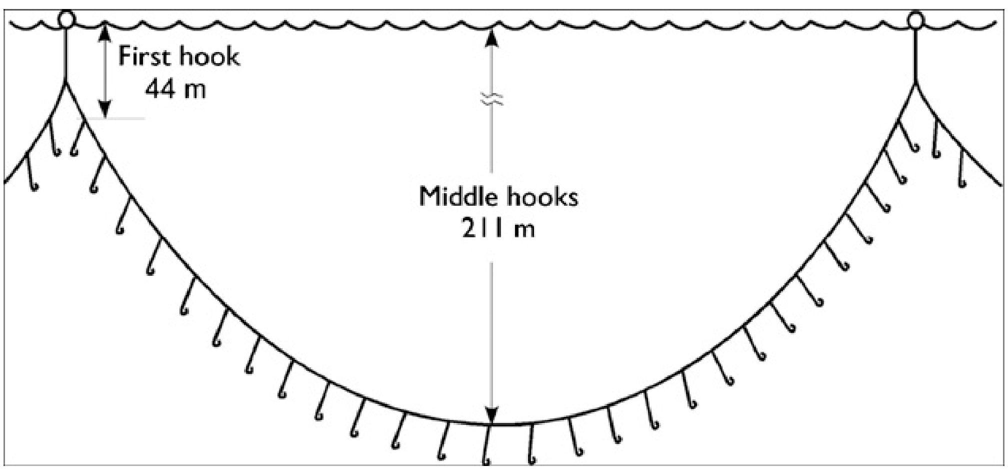

Figure 1. Diagram of a typical pelagic longline configuration showing hooks attached to the mainline by branchlines and suspended between floats. Note that depths shown are average depths from Hawaii-based tuna longline fishery and the length of the branch lines and the average distance between branchlines are not to scale. (Source: Beverly et al. 2009).

Although some longline fisheries capture sharks as commercially viable target species or as low-value incidental catch, the purpose of this review is to summarize studies that have viewed shark capture as unwanted bycatch (i.e., discards). This paper also reviews methods aimed to mitigate catch rates and post release mortality of sharks in fisheries that target tuna and tuna-like species. Some of the research is on a single species, but most is on several of the most commonly encountered species or on species complexes.

Bycatch mitigation investigations can be subdivided into several broad categories. This report will classify research into habitat effects, gear technology/deployment, and handling/release procedures. All of these factors combined have an effect on the overall catch rates, hooking mortality, and post release mortality of shark populations.

This report focuses on the following species and species complexes of sharks that are either most prevalent as catch or bycatch or have been identified as being of concern in longline fisheries (Table 1): Blue shark (*Prionace glauca*), shortfin mako *(Isurus oxyrinchus*), thresher sharks (Alopiidae - *Alopias supeciliosis*, *A. vulpinus*, *A. pelagicus*), hammerhead sharks (*Sphyrna lewini and S. zygaena*), oceanic whitetip (*Carcharhinus longimanus*), and silky (*C. falciformis*).

Table 1. Species covered in this report, their IUCN Red List classifications (IUCN 2013), Ecological Risk Assessment for longline gear (Kirby and Hobday 2007), and their generalized habitat preferences (Compagno et al. 2005, Musyl et al. 2011). The IUCN Red List classifies risk of extinction[3] in six categories: data deficient (DD), least concern (LC), near threatened (NT), vulnerable (VU), endangered (EN) and critically endangered (CR).

Species	**IUCN Red List classification**	**Ecological risk assessment**	**Generalized habitat preference**
Blue shark (*Prionace glauca*)	NT	Medium-low	Mesopelagic
Shortfin mako (*Isurus oxyrinchus*)	VU	Medium	Mesopelagic
Thresher (*Alopias superciliosis*, *A. vulpinus*, *A. pelagicus*)	EN, VU, VU	Medium	Mesopelagic
Hammerhead (*Sphyrna zyganae*, *S. lewini*)	VU, EN	Medium, High	Epipelagic
Oceanic whitetip (*Carcharhinus longimanus*)	VU	Medium	Epipelagic
Silky (*C. falciformis*)	NT	Medium	Epipelagic

Habitat effects:

[3] Categorizations and determinations of extinction risk by the ICUN do not conform to those of the United States. Citation here does not imply endorsement by the United States.

Horizontal movement patterns of sharks exhibit mid-latitudinal species richness peaks similar to peaks found for tunas and billfish (Lucifora et al. 2011). Sharks are also known to increase in available abundance along thermal fronts (Bigelow et al. 1999), when aggregating in sex-specific groups (Muciente et al. 2009), and near seamounts (Gilman et al. 2012). Thus, there is considerable overlap in habitat preferences between sharks, tunas, and billfish. Bromhead et al. 2012 conducted a study of the Marshall Islands tuna longline fishery and used a generalized additive model (GAM) that indicated that blue sharks and thresher sharks are caught in higher numbers when gear is deployed in relatively cooler waters, at night, near a full moon, when the thermocline is proximal to the sea surface (i.e., shallow mixed layer), and during El Niño conditions.

The closure of fishing areas and/or the prohibition of shark catch from otherwise open areas has been implemented in a few locations (e.g., Palau and French Polynesia, Clarke 2013). Other marine protected areas created for different purposes also have become *de-facto* shark sanctuaries in areas that had historically been utilized by longline fisheries (e.g., Papahanaumokuakea National Marine Monument, USA), but no studies were found that examine long term effects of shark populations in these protected areas. Furthermore, none of the Regional Fisheries Management Organizations in the Pacific currently use time area closures for shark mitigation in longline fisheries.

Vertical habitat preferences are species and location specific and some species are more vulnerable to fisheries using deeper (>100 m) set hooks than shallower (<100 m) set hooks. A tagging study by Musyl et al. 2011 (Fig. 2) grouped vertical behavior patterns of five species of shark compared to tuna and billfish in the Pacific Ocean and found that silky and oceanic whitetip sharks spent >95% of their time within 2° C of sea surface temperature (epipelagic, grouped with blue marlin (*Makaira nigricans*), blue sharks and shortfin mako sharks spent >95% of their time between 9.4° C and sea surface temperature (mesopelagic I), and bigeye threshers (*Alopias superciliosis*) spent >95% of their time below the mixed layer (6.4° C – 21.2° C mesopelagic II, grouped with bigeye tuna (*Thunnus obesus*)). Catch rates and vertical habitat preferences are also dependent on day/night effects of when the gear is deployed (Gilman et al. 2008). Several studies all point to species specific vertical movement patterns that indicate that oceanic whitetip and silky sharks are continually vulnerable to shallow set gear, blue sharks make deep dives during the day and often come near the surface at night (making them vulnerable to both deep and shallow set fisheries), and thresher sharks make deep daytime dives; are most active during crepuscular periods, but infrequently come to surface; thus are at increased vulnerability to deep set tuna fisheries (Boggs 1992, Bonfil et al. 2008, Nakano et al. 2003, Weng and Block 2004, Musyl et al. 2011).

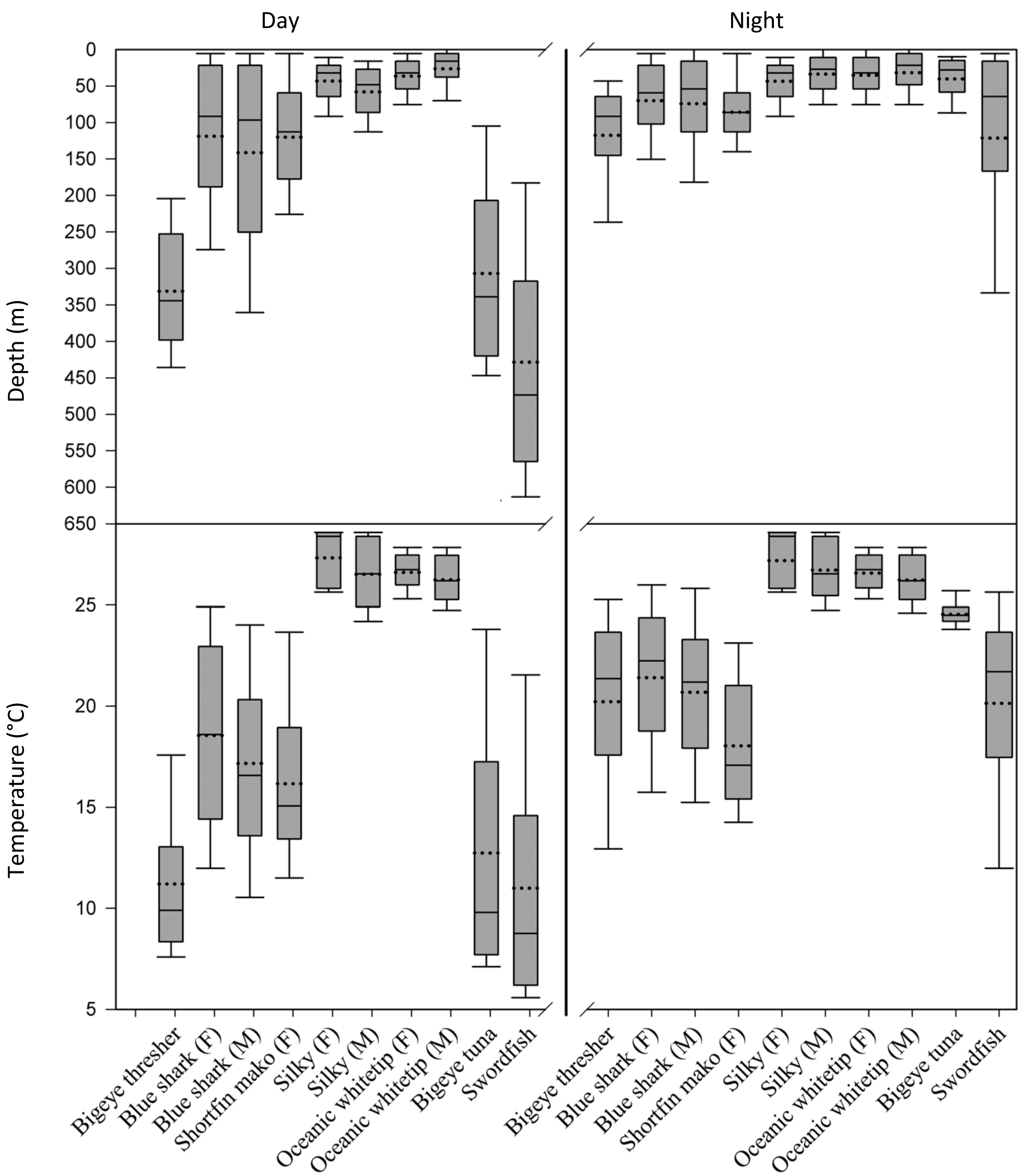

Figure 2. Day and night vertical habitat depth (m) and temperature (°C) profiles of six pelagic shark species compared to bigeye tuna (*Thunnus obesus*) and swordfish (*Xiphias gladius*) (Source: Musyl et al. 2011).

These generalized shark depth preferences are similar to many target finfish species as well. Given the mechanism of fishing relatively deep in a longline fishery, all hooks must also pass through shallow waters when gear is deployed and retrieved, thus other factors such as thermocline depth and vertical oxygen profiles may deliver finer resolution on methods to mitigate interactions with specific fisheries (Bigelow and Maunder 2007). The Eastern Australian tuna and billfish fishery has reported using other fishing behavior modifications based on environmental habitat niches such as setting deeper, avoiding specific areas of sea surface temperature, setting during daytime, or minimizing soak time, to reduce shark interactions (Gilman et al. 2007a). Some studies have found higher catch rates for certain species of sharks on shallower set hooks (Rey and Muñoz-Chapuli 1991, Galeana-Villasenor et al. 2008, Walsh et al. 2009), but Beverly et al. 2009 found no significant reduction in shark catch rates when all hooks were deployed below 100 m depth.

Gear technology/deployment:

Hook effects

There has been a spate of research on the use of circle hooks in longline fisheries to mitigate bycatch rates and mortality of protected species and a symposium was convened in 2011 to focus on circle hook research (Serafy et al. 2012). One meta-analysis of 15 published studies found no significant difference in catch rates of sharks for circle hooks vs. J-shaped hooks, but did find a significant reduction for at vessel mortality (defined as dead or moribund when brought on deck or released from gear) when circle hooks are deployed (Godin et al. 2012 - Fig. 3). However, results and conclusions from many of these studies often conflict. Many studies found no reduction for at vessel mortality with use of circle hooks (Kerstetter and Graves 2006, Yokota et al. 2006, Curran and Bigelow 2011, Pacheco et al. 2011, Afonso et al. 2012, Curran and Beverly 2012) while others report reduced at vessel mortality with use of circle hooks (Carruthers et al. 2009, Afonso et al. 2011).

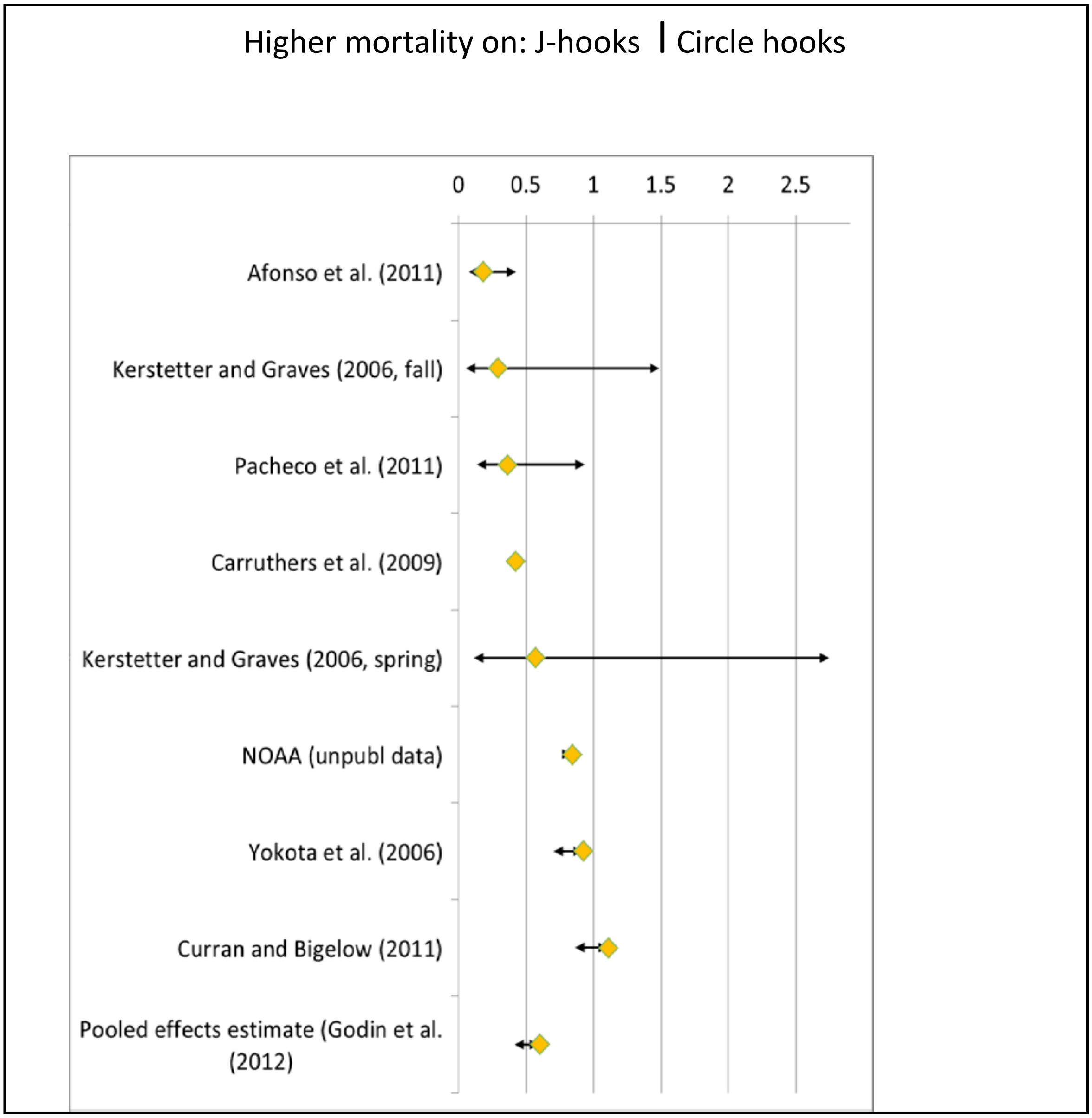

Figure 3. Meta-analysis on at-vessel mortality odds ratios by hook type of shark species with 95% Confidence intervals. Source: Godin et al. (2012).

The overall size dimensions of a hook may also be a factor in catch rate and at vessel mortality. A study by Curran and Beverly 2012 in the South Pacific indicated that larger (>16/0) circle hooks vs. smaller (<16/0) circle hooks significantly reduced at vessel mortality of blue sharks. A study of the Hawaii-based longline fishery found a reduction in catch of blue shark (17.1%) and thresher (27.5%) when larger (18/0) circle hooks replaced the use of the smaller (3.6 sun) tuna hooks (Curran and Bigelow 2011). There are also species specific and size specific effects of hook type/size that needs further study. One meta-analysis of catch by hook type (Godin et al.

2012 – Fig. 4) found that many of these studies are also problematic to compare directly to each other as they are often constrained by small sample sizes, non-standardized protocols, different target species, and different geo-spatial operational practices. For example, a study by Domingo et al. 2012 tested two types of longline gear within a single fishery, but reported higher catch rates of shortfin mako sharks on circle hooks vs. J-shaped hooks for only one type of gear. In general, chances of surviving a hooking event increases with fish body size (Diaz and Serafy 2005, Campana 2009, Coelho et al. 2012).

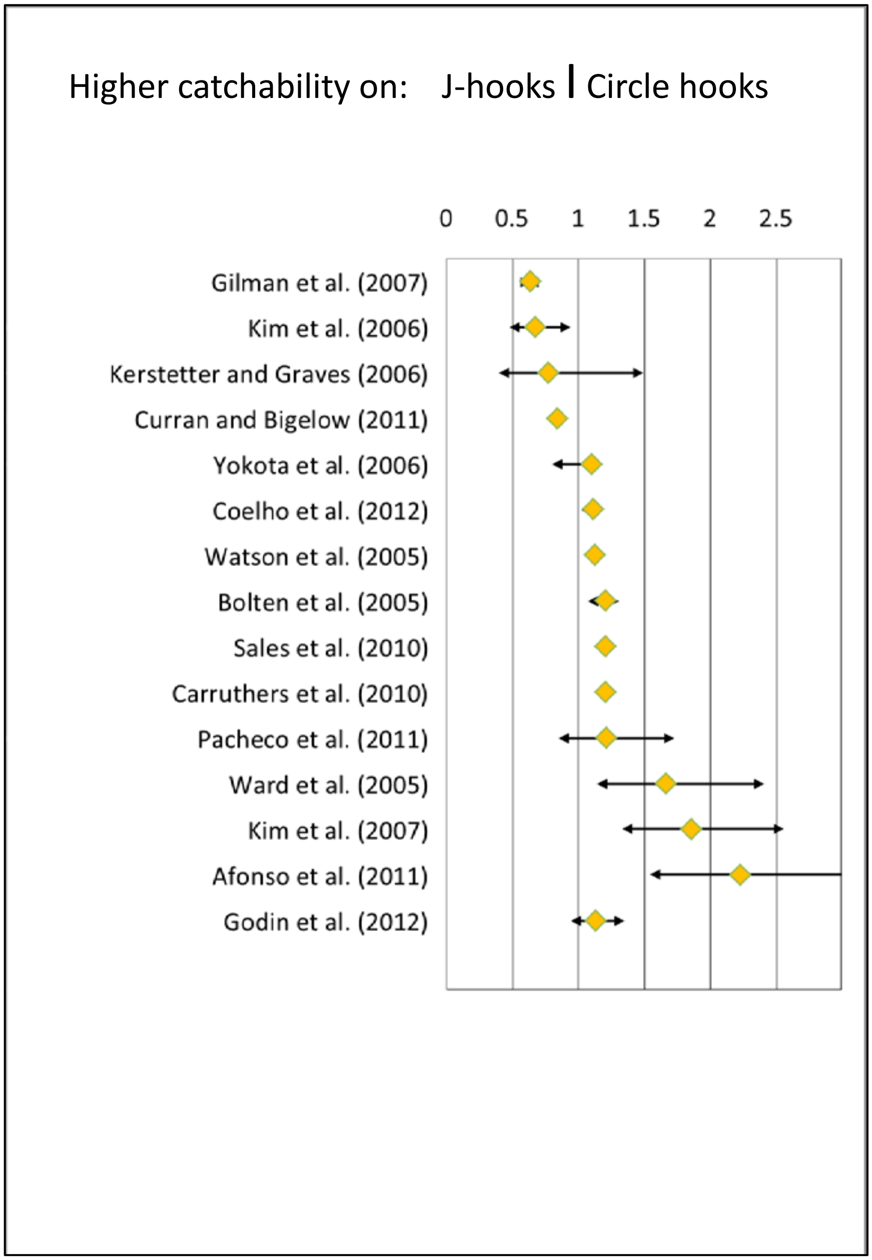

Figure 4. Meta-analysis on catchability odds ratios with 95% confidence intervals of shark species for circle hooks vs. J-hooks (Source: Godin et al. 2012).

Relatively few hook studies have tried to quantify hooking location for examination of mortality effects by hook type. Most studies report hooking location defined as either external (hook visible in jaw, mouth, or exterior of body) or internal/deep (hook ingested and not visible in mouth or jaw). Sharks captured with circle hooks are reported as more likely to be externally hooked than J-shape hooked sharks in several studies (Watson et al. 2005, Carruthers et al. 2009, Afonso et al. 2011, Pacheco et al. 2011). However, two other studies found no significant difference between external and internal hooking rates by hook type (Kerstetter and Graves 2006, Ward et al. 2009). As a result of the paucity of studies reporting on hooking location, Godin et al. 2012 did not attempt a meta-analysis on this factor. The use of 15/0 “weak” (4.0 mm wire diameter) vs 15/0 “strong” (4.5 mm) hooks to mitigate cetacean takes in the Hawaii-based longline fishery found no significant difference in shark bycatch rates (Bigelow et al. 2012).

Bait effects

Most bait related studies have investigated squid vs fish (e.g., mackerel) type bait effects. Often, this has been in combination with other gear modifications such as a change in hook type (Gilman et al. 2008a). Most research does indicate that use of mackerel style bait instead of squid bait reduces bycatch of pelagic sharks (Gilman et al 2008a, Godin et al. 2012). However, one study also reported that use of mackerel bait increased the probability of internal/deep hooking of blue sharks (Epperly et al. 2012).

Leader effects

Several studies have compared wire leaders to monofilament leaders with conflicting results (Branstetter and Musick 1993, Yokota et al. 2006, Ward et al. 2008). As noted by Romanov et al. (2010), the benefit of monofilament leaders is not evident and such conclusions (such as Ward et al., 2008) are based on non-significant differences or very small sample sizes with less than 20 individuals caught. Furthermore, a higher escapement rate may not be synonymous of higher survival and conservation.

Prohibition on the use of wire leaders has been regulated in several fisheries (e.g., Australia, the Cook Islands, Fiji, Palau, Samoa, and South Africa (Clarke 2013), but there is still considerable uncertainty as to the mitigation effects or ability to enforce these bans.

Elimination of shallow set hooks (<100 m)

A few studies have researched the catch effects of ensuring that all hooks are deployed deeper than 100 m (Beverly et al. 2009, Bigelow and Mourato 2010, Watson and Bigelow 2014). Both Bigelow and Mourato (2010) and Watson and Bigelow (2014) predicted that the removal of one or more hooks nearest the floats would result in a reduction in the catch of blue sharks, bigeye, thresher, and oceanic whitetip sharks (Table 2).

Table 2. Percentage reduction in catch rates of shark species in the Hawaii-based (Bigelow and Mourato 2010) and American Samoa (Watson and Bigelow 2014) longline fisheries when one or more hooks nearest floats are removed.

	Reduction in catch (%) when hook(s) nearest floats are removed				
	Hook #1		Hooks #1-2		Hooks #1-3
Species	**American Samoa**	**Hawaii**	**American Samoa**	**Hawaii**	**American Samoa**
Blue shark	4.6	4.7	11.7	10.7	19.6
Bigeye thresher	1.7	1.1	5.6	3.2	9.5
Oceanic whitetip	17.9	15.1	33.1	26.8	42.7
Silky	15.4		26.7		37.9
Shortfin mako	1.8		7.8		13.4

Repellents

Development of shark specific deterrents has been investigated ancillary to efforts to find methods to protect swimmers and divers. Promising candidates for repelling sharks on longline fishing gear include use of magnets, electropositive metals, electric currents, and chemicals.

Studies on electrical current and chemicals have not shown much applicability to wide scale use in longline fisheries (Sisneros and Nelson 2001, Marcotte and Lowe 2010) and the use of chemicals has yet to be tested on a large scale. Stroud et al. 2013 did test shark necromones (i.e., putrefied shark tissue) and induced cessation of all feeding activity for a concentrated group of reef sharks, but further study is needed to test for cost and efficacy in longline operations.

Different combinations and mixtures of electropositive metals (i.e., mischmetals) either incorporated into the hook or attached in proximity to the hook have been tested on a small scale with mixed and often confounding results (Kaimmer and Stoner 2008, Wang et al. 2008, Brill et al. 2009, Robbins et al. 2011, Hutchinson et al. 2012). One study (Hutchinson et al. 2012), concluded that lanthanide metals were not effective at reducing catch rates because pelagic sharks inhabit low turbidity water and typically rely more on the long distance sensory modalities of vision and olfaction, thus mitigating any short range deterrent effects. Even if effective, such metals are relatively expensive and corrode in sea water, thus there are still considerable barriers to design and implementation of an effective delivery method for large scale use in existing fisheries.

Handling/release procedures

Recent research (Table 3) indicates that post-release mortality of large pelagic sharks from longline gear is quite low, especially when handled properly. For example, at vessel and post-release mortality estimates for blue sharks in the Hawaii-based fishery have been estimated and range from as little as 3% (Curran and Bigelow 2011) to approximately 19% (Campana et al. 2009). Release techniques vary by fishery and by species and can be as simple as freeing the hook from the shark's mouth with a quick jerk on the branchline or by simply cutting the line near the hook (Gilman et al. 2008a), to hauling the fish aboard with a gaff in order to retrieve an ingested hook (Campana et al. 2009a). Thresher sharks are sometimes tail hooked and dragged backwards through the water preventing them from properly ventilating (Heberer et al. 2010) leading to higher estimates of post release mortality than other pelagic sharks (Musyl et al. 2011).

Table 3. Estimates of at vessel and post release mortality estimates for five shark species based on observer data and tagging studies.

Species	At vessel mortality range (%)	Post release mortality range (%)	Ranges (References)
Blue shark	3		Curran and Bigelow (2011)
	4		Walsh et al. (2009)
	6	15	Musyl et al. (2011)
	9		Carruthers et al. (2009)
		14	Stevens et al. (2010)
	14		Coelho et al. (2012)
		19	Campana et al. (2009)
Shortfin mako	8		Musyl et al. (2011)
	21		Walsh et al. (2009)
	36		Coelho et al. (2012)
Thresher	12		Curran and Bigelow (2011)
	16		Walsh et al. 2009; Musyl et al. (2011)
	50		Bromhead et al. (2012)
	51		Coelho et al. (2012)
		26	Heberer et al. (2010) Note: caught on recreational gear
Oceanic whitetip	7		Musyl et al. (2011)
	30		Bromhead et al. (2012)

	34	Coelho et al. (2012)
Silky	11	Musyl et al. (2011)
	20	Walsh et al. (2009)
	26	Bromhead et al. (2012)
	56	Coelho et al. (2012)

Conclusions

Although many different approaches to shark bycatch mitigation have been studied, there is no single tool available to reduce catchability and mortality of pelagic sharks in longline fisheries. Many mitigation measures also conflict with methods to mitigate other non-target species. For example, wire leaders and weights are considered to be a good method to ensure negative buoyancy when gear is deployed, thus reducing opportunity for seabirds to be attracted to the bait. Thus, monofilament leaders may reduce shark bycatch in some fisheries, but they may also increase the take of seabirds. Nor is there evidence that the use of wire leaders in the Hawaii-based tuna longline fishery increases the catch or mortality rates of sharks.

As adapted from Gilman et al. 2014, the concept of best practice gear technology methods to mitigate the take and mortality of sharks, sea turtles, seabirds, and cetaceans as a group suggests that most pelagic longline fisheries should: use thawed fish (e.g., mackerel) type bait, weighted leaders, set hooks below 100 m, and use large circle hooks. With regards to location/bathymetry, there is evidence to suggest reduced shark catch rates by avoiding fishing near seamounts or in areas where large numbers of a single species temporarily congregate for reproductive purposes. In order to increase the probability of sharks' post-release survival, there is strong evidence to suggest use of dehooking/line cutting tools to quickly release all discarded animals with minimal physical damage.

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