PAPER

Fishing Techniques to Reduce the Bycatch of Threatened Marine Animals

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ABSTRACT

Unintended injuries and fatalities to non-target marine species—a major component of "bycatch"—is one of the principal threats to the survival of many endangered marine populations and species. This paper describes both proposed and existing fishing techniques for reducing non-target species bycatch, and reviews their focus across different fisheries and wildlife groups. The intent of this inventory was to gain a better understanding of the range of techniques available and to highlight priorities for research and development. In all, 55 techniques were identified, with the majority directed at reducing bycatch in longline fisheries, and intended to benefit primarily seabirds, sea turtles, and small mammals. Bycatch reduction is a dynamic field with many examples of effective techniques, though some underserved fisheries and wildlife groups should receive more attention.

Introduction

Millions of dollars are spent each year in the research and development of fishing techniques to reduce unintended injuries and fatalities to non-target marine species that forms a major component of "bycatch." The vast majority of this investment in conservation occurs in economically developed countries (principally the United States, Canada, Australia, and Europe) although the problem is global in scale. Taken as a whole, bycatch is one of the major threats to the survival of many endangered marine populations and species.

This paper describes both proposed and existing fishing techniques for reducing non-target species bycatch, and reviews their focus across different fisheries and wildlife groups. The intent of this inventory was to gain a better understanding of the range of techniques available and to highlight priorities for research and development.

The bycatch reduction methods summarized in this paper are all intended to accommodate continued fishing of target species. Other strategies that can lead to lowered bycatch levels include fishing area closures, temporal closures, reductions in fishing effort, and cessation of fishing altogether. In some cases, applying one or more of these other measures may represent a better strategy for solving a particular bycatch challenge than altering fishing methods, though they often face resistance from the fishing industry.

Methodology

We attempted to document all available information on fishing techniques that have been used to reduce non-target wildlife species bycatch in world fisheries. Information on bycatch reduction methods is highly diffuse and for this review we consulted various sources including journal articles, unpublished government reports, and experts in the field. A number of reviews have examined bycatch reduction for particular fisheries (e.g., Broadhurst, 2000; Hall, 1995) or for wildlife groups within particular fisheries (e.g., Gilman et al., 2005), but the scope of this study is all commercial fishing methods and multiple wildlife groups. The decision to pursue a more comprehensive treatment was motivated by an interest in identifying bycatch reduction approaches that might find application in more than one fishing method, and to better appreciate the potential impacts on species or wildlife groups apart from the one targeted.

Excluded from consideration were recreational fishing, target species bycatch (i.e., juvenile fish), and strategies for mitigating the consequences of ghost fishing, a serious and widespread form of bycatch in which fishing gear can continue to catch and kill animals after it has been lost, discarded, or abandoned by fishers. Depredation, or the predation of fishing bait or catch by non-target species, *was* considered in this review. This meant that some techniques mainly used in aquaculture operations became part of the final list.

Generally, in categorizing bycatch reduction approaches the tendency was to be inclusive. For example, Turtle Excluder Devices and Sea Lion Excluder Devices were combined as one approach, under "excluders", because they fundamentally work the same way.

Both existing and proposed bycatch mitigation techniques were considered, and organized according to whether they represented an approach (1) intended to avert contact with a fishing operation and gear altogether, (2) intended to facilitate escape from temporary capture, or (3) that required release post-capture. For each technique we identified the fishing method (gillnet, surrounding net, trap/pot, trawl, dredge, and hook-and-line) in which it was or could be used, and identified studies undertaken to evaluate its efficacy for various wildlife groups. The studies compiled consisted mainly of ones that directly reported on a scientific field trial as opposed to papers summarizing general findings or synthesizing responses from fishers. Occasionally, however, reports of lab studies or third-party papers reporting on original field research were included. Wildlife group classifications were selected somewhat arbitrarily and represent broad categories (sea birds, for example) in order to keep this review at a manageable scale. Certainly the number of categories could be expanded to include different groups (most notably non-pelagic fin fish) as well as subsets of the headings already represented. Nevertheless, using broad categories of wildlife groups enables a cursory analysis of the taxonomic emphasis in bycatch reduction research and implementation of its methods.

Description of Techniques

Fifty-five modifications to fishing gear or methods were identified for reducing non-target species bycatch. Below is a brief description of each. Those in italics indicate methods either not yet developed or widely used by the fishing industry that may be undergoing experimental evaluation.

Acoustic pingers/alarms

Underwater sound-emitting devices (maximum level of intensity equivalent to approximately 175 dB re 1 μPa @ 1m) attached to fishing gear, principally gillnets. [Under NOAA's Harbor Porpoise Take Reduction Plan for the Gulf of Maine, the sound output intensity for pingers is stipulated as 10 (±2) kHz at 132 (± 4) dB re 1 μPa @ 1m (NMFS/NOAA, 1998)]. Pingers are now mandated for use in some fisheries in the U.S. Northwest Atlantic, California driftnet, and in Europe. The sound of these devices is believed to alert an animal to the presence of the net and thus decrease the probability of entanglement. Although some studies have shown that pingers can have the unintended consequence of attracting pinnipeds to fishing operations (Bordino et al., 2002), this may be controllable by raising the emitted frequency of the pingers above seal hearing (Kraus et al., 1997).

Acoustic harassment devices (AHDs)

Devices that emit sounds of such high intensity that they cause pain or alarm in certain underwater species. The minimum sound level is approximately 200 dB re 1 μPa @ 1m. References for AHDs primarily dealt with aquaculture operations. These devices may exclude some animals from important habitat (Olesiuk et al., 2002), and pose a risk of impairing an animal's hearing. These drawbacks render this approach potentially harmful and dangerous.

Passive acoustic deterrents

Objects such as rubber tubes, thick polyester rope, and chains attached to fishing nets to alert a marine cetacean to their presence using echolocation.

Vessel noise reductions

Structural or operational changes to fishing vessels that would decrease the intensity or signature of their sound output, potentially decreasing the degree to which they attract animals that presumably associate these vessels with a feeding opportunity. At least one study in the Pacific indicated that the noise from longline haulers attracted false killer whales from long distances (J. Watson, pers. comm.).

Animal predation sounds

Audio recordings of an animal in distress, or of its predator, played to deter individuals of that species from entering into a fishing area. Jefferson and Curry (1996) concluded that this technique was largely ineffective for reducing marine mammal interactions with fishing activity based on their review of multiple studies.

Metal oxide nets

Nylon nets infused with barium sulfate or other metal compounds that have acoustical detection features for reducing small cetacean bycatch. These may reduce small cetacean and sea turtle bycatch by increasing the likelihood that these animals would "bounce" off the netting. Experimental results show that they can be effective in reducing the bycatch of harbor porpoise and greater shearwater (Trippel et al., 2003), though it has not been ascertained if this is because of their acoustic reflectivity, increased stiffness, or greater visibility over conventional gillnets.

Echolocation disruptors

Sounds produced to disrupt the normal echolocation abilities of cetaceans. Preliminary research in Europe has shown some promise that these devices reduce depredation by bottlenose dolphins in gillnets and trammel nets, although habituation may be a challenge (S. Northridge, pers. comm.).

Pyrotechnics

The use of loud explosive devices, including gunshots, to scare non-target species such as sea lions away from a fishing operation. Deterrence may result from noise or tactile annoyance. Anecdotal evidence from some fishermen suggests this practice is widespread though its efficacy is not backed up by a number of studies, and it obviously threatens animal survival.

Quick-release metal wire

A metal wire attached to an outrigger clip on a troll line. The quick-release mechanism of the outrigger clip causes the wire to travel down the bait line when a fish is captured. The metal wire may deter dolphin depredation (Zollett and Read, 2006).

Glow rope

Rope consisting of polypropylene blended with a phosphor that glows a bright yellow-green underwater in wavelengths large cetaceans can see. It glows for 48 hours after activation at an intensity a human can see readily at 20 yards (18 m). The design is based on the premise that with increased visibility cetaceans and perhaps turtles would be more likely to avoid rope entanglements at night or at depth. Current research is looking at how to maintain the glowing properties under the rigors of mechanized hauling.

Bird-scaring devices

A number of devices used to disturb birds from foraging on bait. These include streamers attached to a pole suspended above the area where bait is set or placed in the water, towed buoys, and water jets.

Dyed bait

Bait dyed blue to reduce its visibility to non-target species such as seabirds hovering around longlines as baited hooks are deployed.

White mesh on gillnets

White mesh panels on the upper part of a gillnet to make it more visible to diving seabirds. The mesh probably also increases net visibility to other animals such as cetaceans, pinnipeds, and sirenians though the effect would be reduced in water with poor visibility.

Flashing lightsticks

Battery-operated lights set at different flicker rates intended to attract fish but not sea turtles.

Reflective/colored buoys

Buoys coated with a material to make them reflect or blend into the natural environment so that they are a less conspicuous signal to sea turtles, which are thought to be attracted to buoys used in fishing operations.

Scent deterrents

The application of substances that produce odors to deter non-target species from entering into a fishing area.

Noxious bait

Bait that is treated with compounds intended to make it unpalatable to non-target species.

Artificial bait

Bait manufactured from non-natural substances as a substitute to natural bait that may render it less appealing to non-target animals.

Novel bait species

Changing the type of bait, such as switching from squid to mackerel, to deter non-target animals (such as sea turtles) that prefer one type of bait versus another.

Animal prodding

The physical prodding of non-target species using a pole or other implement to deter them from interacting with a fishing operation.

Electromagnetic deterrents

Electromagnetic fields created in the vicinity of a fishing activity to deter interaction of non-target species with fishing gear, bait, or target species. The main prize of the 2006 Smart Gear competition run by the World Wildlife Fund was for a magnetic shark deterrent to be tested on pelagic longlines. Polet et al. (2005) describe evaluations of an "electro-trawl" in which electric charges stimulated shrimp into moving upward from the sea floor into the path of the trawl mouth. In this approach, the space between the groundrope and the benthos might be increased without reducing target catch levels but decreasing the contact the trawl might have with some non-target benthic invertebrates and groundfish.

Buoy line messenger system

Underwater traps or nets linked to a surface buoy by a weak line. To haul the gear, a messenger device would be sent down the weak line along with a stronger hauling line. The messenger device would attach the hauling line to the bottom gear for retrieving the gear. The premise is that a large whale would easily break free from a weak line suspended in the water column, and the stronger line needed for hauling could be located out of harm's way.

Acoustic releases

Devices that use an acoustic trigger for releasing a buoy attached to submerged pots that would then float to the surface for retrieval. This would eliminate vertical (and potentially entangling) lines in the water column.

Bait casting machines

Devices that toss the bait beyond the turbulence of longline boat propellers that tend to keep bait buoyant longer where it is more prone to seabird predation.

Thawed bait

Frozen bait is thawed before it is set in the water to increase the rate at which it sinks in longline fisheries. (The sinking rate can also be increased by puncturing the swim bladder of fish bait).

Alternative offal discharge

Discarding waste away from where bait enters the water to lure non-target species (seabirds) away from baited hooks in longline fisheries.

Side sets

The placement of fishing gear over the side of a longline vessel rather than the stern. Studies have shown that seabirds avoid going after baited hooks near the vessel hull, and by the time the stern passes the hooks they are deeper in the water than they would be in stern sets (Brothers and Gilman, 2006).

Night sets

The setting of fishing gear at night so that seabirds are less likely to see sets. Lights may also be dimmed to enhance the effect.

Underwater sets

Methods that reduce bycatch by eliminating gear sets at the ocean surface. These include devices such as setting chutes that place sets below the ocean surface in longline operations where they are less prone to seabird predation, and setting gillnets below the sea surface to reduce entanglement rates of small cetaceans.

Line shooter

A device used on longline vessels to increase the speed at which baited lines get below the water's surface where seabird predation mainly occurs.

Raised footropes

An alteration to the lower edge of a trawl net in which the "mouth" is raised high enough in the water column to prevent it from dragging across the benthos. Raised footropes are obligatory during certain periods of the year in bottom trawling in Massachusetts to reduce the bycatch of non-target demersal species such as flounder.

Decreased soak time

Soak time is the length of time that fishing gear is submerged between hauls; reducing it appears to change bycatch probabilities.

Sinking/weighted lines

Changing the property of fishing lines so that they are less likely to catch or ensnare animals feeding at the surface or in the mid-water column. They include low profile line, a kind of rope linking lobster pots that might be suspended deep enough to avoid whale entanglements but with enough floatation to lie above rocky bottoms that tend to abrade them. Weighted mainlines may also increase the sinking rate of pelagic longline gear, making it less likely to capture surface-feeding seabirds.

Decoy deterrents

Approaches that include setting longlines in novel patterns (such as in a sinusoidal shape) or using "dummy" sets to mask the presence of a fishing operation.

Vessel chasing (hazing)

The use of boats to chase non-target marine animals from a fishing area.

Remote attractor devices

Devices used for attracting non-target animals away from fishing activity where they might become captured or entangled in gear.

Deep-water sets

Baited hooks in longline fisheries set below 100 meters of water to avoid the principal feeding zones of sea turtles and other epipelagic species. Increasing the depth at which pelagic drift nets are set may also reduce bycatch rates of air-breathing vertebrates.

Fence or net barriers

Barriers erected in aquaculture and corral-type fishing gear to exclude non-target species. Barrier nets can create a separate bycatch problem based on reports of fatal entanglements that have occurred with California sea lions and humpback whales (Petras, 2003).

Trap guards (T-bars, otter guards)

Welded bars or netting placed in some pot traps to prevent pinnipeds or otters from entering them and preying on the target catch (such as eels). Bungee trap guards have also shown success at reducing bottlenose dolphin interactions with crab pots (Noke and Odell, 2002).

Fleet communication

The dissemination of real time information between fishing vessels on the presence of non-target animals to avoid fishing in areas in which they are congregating.

Excluder devices

A grid of metal bars or mesh placed usually within the neck of a trawl that has an opening for escape at either the top or bottom. Large animals that strike the bar exit through the opening, while the smaller target species pass through the bars and are captured in the net. Examples of excluder devices in trawls are the Nordmore grid, the Turtle Excluder Device (TED), and the Sea Lion Excluder Device (SLED). A sea turtle excluder chain mat is used in the Northwest Atlantic scallop dredge fishery. A new modification to pound nets may reduce sea turtle bycatch by replacing the upper two-thirds of the leader netting with vertical ropes spaced wide enough apart to let sea turtles swim through without becoming entangled (DeAlteris et al., 2005).

Circle hooks

A circular hook design in which the point of the hook is perpendicular to the hook shank. Circle hooks are used widely in many recreational and commercial fisheries and recently have been shown to reduce both the hooking rate and the mortality of turtles that are hooked on pelagic longline gear. As a result of several successful field trials (Bolten and Bjorndal, 2005; Watson et al., 2005), these hooks are becoming increasingly used in longline fisheries.

Break-away lines

Ropes that use weak links or are designed to break at strengths substantially lower than usual for hauling ropes. The intent is for ropes to function normally for fishing but allow a large whale to break free if entangled.

Time tension line cutter

A link connecting the bottom gear and vertical line in a pot fishery that would break under any pressure sustained longer than the time it takes to haul in the gear when fishing. This device was designed to reduce large whale entanglements in pot fishery endlines. The line cutter can be reset before it is redeployed.

Buoy line trigger release

A line-cutting device that will detach a surface buoy from vertical line when pressure—such as that from a whale's baleen—is exerted against a plate that is attached to the buoy. It was designed in order to prevent ropes becoming entangled in whale baleen.

Stiff rope

A kind of rope that would be stiff in the water column but loose on the deck of a boat. Various prototypes are in research and development. The theory behind these ropes is that their rigidity will prevent them from entangling large whales while fishers will find them at least as practical as regular rope.

Medina Panel

Used in the purse seine fishery for yellowfin tuna in the Eastern Tropical Pacific, this is a panel of fine mesh attached to the part of the purse seine farthest from the boat when the net is "pursed." The mesh is fine enough so that dolphins are unlikely to be entangled, and allows dolphins to escape over the top of the net. These panels are used in conjunction with a "back down" procedure in which the purse seine is towed backwards, lowering the cork line to facilitate the escape of dolphins.

Alternative net filaments

Varying the diameter of gillnet filaments or their weaves (e.g., multi-monofilament) to reduce mortality of small cetaceans and other animals in gillnets by making the nets stronger and stiffer. Stronger nets may result in larger non-target animals being less prone to entanglement.

Galvanic releases

Links on fishing gear (such as crab pots or lines) designed to eventually dissolve thereby releasing any entrapped or entangled animal. Galvanic releases have been proposed to reduce the number of vertical lines in the water by securing hauling lines in a coil at the ocean floor until the release dissolves, freeing a buoy that brings the hauling line to the surface.

Weak hooks

Hooks that are strong enough to hold the target catch but straighten out under the pull of larger, non-target animals.

Baiting techniques

Applying alternative methods of securing bait to a hook or other fishing gear. A singly threaded baiting technique is being evaluated as an approach for reducing loggerhead sea turtle bycatch in longline fisheries (Eric Gilman, pers. comm.).

Long gangions

Longer gangions (leader lines attached to the main floating line of a longline) are used to reduce sea turtle bycatch mortality by allowing turtles to swim to the water's surface to breathe if hooked. NOAA Fisheries prohibits longliners from setting gangions within two gangion lengths of the floatline, and requires that "the length of the gangion [be] at least 10 percent greater than the length of the floatline for longline sets in which the combined length of the floatline and the gangion is 100 meters or less" (NMFS/NOAA, 2002).

Lipid soluble rope

A fishing line that would dissolve once embedded in the blubber of a large whale.

Sea turtle-friendly bridles

A bridle design used in trap fishing for minimizing sea turtle entanglement.

De-hookers

Devices designed to safely remove hooks from sea turtles and other byatch species captured by hook-and-line fisheries. Dipnets may be used for small turtles or other non-target animals to haul them on to the deck more safely for hook removal.

Summary of Results

Table 1 lists these techniques together with an indication of the commercial fishing method in which they are or could be used, and a reference to studies evaluating their efficacy for various groups of wildlife. An estimated 33 of the methods are presently used with the remainder proposed for potential development and application. By far, most of the techniques in use take an approach of avoiding contact with fishing gear (81%) as opposed to facilitating escape or release once an animal has come into contact with it. Considering only those approaches geared towards avoiding conflicts, 61% (or 16/26) operate under the principle of physically excluding animals from fishing areas, gear or bait. The other 10 can be divided according to the type of sensory detection the animal would use in averting conflict: auditory, visual, olfactory, gustatory, tactile, or electromagnetic. Of these, the visual and auditory approaches predominate with seabirds being the principal target group based on the number of available techniques.

Circle hooks were listed as both a device for escaping contact with gear and for facilitating release upon capture. This is because circle hooks have been shown to reduce the capture rate of sea turtles over J-hooks as well as result in fewer deep hookings that cause greater injury to the animal (Bolten and Bjorndal, 2004; Watson et al., 2005). Pyrotechnics also were listed twice, once as an acoustic deterrent and again as a tactile deterrent because the effect on an animal may be sensed both ways. One more device, the quick-release metal wire, occurs twice in Table 1 because it may be sensed by dolphins using eyesight or echolocation.

More techniques have been applied to hook-and-line fisheries (longlines, specifically) than for all other fishing methods combined. This is due to the large number (nearly half of the total longline techniques) of bycatch mitigation approaches developed exclusively to deter sea bird bycatch that results from predation on baited longline hooks as they are being set. In contrast, only one bycatch reduction method was identified for dredges (although see Smolowitz, this issue of MTSJ). Similarly lacking were studies evaluating bycatch reduction methods for a number of wildlife groups suspected or known to perish following conflicts with fishing operations, including sirenians (manatees and dugong), sea snakes, and non-commercial pelagic fishes (Read et al., 2006; Milton, 2001; Goodyear, 1999). The list also highlights the absence of mitigation techniques for two other non-target groups commonly occurring as bycatch: elasmobranchs and invertebrates. The former includes many species vulnerable to extinction from fishing and the latter represents diverse and threatened communities such as deep-sea coral reefs (Fowler et al., 2005; Probert et al., 1997). Table 2 shows the taxonomic coverage of the studies compiled as part of this review.

The number of available approaches, however, is not necessarily a proxy for the success of bycatch mitigation. A single effective approach, such as excluder devices for sea turtles in prawn trawl fisheries, may be sufficient for achieving the reductions desired.

Nearly all of the techniques used by the fishing industry have been subjected to some degree of scientific field evaluation as shown in Table 1. It is important that modifications to fishing gear and methods undergo this scrutiny to ensure that they are likely to have the desired impact on bycatch rates and that the industry has adequate justification before making costly changes. Sometimes, however, researchers need to adopt creative approaches, particularly in cases in which bycatch events are rare in space and time even though the consequences may be critical for species survival. The entanglements of North Atlantic right whales in lobster pot and gillnet lines represent a perfect example of this point. This species occurs exclusively in the Northwest Atlantic and its total population is an estimated 350 individuals. Its small population size means that even infrequent entanglement events may be catastrophic for the population. Very high levels of fishing effort, even when offset by a low encounter rate, mean that a large proportion (15%) of this remnant population interacts with fishing gear each year (Knowlton et al., 2005). The low encounter rate and critical status of this population rule out any field evaluation of potential bycatch mitigation measures, so alternative methods for testing gear must be devised. Several scientists in the United States and Canada are working with the fishing industry to experiment with alternative gear types to see whether or not they are viable fishing techniques. But the best methods for testing "whale-safe" gear may be in tank tests with models, and monitoring whale entanglement records to determine progress as new gear types are implemented.

The development and use of bycatch reduction methods (particularly gear modifications) almost always targets one population, species, or animal group. Based on the 52 studies identified that reviewed the efficacy of these methods (Table 1), all but 7 evaluated bycatch levels for just one species or wildlife group; typically the results apply to only a subset of that population. Though not surprising, an obvious concern in altering fishing methods is the impact that the change might have not only on one population but also on different groups and ecosystems. An undesirable consequence of using new fishing methods would be to increase the total mortality of endangered marine species or populations even though bycatch is reduced for the species of initial concern. For example, many studies indicate that circle hooks can reduce sea turtle byatch in longline fisheries but in at least one study they were shown to increase the catch of blue sharks (Bolten and Bjorndahl, 2003). In that particular study, blue sharks made up the target catch and so the study results represented an optimal outcome for fisheries bycatch research in which a low-cost modification produces not only a reduc-

TABLE 1

A list of techniques for reducing non-target species bycatch. The ones in bold presently exist; the remainder are proposed for possible use or further development. An "X" under Fishing Method indicates where a technique is known to be used, and an asterix denotes where it potentially could be used (excluding any assumption of its efficacy). Large whales and large elasmobranchs (e.g., whale sharks) were combined in one column due to shared large body size. Checkmarks in Wildlife Group columns refer to field studies that showed the efficacy of a method; an "X" in these columns represents studies that showed no effect. The numbers used are identified in the References, and the Appendix summarizes details from these studies. [a]The types of circle hooks used did not reduce sea turtle hookings, but there were fewer throat hookings which is though to increase post-hooking survivability; [b]also reduced some non-target finfish bycatch; [c]unclear if the potential benefits extend beyond the entrapment section of the gear; [d]summary of other studies; [e]simulation in flume tank using dummy animals; [f]in this case, blue shark was a target species; [g]results contrasted between trial periods.

	Bycatch Reduction Technique	Fishing Method						Wildlife Group					
		Gillnets	Surrounding nets	Traps/ Pots	Trawls	Dredges	Hook-and-line (incl. longlines)	Large whales and sharks	Small cetaceans	Pinnipeds	Elasmobranchs (except largest species)	Seabirds	Sea Turtles
Contact Averted	*Acoustic*												
	Pingers/alarms	X		*	*			☑ - 1	☑ - 2, 3, 4, 5, 6, 7, 8, 52 X - 48, 49	☑ - 2 X - 3, 4		☑ - 9	
	Acoustic harassment devices	*	*	*	*				☑ - 10	X - 11, 12[d]			
	Passive acoustic deterrents	*		*					☑ - 39 X - 7, 13				
	Vessel noise reductions	*	*				*						
	Animal predation sounds	*		*			*	☑ - 16	☑ - 14, 15[d]	X - 17			
	Metal oxide nets (also listed under escape deterrents)	*							☑ - 18 X - 49	X - 49		☑ - 18	
	Echolocation disruptor	X											
	Pyrotechnics (also under tactile deterrents)	*	*	*			*		X - 19	X - 21			
	Quck release metal wire (also under visual deterrents)						*						
	Visual												
	Glow rope	*		*									
	Bird-scaring devices						X					☑ - 22, 23, 24	
	Dyed bait						X				☑ - 24[f]	☑ - 23, 24, 25	X - 26, 27
	White mesh on gillnets	X										☑ - 9, 40	
	Flashing lightsticks						*						
	Reflective/colored buoys						*						
	Quick release metal wire (also under acoustic deterrents)						*						
	Olfactory												
	Scent deterrents			*			*						
	Gustatory												
	Noxious bait						*			X - 28			
	Artificial bait						*						
	Novel bait species						X						☑ - 29
	Tactile												
	Animal prodding		*										
	Pyrotechnics (also under acoustic deterrents)	*	*	*			*		X - 19	X - 21			
	Electromagnetic												
	Electromagnetic deterrents	*	*	*	*		*						
	Physical exclusion												
	Buoy line messenger system	*		*									
	Acoustic releases	*		*									
	Bait casting machines						X						
	Thawed bait						X						
	Alternative offal discharge						X					☑ - 24	
	Side sets						X					☑ - 25, 34, 41	
	Night sets		*		*	*	X					☑ - 24, 30	
	Underwater sets/chutes	*					X		☑ - 13			☑ - 22, 25, 32	
	Line shooter						X						
	Raised footropes				X								
	Decreased soak time	X		X	*		X						☑ - 29
	Sinking/weighted lines			X			X					☑ - 23	
	Decoy deterrents	*	*				X						
	Vessel chasing	*					X						
	Deep-water sets	X					X						
	Remote attractor devices		*				*						
	Fence/net barriers			X						☑ - 51[d]			
	Trap guards (T-bars, otter guards)			X					☑ - 50				
	Fleet communication		X		*	*	X						
Escape Contact	**Excluder devices (multiple taxa)**				X	X			☑ - 46 X - 47	☑ - 45[e]			☑ - 20, 35[b], 36[g], 38[c] X - 36[c]
	Circle hooks (also listed under post-capture release)						X				X - 33[f], 37		☑ - 29, 31, 43 X - 33, 42[a]
	Break-away lines	X		X									
	Time tension line cutter	*		*									
	Buoy line trigger release	*		*									
	Stiff rope	*		*									
	Medina panel		X						☑ - 44[d]				
	Metal oxide nets (also listed under acoustic deterrents)	*							☑ - 18 X - 49	X - 49		☑ - 18	
	Alternative net filaments	*							☑ - 49 X - 49				
	Galvanic releases	*		*									
	Weak hooks						*						
	Baiting techniques						*						
Release post-capture or entanglement	**Long gangions**						X						
	Circle hooks (also listed under escape contact)						X				X - 33[f], 37		☑ - 29, 31, 43 X - 33, 42[a]
	Lipid soluble rope	*		*									
	Sea turtle-friendly bridles			*									
	De-hookers						X						

TABLE 2

The focal species of studies that evaluated bycatch reduction techniques for non-target animals based on this review. (Note: some occurrences may reflect multiple references from one long-term study).

Species	Number of occurrences
Loggerhead sea turtle (*Caretta caretta*)	11
Harbor porpoise (*Phocoena phocoena*)	7
Black-footed albatross (*Phoebastria nigripes*)	6
Laysan albatross (*P. immutabilis*)	6
Leatherback sea turtle (*Dermocheles coriacea*)	5
California sea lion (*Zalophus californianus*)	3
Common dolphin (*Delphinus delphis*)	3
Bottlenose dolphin (*Tursiops truncatus*)	3
Green sea turtle (*Chelonia mydas*)	3
Harbor seal (*Phoca vitulina*)	2
Common murre (*Uria aalge*)	2
Rhinoceros auklet (*Cerorhinca monocerata*)	2
Killer whale (*Orcinus orca*)	2
Kemp's ridley sea turtle (*Lepidochelys kempii*)	2
Franciscana (*Pontoporia blainvillei*)	1
Short-beaked common dolphin (*Delphinus delphis*)	1
Humpback whale (*Megaptera novaeangliae*)	1
Hector's dolphin (*Cephalorhynchus hectori*)	1
New Zealand fur seal (*Arctocephalus forsteri*)	1
Pan-tropical spotted dolphin (*Stenella attenuata*)	1
Gray whale (*Eschrichtius robustus*)	1
Beluga whale (*Delphinapterus leucas*)	1
Dall's porpoise (*Phocoenoides dalli*)	1
Shearwater (*Puffinus gravis*)	1
Olive ridley sea turtle (*Lepidochelys olivacea*)	1
Long-snouted spinner dolphin (*Stenella longirostris*)	1
Hawksbill sea turtle (*Eretmochelys imbricata*)	1
Hooker's sea lion (*Phocarctos hookeri*)	1

tion in non-target species bycatch but an increase in target catch. However, this finding raises the question of what impact circle hooks may have on pelagic sharks generally.

On the other hand, many bycatch reduction methods showed benefits across multiple non-target groups of wildlife. Acoustic pingers provide a good example; multiple studies have shown that their use can reduce the bycatch of cetaceans, pinnipeds, and seabirds (Barlow and Cameron, 2003; Bordino et al., 2002; Gearin et al., 2000; Culik et al., 2001; Koschinski and Culik, 1997; Kraus et al., 1997; Lien et al., 1992; Melvin et al., 1999; Stone et al. 1997), although pinnipeds may habituate to and even increase their interactions with fishing operations with prolonged use (Geiger and Jeffries, 1987; Stewardson and Cawthorn, 2004). In another example, TEDs reduced non-target finfish bycatch in addition to that of sea turtles (Christian and Harrington, 1997). In general, excluder devices in trawl gear appear to work well for many different wildlife groups which in part explains why they have received so much research attention around the world.

Conclusion

Mitigating bycatch in non-target species through modifications to fishing gear and methods is a dynamic field that has produced many effective strategies for some endangered populations of marine wildlife. In commercial fisheries, most available techniques are directed at reducing the bycatch of small marine mammals, seabirds, and sea turtles. Although this taxonomic emphasis is justifiable given the high degree of endangerment from fishing encounters, it is certainly the case that other non-target species are as or more seriously endangered by conflicts with fishing operations but to date have received little bycatch mitigation attention. With respect to gear type, hook-and-line fisheries appear to have more bycatch mitigation techniques available than exist in other fishing methods. This is encouraging given the concerns about the consequences of longline fisheries to non-target species bycatch, but at the same time it amplifies the contrast with other fishing methods in which there are relatively fewer techniques for reducing bycatch. In other fisheries such as coastal gillnets, individual nets may cause lower levels of bycatch than trawls and longlines, but because of their widespread use worldwide they may have a major contribution to non-target species bycatch. These are areas of research worthy of attention.

To suggest that this review was exhaustive would be misleading. Fisheries bycatch reduction is a very active area of research with many ongoing studies and the frequent development of novel initiatives. Among these are initiatives to address mammal bycatch in trawls, the research and development of innovative ground and endlines for trap and gillnet fisheries by the Consortium for Wildlife Bycatch Reduction (administered by the New England Aquarium), and several prospective techniques supported through World Widlife Fund's Smart Gear competition. Nevertheless, we hope that the information contained in this article will contribute to the evolving global knowledge base of bycatch reduction approaches. We intend to publish this content on the Worldwide Web where it will be available for use and application by the fishing industry, fisheries researchers, marine biologists, and managers of living marine resources. Over time, such a Web-based database could invite ongoing contributions and updates by international experts and thus more efficiently capture the state of the art of bycatch reduction.

Appendix

Studies evaluating the efficacy of bycatch reduction methods for non-target species. (NR = not reported or not recorded as part of the experimental design).

Technique	Target Organism(s)	Fishery, location	Results	Effect on target catch	Reference
Acoustic pingers	Short-beaked common dolphin (*Delphinus delphis*) California sea lion (*Zalophus californianus*)	California drift gillnet fishery	Reduced bycatch in both species	Catch of target fish species (broadbill swordfish, common thresher shark, and shortfin mako shark) were not affected by pinger use	Barlow and Cameron, 2003
Acoustic pingers	Franciscana (*Pontoporia blainvillei*)	Argentinian bottom gillnet fishery	Reduced bycatch	NR but resulted in increased interactions with South American sea lions (*Otaria byronia*)	Bordino et al., 2002
Acoustic pingers	Harbor porpoise (*Phocoena phocoena)*	Canadian non-lethal, experimental gillnet	Avoided area around experimental gillnet equipped with a pinger	NR, though herring (*Clupea harengus)* catch recorded from a different fishery in the Baltic Sea was unchanged using same pingers	Culik et al., 2001
Acoustic pingers	Harbor porpoise (*Phocoena phocoena)* Harbor seal (*Phoca vitulina*)	Salmon and sturgeon gillnet fishery in northern Washington State	Reduced porpoise bycatch but not that of seals	No significant difference	Gearin et al., 2000
Acoustic pingers	Harbor porpoise (*Phocoena phocoena*)	Tested experimental float lines in British Columbia, Canada	Avoided gillnet float lines	NR	Koschinski and Culik, 1997
Acoustic pingers (“alarms”)	Harbor porpoise (*Phocoena phocoena*)	Gulf of Maine sink gillnet fishery	Reduced bycatch	Target species catch (cod, pollock) not affected; non-target silver hake not affected, and less non-target herring caught in nets with pingers	Kraus et al., 1997
Acoustic pingers	Humpback whale (*Megaptera novaeangliae*)	Newfoundland cod trap fishery	Reduced collisions	Traps with alarms caught more fish	Lien et al., 1992
Acoustic pingers	Harbor porpoise (*Phocoena phocoena*)	Gillnets off of New Hampshire, USA	Reduced bycatch	NR – Frequency of alarm sounds were above groundfish hearing and not expected to affect catch	Lien et al., 1995
Acoustic pingers	Common murre (*Uria aalge*) Rhinoceros auklet (*Cerorhinca monocerata*)	Puget Sound salmon gillnet fishery	Reduced bycatch of common murre but not the rhinoceros auklet	Reduction not significant	Melvin et al., 1999

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Appendix

Technique	Target Organism(s)	Fishery, location	Results	Effect on target catch	Reference
Acoustic pingers	Hector's dolphin (*Cephalorhynchus hectori*)	Akaroa Harbour, New Zealand	Avoided gillnet areas	NR	Stone et al., 1997
Acoustic pingers (placed around mouth of net)	Common dolphin (*Delphinus delphis*)	United Kingdom bass pair trawl fishery	Did not reduce cetacean bycatch	NR	Northridge, 2003a
Acoustic pingers (placed in rear of net)	Common dolphin (*Delphinus delphis*)	United Kingdom bass pair trawl fishery	Did not reduce cetacean bycatch	NR	Northridge et al., 2003
Acoustic harassment devices	Harbor seal (*Phoca vitulina*)	Oregon salmon gillnet fishery	Habituated to sound	Inconclusive; possible reduction in "damaged" salmon, at least over the short-term	Geiger and Jeffries, 1987
Acoustic harassment devices	Harbor porpoise (*Phocoena phocoena*)	Bays in British Columbia	Avoided area	NR	Olesiuk et al., 2002
Acoustic harassment devices	New Zealand fur seal (*Arctocephalus forsteri*)	New Zealand hoki trawl fishery	Not effective	NR	Stewardson and Cawthorn, 2004
Passive acoustic deterrents (metallic beads)	Bottlenose dolphin (*Tursiops truncatus*) Pan-tropical spotted dolphin (*Stenella attenuata*)	North Australia multi-species pelagic gillnet	(1985 trial) - No reduced bycatch	Total catch comprising sharks, tuna, mackerel, billfish, and other species reported as 21.3% higher in unmodified nets	Hembree & Harwood, 1987
Passive acoustic deterrents	Harbor porpoise (*Phocoena phocoena*)	Tested experimental float lines in British Columbia, Canada	Did not avoid a barrier with passive reflectors	NR	Koschinski and Culik, 1997
Passive acoustic deterrents	Bottlenose dolphin (*Tursiops truncatus*)	Barriers simulating surface-set gillnets in Moray Firth, Scotland	Increased avoidance	NR	Goodson and Mayo, 1995
Predator sounds (killer whales)	Gray whale (*Eschrichtius robustus*)	California coast	Avoided area	NR	Cummings and Thompson, 1971
Predator sounds (killer whales)	Beluga whale (*Delphinapterus leucas*)	Not tested in a fishery but in Alaska's Kvichak River	Belugas excluded when killer whale sounds played	NR	Fish and Vania, 1971
Predator sounds (killer whales)	Dall's porpoise (*Phocoenoides dalli*)	Northern Japanese waters	Area departure	NR	Jefferson and Curry, 1996

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Appendix

Technique	Target Organism(s)	Fishery, location	Results	Effect on target catch	Reference
Predator sounds (killer whales)	California sea lion (*Zalophus californianus*)	Washington Steelhead trout (*Salmo gairdneri*) fishery	No deterrence	NR	Scordino and Pfeifer, 1993
Metal oxide nets[1]	Harbor porpoise (*Phocoena phocoena*) Shearwater (*Puffinus gravis*)	Eastern Canada demersal gillnet fishery	Reduced bycatch in both species	No change in catch of commercial fish species (cod, pollock, haddock, spiny dogfish)	Trippel et al., 2003
Metal oxide nets	Harbor porpoise (*Phocoena phocoena*) Seals (Species NR)	North Sea and West Scotland gillnet fisheries	Higher bycatch of both species	NR	Northridge et al., 2003
Multi-monofilament net (compared to monofilament net)	Harbor porpoise (*Phocoena phocoena*)	North Sea and West of Scotland gillnet fisheries	No significant reduction	NR	Northridge et al., 2003
Thick (.6mm twine diameter, 267 mm mesh size) versus thin (.4mm twine diameter, 90 mm mesh size) twine monofilament nets	Harbor porpoise (*Phocoena phocoena*) Seals (Species NR)	North Sea and West of Scotland gillnet fisheries	Thin twine reduced bycatch of both species	NR	Northridge et al., 2003
Pyrotechnics (cracker shells)	Killer whale (*Orcinus orca*)	Alaskan sablefish (*Anoplopoma fimbria*) fishery	No reduced depredation (as reported by fishermen)	NR	Dahlheim, 1988
Pyrotechnics (seal bombs)	California sea lion (*Zalophus californianus*)	Washington locks	No deterrence over time	NR	NMFS/Washington DFW, 1995
Bird-scaring devices (streamer lines)	Black-footed albatross (*Phoebastria nigripes*) Laysan albatross (*P. immutabilis*)	Hawaiian swordfish longline fishery	Reduced contact with bait for both species	NR, but assume would increase due to more available baited hooks	Boggs, 2001

[1] It was not ascertained if the results obtained were due to the increased acoustic reflectivity, physical stiffness, or greater visibility of the nets, though the last characteristic likely caused the reduction in shearwater bycatch.

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Appendix

Technique	Target Organism(s)	Fishery, location	Results	Effect on target catch	Reference
Bird-scaring devices (streamer lines)	Seabirds	Norwegian longlines	Reduced bycatch	Increased catch – haddock (*Melanogrammus aeglefinus*), torsk (*Brosme brosme*), and ling (*Molva molva*)	Løkkeborg, 2001
Bird-scaring devices (streamer lines)	Black-footed albatross (*Phoebastria nigripes*) Laysan albatross (*P. immutabilis*)	Hawaiian swordfish and tuna longline fisheries	Reduced bycatch	NR	McNamara et al., 1999
Bird-scaring devices (towed buoys)	Black-footed albatross (*Phoebastria nigripes*) Laysan albatross (*P. immutabilis*)	Hawaiian swordfish and tuna longline fisheries	Reduced bycatch	NR	McNamara et al., 1999
Dyed bait (blue)	Black-footed albatross (*Phoebastria nigripes*) Laysan albatross (*P. immutabilis*)	Hawaiian swordfish and tuna longline fisheries	Reduced bycatch	No effect on target and marketable species (all marlin and tuna spp., swordfish, shortbill spearfish, opah, wahoo and dolphinfish); reduced blue shark catch	McNamara et al., 1999
Dyed bait (blue)	Black-footed albatross (*Phoebastria nigripes*) Laysan albatross (*P. immutabilis*)	Hawaiian swordfish longline fishery	Reduced contact with bait for both species	NR, but assume would increase due to more available baited hooks	Boggs, 2001
Dyed bait (blue)	Laysan albatross (*Phoebastria immutabilis*) Black-footed albatross (*P. nigripes*)	Hawaiian longline tuna and swordfish fishery	Reduced bycatch in tuna fishery	NR, but assume would increase due to more available baited hooks	Gilman et al., 2003a
Dyed bait (blue)	Olive ridley sea turtle (*Lepidochelys olivacea*) Green sea turtle (*Chelonia mydas*)	Cost Rica longline fishery	No reduced bycatch	NR	Swimmer et al., 2005
Dyed bait (blue)	Loggerhead sea turtle (*Caretta caretta*) Leatherback sea turtle (*Dermocheles coriacea*)	Western Atlantic longline fishery	No significant reduction	NR	Watson et al., 2002

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Appendix

Technique	Target Organism(s)	Fishery, location	Results	Effect on target catch	Reference
White mesh on gillnets	Common murre (*Uria aalge*) Rhinoceros auklet (*Cerorhinca monocerata*)	Puget Sound salmon gillnet fishery	Reduced bycatch	Decreased catch in 50-mesh but no significant reduction using 20-mesh	Melvin et al., 1999
White mesh on gillnets (opaque mesh netting)	Common murre (*Uria aalge*) Rhinoceros auklet (*Cerorhinca monocerata*)	Puget Sound salmon gillnet fishery	Reduced bycatch	Decreased catch of target salmon species	Melvin and Conquest, 1996
Noxious bait	California sea lion (*Zalophus californianus*)	Washington steelhead trout (*Salmo gairdneri*) fishery	No deterrence over time	No effect	Gearin et al., 1988
Novel bait (switching from squid to mackerel)	Loggerhead sea turtle (*Caretta caretta*) Leatherback sea turtle (*Dermocheles coriacea*)	Atlantic longline swordfish fishery	Reduced bycatch; highest bycatch reduction achieved when combined with circle hooks	No reduction	Watson et al., 2005
Alternative offal discards	Black-footed albatross (*Phoebastria nigripes*) Laysan albatross (*P. immutabilis*)	Hawaiian swordfish and tuna longline fisheries	Distracted seabirds from hooked bait	NR	McNamara et al., 1999
Side sets	Laysan albatross (*Phoebastria immutabilis*) Black-footed albatross (*P. nigripes*)	Hawaiian longline swordfish and tuna fisheries	Reduced bycatch in tuna fishery	NR, but assume would increase due to more available baited hooks	Gilman et al., 2003a
Side sets (with bird curtain)	Black-footed albatross (*Phoebastria nigripes*) Laysan albatross (*P. immutabilis*)	Hawaiian longline swordfish and tuna fisheries	Reduced bycatch	NR	Gilman et al., in press
Side sets	Black-footed albatross (*Phoebastria nigripes*) Laysan albatross (*P. immutabilis*)	Western North Pacific longline fishery	Deterred seabirds from taking bait and improved sinking rates of baited hooks	NR	Yokota and Kiyota, 2006

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Appendix

Technique	Target Organism(s)	Fishery, location	Results	Effect on target catch	Reference
Night sets	Black-footed albatross (*Phoebastria nigripes*) Laysan albatross (*P. immutabilis*)	Hawaiian swordfish and tuna longline fisheries	Reduced bycatch	NR	McNamara et al., 1999
Night sets	Seabirds	Hawaiian swordfish longline fishery	Reduced bycatch	NR	Boggs, 2003
Underwater sets (chutes)	Laysan albatross (*Phoebastria immutabilis*) Black-footed albatross (*P. nigripes*)	Hawaiian longline swordfish and tuna fisheries	Reduced bycatch in tuna fishery	NR, but assume would increase due to more available baited hooks	Gilman et al., 2003a
Underwater sets (funnel)	Seabirds	Norwegian longlines	Reduced bycatch	Increased catch – haddock (*Melanogrammus aeglefinus*), torsk (*Brosme brosme*), and ling (*Molva molva*)	Løkkeborg, 2001
Underwater sets (chutes)	Laysan albatross (*Phoebastria immutabilis*) Black-footed albatross (*P. nigripes*)	Hawaiian longline tuna fishery	Reduced bycatch	NR, but assume would increase due to more available baited hooks	Gilman et al., 2003b
Underwater sets (subsurface gillnet)	Bottlenose dolphin (*Tursiops truncatus*) Long-snouted spinner dolphin (*Stenella longirostris*)	North Australia multi-species pelagic gillnet	(1986 trial) - Reduced bycatch (~50%)	Of the total catch comprising sharks, tuna, mackerel, billfish, and other species, only the mackerel catch was significantly lower in subsurface nets	Hembree and Harwood, 1987
Decreased soak time	Loggerhead sea turtle (*Caretta caretta*)	Atlantic swordfish longline fishery	Turtle bycatch increased with an increase in total soak time	NR - Soak time was not significant for swordfish but was for bigeye tuna	Watson et al., 2005
Weighted bait	Black-footed albatross (*Phoebastria nigripes*) Laysan albatross (*P. immutabilis*)	Hawaiian swordfish longline fishery	Reduced contact with bait for both species	NR, but assume would increase due to more available baited hooks	Boggs, 2001

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Appendix

Technique	Target Organism(s)	Fishery, location	Results	Effect on target catch	Reference
Trap guards (made of bungee cord)	Bottlenose dolphin (*Tursiops truncatus*)	Indian River Lagoon blue crab (*Callinectes sapidus*) pot fishery	Reduced interactions with pot gear	NR	Noke and Odell, 2002
Excluder devices (sea turtle)	Loggerhead sea turtle (*Caretta caretta*) Finfish: Atlantic croaker (*Micropogonias undulateus*), spot (*Leiostomus exanthurus*), sea catfish (*Arius felis*), weakfish (*Cynoscion regalis*)	Gulf of Mexico prawn trawl fishery	Reduced bycatch of turtles and finfish	No significant difference in shrimp catch rates in 3 of the 4 TEDs when compared with a control net. One experimental TED in Texas exhibited a decrease in shrimp catch.	Christian and Harrington, 1997
Excluder devices (sea turtle)	Atlantic and Gulf of Mexico sea turtles	Atlantic and Gulf of Mexico shrimp trawl fishery	Depending on different trial period, TEDs showed either higher or lower bycatch compared with standard nets	NR	Renaud et al., 1997
Excluder devices (sea turtle)	Loggerhead sea turtle (*Caretta caretta*) Leatherback sea turtle (*Dermocheles coriacea*) Green sea turtle (*Chelonia mydas*)	Northwest Atlantic scallop dredge fishery	Eliminated bycatch of sea turtles	Reduction of catch (6.71%)	DuPaul et al., 2004
Excluder devices (pinnipeds)	Hooker's sea lion (*Phocarctos hookeri*) New Zealand fur seal (*Arctocephalus forsteri*)	Tested trawl net with excluder device in a flume tank with dummy seals	Excluded dummy seals from codend of net	NR	Gibson and Isakssen, 1998
Excluder devices (small cetaceans)	Common dolphin (*Delphinus delphis*)	United Kingdom bass pair trawl fishery	Reduced cetacean bycatch	Negligible fish loss (<1%)	Northridge, 2003b
Excluder devices (small cetaceans)	Common dolphin (*Delphinus delphis*)	United Kingdom bass pair trawl fishery	Did not reduce bycatch	NR	Northridge et al., 2004

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Appendix

Technique	Target Organism(s)	Fishery, location	Results	Effect on target catch	Reference
Circle hooks (non-offset 16/0 and 8/0) compared to straight and offset 9/0 J-hooks	Loggerhead sea turtle (*Caretta caretta*)	Azores longline swordfish and blue shark fishery	No significant reduction in bycatch	Caught significantly more blue sharks than using 9/0 J-hooks	Bolten and Bjorndal, 2003
Circle hooks (non-offset 16/0, offset 16/0, offset 18/0)	Loggerhead sea turtle (*Caretta caretta*)	Azores longline swordfish and blue shark fishery	No reduction in bycatch, although circle hooks decreased rate of throat-hooking	Blue shark catch varied by hook size, with non-offset 16/0 catching the most and offset 16/0 catching the fewest	Bolten and Bjorndal, 2004
Circle hooks (non-offset 16/0 and non-offset 18/0) compared with Japanese tuna hook 3.6 mm S/S	Loggerhead sea turtle (*Caretta caretta*)	Azores longline swordfish and blue shark fishery	Japanese hook caught more turtles than circle hooks and hooked more turtles in the throat. (Non-offset 18/0 circle hooks caught fewer turtles than non-offset 16/0 circle hooks)	NR, but no significant difference in catch of blue sharks between two circle hooks	Bolten and Bjorndal, 2005
Circle hooks	Loggerhead sea turtle (*Caretta caretta*) Leatherback sea turtle (*Dermocheles coriacea*)	Western Atlantic longline fishery	Reduced bycatch significantly; achieved greatest level of bycatch reduction when circle hooks were baited with mackerel instead of squid	Swordfish catch decreased when circle hooks were baited with squid, but increased when baited with mackerel. Tuna catch increased when circle hooks were baited with squid but decreased when baited with mackerel.	Watson et al., 2004
Circle hooks (18/0) compared with J-hooks	Loggerhead sea turtle (*Caretta caretta*) Leatherback sea turtle (*Dermocheles coriacea*)	Atlantic longline swordfish fishery	Reduced bycatch significantly; circle hooks also reduced rate of hook ingestion by loggerhead sea turtles; combination of circle hooks with mackerel bait achieved highest level of bycatch reduction	Combination of circle hooks and mackerel bait had no negative effect on swordfish catch	Watson et al., 2005
Alternative leader design	Loggerhead sea turtle (*Caretta caretta*) Kemp's ridley sea turtle (*Lepidochelys kempii*)	Chesapeake Bay pound net fishery for finfish	Reduced sea turtle interactions at least in the entrapment area of the net	Did not appear to reduce the catch of weakfish (*Cynoscion regalis*), croaker (*Micropogonias undulates*), or harvestfish (*Peprilus alepidotus*)	DeAlteris et al., 2005

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