Comparing Effectiveness of Experimental and Implemented Bycatch Reduction Measures: the Ideal and the Real

T. M. COX,*§ R. L. LEWISON,† R. ŽYDELIS,* L. B. CROWDER,* C. SAFINA,‡ AND A. J. READ*

*Duke Center for Marine Conservation, Duke University Marine Laboratory, 135 Duke Marine Lab Road, Beaufort, NC 28516-9721, U.S.A.
†Biology Department, San Diego State University, 5500 Campanile Drive, San Diego, CA 92182, U.S.A.
‡Blue Ocean Institute, 250 Lawrence Hill Road, Cold Spring Harbor, NY 11724, U.S.A.

Abstract: *Fishers, scientists, and resource managers have made substantial progress in reducing bycatch of sea turtles, seabirds, and marine mammals through physical modifications to fishing gear. Many bycatch-avoidance measures have been developed and tested successfully in controlled experiments, which have led to regulated implementation of modified or new fishing gear. Nevertheless, successful bycatch experiments may not translate to effective mitigation in commercial fisheries because experimental conditions are relaxed in commercial fishing operations. Such a difference between experimental results and real-world results with fishing fleets may have serious consequences for management and conservation of protected species taken as bycatch. We evaluated preimplementation experimental measures and postimplementation efficacy from primary and gray literature for three case studies: acoustic pingers that warn marine mammals of the presence of gill nets, turtle excluder devices that reduce bycatch of turtles in trawls, and various measures to reduce seabird bycatch in longlines. Three common themes to successful implementation of bycatch reduction measures are long-standing collaborations among the fishing industry, scientists, and resource managers; pre- and postimplementation monitoring; and compliance via enforcement and incentives.*

Keywords: bycatch, fisheries, marine mammals, mitigation, seabirds, sea turtles

Comparación de la Efectividad de Medidas Experimentales e Implementadas para la Reducción de Capturas Incidentales: lo Ideal y lo Real

Resumen: *Pescadores, científicos y manejadores de recursos han progresado sustancialmente en la reducción de la captura incidental de tortugas marinas, aves marinas y mamíferos marinos mediante modificaciones físicas de las artes de pesca. Muchas medidas para evitar la captura incidental se han desarrollado y probado exitosamente en experimentos controlados, que han llevado a la implementación regulada de artes de pesca modificadas o nuevas. Sin embargo, los experimentos exitosos pueden traducirse en mitigación no efectiva en pesquerías comerciales porque las condiciones experimentales son relajadas en operaciones pesqueras comerciales. Tal diferencia entre los resultados experimentales y los resultados en el mundo real con flotas pesqueras puede tener serias consecuencias para el manejo y conservación de especies protegidas capturadas incidentalmente. Evaluamos medidas experimentales pre-implementación y eficacia post-implementación en la literatura primaria y gris para tres casos de estudio: aparatos acústicos que advierten a mamíferos marinos de la presencia de redes agalleras, dispositivos excluyentes de tortugas que reducen la captura incidental de tortugas marinas en redes de arrastre y varias medidas para reducir la captura incidental de aves marinas en palangres. Tres temas comunes a la implementación exitosa de medidas para la reducción de captura incidental son la colaboración entre la industria pesquera, científicos y manejadores de recursos; el monitoreo pre- y post implementación; y el acatamiento por medio de la fuerza e incentivos.*

§*email tara.cox@duke.edu*
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Palabras Clave: aves marinas, captura incidental, mamíferos marinos, mitigación, pesquerías, tortugas marinas

Introduction

Bycatch—capture of nontarget species—is a principal problem in fisheries management. Bycatch is a particular threat for long-lived animals with slow population growth rates, such as marine mammals, seabirds, and sea turtles (Heppell et al. 2005). These species are at even greater risk if they are captured in a fishery that is managed to maximize yield of short-lived, fast-reproducing species (Dayton et al. 2002). Even low levels of bycatch can have catastrophic results for small populations, such as the vaquita (*Phocoena sinus*; Rojas-Bracho & Taylor 1999) and Tristan Albatross (*Diomedea dabbenena*; Cuthbert et al. 2004). In addition, changes in the abundance of large predators can have impacts on the trophic structure of marine communities and the functioning of marine ecosystems (Dayton et al. 2002; Magnuson et al. 2006; Myers et al. 2007).

Several approaches exist to mitigate bycatch, including limiting fishing effort or modifying fishing practices. The latter approach includes a variety of techniques, such as gear modifications and time-area closures (Hall 1996). Often, such measures (especially changes to fishing gear or practices) are evaluated in experimental field trials prior to implementation (e.g., Weber 1995; Kraus et al. 1997). If successful under experimental conditions, the approaches are then implemented in the fishery, typically through regulations.

Whether a successful experiment leads to a concomitant reduction of bycatch under real-world conditions of a commercial fishery has not been evaluated. The effectiveness of any bycatch mitigation strategy may be reduced by a lack of compliance, inappropriate use of the gear, or other factors. A decrease in efficacy between experimental results and fleet-implementation results may have serious consequences for the conservation of species taken as bycatch, especially in the absence of an effective monitoring program.

We considered three case studies of bycatch-reduction programs and compared the efficacy of these measures under experimental and real-world conditions. We focused on conservation techniques designed to reduce bycatch of marine mammals, sea turtles, and seabirds: (1) acoustic alarms designed to reduce the bycatch of small cetaceans in gill-net fisheries, (2) turtle excluder devices (TEDs) designed to keep sea turtles out of trawl nets, and (3) various mitigation strategies developed to reduce bycatch of seabirds in longline fisheries. Our objective was to compare efficacy of bycatch mitigation technology in experimental versus implemented conditions and identify the factors that contributed to the most successful measures.

Case Study 1: Small Cetaceans and Gill Nets

Hundreds of thousands of dolphins and porpoises are killed each year in the world's gill-net fisheries (Perrin et al. 1994; Read et al. 2006). One measure used to reduce this bycatch is the acoustic alarm, or "pinger," which is intended to alert animals of the presence of a net. In 1994 a large-scale field experiment was conducted to determine whether pingers could reduce the bycatch of harbor porpoises (*P. phocoena*) in the Gulf of Maine (Kraus et al. 1997). The experimental protocol required an independent observer on each vessel, restricted the number and size of nets, and implemented a double-blind experimental design in which both control (i.e., silent) and active alarms were used. In this first large-scale experiment, pingers reduced the bycatch rate of harbor porpoises by 92% and catch levels of target species were maintained (Kraus et al. 1997). Following this initial success, pinger trials were conducted in drift gill-net fisheries in California in 1996 and 1997. In these experiments there was an 85% reduction in the bycatch of short-beaked common dolphins (*Delphinus delphis*) and California sea lions (*Zalophus californianus*; Barlow & Cameron 2003). Other pinger experiments have been conducted in Washington (Gearin et al. 2000), the Bay of Fundy (Trippel et al. 1999), the North Sea (Larsen 1999), and Argentina (Bordino et al. 2002). All these trials reported similar reductions in the bycatch of various small cetaceans of approximately 70–90% (Table 1).

Based on the results of these trials, pingers have been recommended by the International Whaling Commission (IWC) as a means to reduce bycatch of harbor porpoises and other species (IWC 2001). Acoustic alarms were included as an integral component of the U.S. National Marine Fisheries Service (NMFS) Take Reduction plans both in the Gulf of Maine and the California–Oregon drift-net fishery (U.S. Department of Commerce 1997*a*, 1998). Acoustic alarms are now required in several fisheries: the U.S. Gulf of Maine bottom-set gill-net fishery for groundfish, the California–Oregon drift-net fishery for thresher sharks (*Alopias vulpinus*) and swordfish (*Xiphias gladius*), and the Danish bottom-set gill-net fishery for cod (*Gadus*). In addition, the European Union is in the process of phasing in requirement of acoustic alarms in many gill-net fisheries (European Union 2004). There is sufficient information to evaluate the efficacy of acoustic

Table 1. Results of experiments to determine marine mammal bycatch reduction in set and drift gill nets.

Study	*Ocean region*	*Species*	*Reduction in bycatch (%)**
Kraus et al. 1997	Gulf of Maine	harbor porpoise (*Phocoena phocoena*)	92
Trippel et al. 1999	Bay of Fundy	harbor porpoise	68–85
Larsen 1999	North Sea	harbor porpoise	93
Gearin et al. 2000	Washington State	harbor porpoise	90–93
Bordino et al. 2002	Argentina	Franciscana dolphin (*Delphinus franciscana*)	85
Barlow & Cameron 2003	California	short-beaked common dolphin (*D. delphis*).	85

**Change in bycatch between nets with and without pingers.*

alarms in reducing bycatch in only two operational fisheries: the Gulf of Maine sink gill-net fishery and the California–Oregon drift-net fishery.

Gulf of Maine

In the Gulf of Maine harbor porpoises are killed in gill nets set on the sea floor to catch cod (*Gadus morhua*), haddock (*Melanogrammus aeglefinus*), pollock (*Pollachius virens*), and other species. Between 1992 and 1996, allowable bycatch of harbor porpoises under the U.S. Marine Mammal Protection Act, referred to as Potential Biological Removals (PBR), was estimated at 483 (Waring et al. 1999). Nevertheless, during this period, an average of 2100 harbor porpoises died annually in these gill nets, which was approximately 4% of the population each year (Waring et al. 1999). This large amount of bycatch spurred several management actions, including the implementation of time-area closures in the Gulf of Maine and the listing of the harbor porpoise as a candidate species for a designation as threatened under the U.S. Endangered Species Act.

Following the successful pinger experiment in the Gulf of Maine (Kraus et al. 1997), the formal Take Reduction Plan required acoustic alarms on gill nets in areas and seasons when porpoises were likely to be present (U.S. Department of Commerce 1998). The first indication that the adoption of acoustic alarms in the Gulf of Maine might not achieve the full success of the experiments came during several less-formal field trials. In these trials, which NMFS referred to as "experimental fisheries," there were no controls, oversight, or instruction of the proper use of acoustic alarms, and bycatch was reduced by only 50–80% (Allen et al. 1999; Rossman 2000).

The government required acoustic alarms throughout the Gulf of Maine in 1999, and harbor porpoise bycatch dropped to 270, well below the allowed threshold. Bycatch was reduced even further, to only 53 animals, in 2001 (Waring et al. 2005). Nevertheless, by 2003 the bycatch of harbor porpoises increased to 592 in this fishery (Waring et al. 2005). Although a 2001 assessment increased the allowable removal to 747 (Waring et al. 2001), the trend for increased bycatch suggests that the allowable threshold will soon be exceeded.

In the Gulf of Maine fishery pinger effectiveness is affected by pinger performance, porpoise habituation, and fisher compliance. The alarm's high-frequency sound is difficult to hear over the noise of a fishing vessel. Thus, alarm malfunction could go undetected. Some alarms have salt-water switches and remain silent while aboard the vessel, and fisheries observers are not required to check functionality, only whether alarms are present on nets. Furthermore, alarm effectiveness may decline if harbor porpoises habituate to signals (Cox et al. 2001).

Dockside monitoring, the most common form of enforcement, does not ensure that pingers are actually being used in accordance with regulations. There are also disincentives for pinger use, including costs, maintenance, and perception that pingers may attract mammals that might pilfer the catch. In 2003 during Gulf of Maine gill-net trips with NMFS observers (who have no enforcement authority), 173 of 217 trips were not in compliance with harbor porpoise regulations. In 18 trips fishers set gill nets in areas completely closed to fishing. Nevertheless, 155 out of the 173 noncompliance cases involved deploying gill nets without alarms—a noncompliance rate of 78% (M. Rossman, personal communication). These data were recorded by federally trained observers; compliance is likely lower on unobserved trips.

California

The California drift gill-net fishery for thresher sharks and swordfish captures several cetaceans, most commonly short-beaked common dolphins. Following an experiment with acoustic alarms (Barlow & Cameron 2003), the NMFS required acoustic alarms on all nets and required training workshops to educate boat captains in their proper use (U.S. Department of Commerce 1997*a*).

After pingers were required, common dolphin bycatch mortality dropped from an estimated 345 in 1996 to 51 in 1998. In 1999 and 2000 the bycatch of short-beaked dolphins increased to 180 and 105, respectively, before declining again in 2001 (34) and 2002 (32; Caretta et al. 2005). These fluctuations likely reflect a combination of increasing compliance and improved pinger maintenance and technology. Based on observed trips, compliance with the requirement to use alarms increased from 75% in 1997 to 99% in 2001 (Caretta et al. 2005), which may account for the initial decrease in bycatch. Although pingers were frequently used, there was no requirement to monitor pinger function. Federal fisheries observers started testing alarms in 2001, indicating that the possible increase and subsequent decrease in bycatch were due to changes in pinger maintenance (Caretta et al. 2005).

Efficacy of Pingers

Compliance has been much greater in the California fishery than in the Gulf of Maine. Reasons may include more education and outreach in California and more support from California fishers. The mandatory training workshops likely increased fishers' knowledge on bycatch, ability to maintain alarms, and, perhaps, better acceptance of pingers. Furthermore, fishers' input at the workshops directly resulted in regulatory changes allowing fishers to attach pingers via lanyards or extender lines, easing deployment (U.S. Department of Commerce 1999). Responsiveness of government regulators to fishers may have increased compliance. In addition, the Take Reduction Team was small, effective, and communicated well with government scientists, which built trust among all participants (Young 2001).

Case Study 2: Turtles and Trawls

Six of seven species of sea turtles are listed as threatened or endangered on the World Conservation Union (IUCN) Red List. (The seventh, the flatback turtle [*Natator depressus*], is considered "data deficient" [IUCN 2006]). There have been encouraging recoveries in some populations (e.g., Bjorndal et al. 1999; Balazs & Chaloupka 2004), but many others are declining from the effects of loss of terrestrial nesting habitat, pollution, direct hunting, and bycatch in various fishing gear (Lutcavage et al. 1997). TEDs are used to reduce bycatch of sea turtles in trawl nets. A TED is a metal grate fitted into the neck of a shrimp trawl net; shrimp can pass through the bars to reach the bag end of the trawl, but turtles are stopped by the grid bars and slide out an open flap in the net. TEDs have been formally tested and implemented in the United States and Australia.

United States

In the U.S. Gulf of Mexico trawlers killed approximately 11,000 sea turtles per year between 1979 and 1981 (Henwood & Stuntz 1987). A subsequent National Academy of Sciences panel estimated kills as high as 55,000 sea turtles per year. They concluded that interactions with trawls were the most serious threat to sea turtles in U. S. waters (National Research Council [NRC] 1990). Development of TEDs took nearly a decade while government scientists and fishers tested different TEDs in waters off the United States' southeastern Atlantic and Gulf of Mexico coasts (Donnelly 1989). Commercial shrimp fishers conducted paired trawls, deploying a trawl with no TED on one side of the vessel and an identical trawl with a TED on the other. An NMFS observer recorded shrimp, turtle, and total catch rates for each trawl. The trawl with no TED had a mean catch rate of 1.43 turtles/h, whereas trawls with TEDs had a mean catch rate of 0.04 turtles/h: a 97% reduction in bycatch rate (Watson 1981). Consequently, in 1987 the U.S. Fisheries Service required seasonal use of "certified" TEDs on all shrimp trawlers longer than 25 feet in offshore waters of the U.S. Gulf of Mexico and southern Atlantic (U.S. Department of Commerce 1987). In 1992 the Service required all U.S. shrimp trawlers in the Atlantic and Gulf of Mexico to use TEDs in all waters in all seasons (U.S. Department of Commerce 1992).

There has been no published documentation of catch reduction due to TEDs since their use was mandated. Turtles washed up dead ("strandings") are not a direct measurement of turtle bycatch in trawl nets, but they have been used as a proxy for bycatch (NRC 1990; Crowder et al. 1995; Caillouet et al. 1996). Retrospective analyses of turtle strandings suggest that TEDs reduced turtle mortality off the South Carolina coast by approximately 40% (Crowder et al. 1995). Researchers later realized that approximately 40% of stranded loggerheads were too large to fit through the minimum-sized TED opening, likely leading to higher sea turtle mortality than the 97% reduction in bycatch objective (Epperly & Teas 2002). Not until 2004 (17 years after the initial TED regulations) did the NMFS require a TED opening large enough to facilitate the escape of adult loggerheads (Heppell et al. 2003). Results of another stranding analysis suggest that TEDs reduce sea turtle mortality by 20–40% in the Gulf of Mexico (Lewison et al. 2003). The high Gulf of Mexico mortality is correlated with low compliance; therefore, TED compliance is a significant factor in stranding variability (Lewison et al. 2003). Dockside enforcement of TED use is inadequate and at-sea enforcement is extremely difficult because it is possible for a TED to be installed in a net but for the escape flap by which a turtle would be excluded to be sewn shut.

Australia

Approximately 11,000 sea turtles were caught annually in Australia's northern prawn fishery and Queensland's east-coast trawl fishery in the 1990s (Robins et al. 1999). In experiments a TED comparable to that used in the United States reduced turtle bycatch by more than 90% (Brewer et al. 1998; Robins & McGilvray 1999). The TEDs were made mandatory in the Queensland east-coast fishery in 1999 and the northern prawn fishery in 2000 (Robins et al. 1999). Turtle bycatch in the northern prawn fishery fell by 90% in the first 2 years and subsequently by 95% (Garvey & Lilly 2001; Perdrau & Garvey 2003, 2004, 2005; Haine & Garvey 2005). Bycatch rates dropped from approximately 0.30 turtles per day to 0.009 turtles per day after TED implementation in the northern prawn fishery (Robins et al. 2002).

In Australia TED efficacy after implementation matched the experimental results. Partial credit may be due to an outreach and education project initiated in 1996 (Robins 1997, cited in Robins et al. 1999). Researchers loaned TEDs to commercial fishers so they could try TEDs before buying them. Then, research staff modified TEDs to suit individual fishers' needs (e.g., modifications that reduced jellyfish bycatch thereby increasing prawn catch). Because trawl fishers had an economic incentive to comply with TED regulations and the opportunity to try TEDs before investing in them, 80% of fishers were using TEDs by 1999 (Robins et al. 1999).

Efficacy of TEDs

In the United States TEDs appear to have achieved less than half of their projected efficacy compared with experimental trials, whereas in Australia, TEDs have achieved turtle catch-reduction targets. Without direct measures of bycatch reduction in the U.S. fleet, the actual bycatch reduction is uncertain. Nevertheless, in the United States, lack of compliance or inadequate TED design (escape opening too small) may have led to a 50% shortfall in implemented TED efficacy (Lewison et al. 2003). The modified opening size may lead to higher bycatch reduction; nevertheless, compliance remains problematic. Many countries now require TEDs in their fisheries, but information from U.S. and Australian fisheries strongly suggests that regulations need to be enforced or that incentives are required if TEDs are to reduce turtle bycatch to targeted levels. Although the U.S. requires TEDs in import fisheries, compliance and enforcement is inadequate in most countries, which in turn is a further disincentive for U.S. fishers to comply with TED regulations (Lewison et al 2003).

Case Study 3: Seabirds and Longlines

Gill nets, longlines, and trawls kill large numbers of seabirds (e.g., Melvin et al. 1999; Gilman et al. 2005; Sullivan et al. 2006). Most attention regarding seabird bycatch has been directed toward longline gear (but see Melvin et al. 1999; Sullivan et al. 2006).

Longline bycatch of long-lived albatrosses and petrels occurs globally (Lewison et al. 2005). Whether set to drift in the water column (pelagic) or to rest on or near the bottom (demersal), longlines are often 10–80 km in length and bear hundreds to thousands of baited hooks. Seabirds attempt to take the bait as the line is deployed and before it sinks. Birds hooked at this time are pulled down with the line and drowned (Brothers et al. 1999). In addition, offal discards that coincide with gear deployment attract birds to the boat and can lead to even higher numbers of hooked birds (Sullivan 2004).

A suite of measures has been developed to reduce seabird bycatch by longline fisheries (Table 2). The various measures stem from variation in fishing practices and bird behavior. Measures that have been tested experimentally include bird-scaring streamer lines, blue-dyed bait, line shooting, line weighting, night setting, side setting, and underwater line setting (see Løkkeborg [1998] and Gilman et al. [2005] for descriptions of these measures). These measures have been tested in experiments in the North Pacific, Atlantic and Southern oceans (Table 2). We focused on two regions where there has been implementation of seabird bycatch reduction and monitored bycatch following implementation: the demersal longline fishery around South Georgia, managed by the Commission for the Conservation of Antarctic Marine Living Resources (CCAMLR), and the demersal longline fishery in Alaska (U.S.A.). Few cases of mandatory fleet-wide implementation allow for a comparison of bycatch rates pre- versus postimplementation. This is because preimplementation data are often spotty and postimplementation requirements change.

South Georgia

The demersal longline fishery around South Georgia targets Patagonian toothfish (*Dissostichus eleginoides*), and this area also supports large populations of nesting seabirds (Poncet et al. 2006). Anecdotal reports of high seabird bycatch led CCAMLR to require bycatch mitigation measures in 1991 (Scientific Committee—Commission for the Conservation of Antarctic Marine Living Resources [SC-CCAMLR] 1991): (1) sinking of baited hooks as soon as possible after they are put in the water, (2) minimized light use for night sets, (3) no dumping of offal while gear is deployed, and (4) use of streamer lines for day sets (SC-CCAMLR 1991). The first thorough, quantitative assessment of seabird bycatch around South Georgia indicated that a minimum of 5755 birds were killed in 1996 and 1997, primarily Black-browed Albatross (*Thalassarche melanophris*) and White-chinned Petrel (*Procellaria aequinoctialis*; SC-CCAMLR 1998).

In the South Georgia demersal longline fishery, although bird bycatch reduction was not rigorously quantified prior to implementation, the management objective was to sharply reduce seabird mortality. Subsequent experimental testing in many parts of the world demonstrated that mitigation measures used alone or in combination achieve bycatch reduction of 80–100% (reviewed

Table 2. Results of seabird bycatch mitigation experiments with longline gear.[a]

Study[b]	*Measures tested*	*Ocean region*	*Reduction in catch rate (%), control vs. treatment*[c]
Cherel et al. 1996	night setting	S. Indian	100
	strategic offal discharge		91
McNamara et al. 1999	blue-dyed bait	N. Pacific	95
	bird-scaring device (line & buoy)	(Hawaii)	79–88
	strategic offal discard		86
	night setting		97
Boggs 2001	blue-dyed bait	N. Pacific	94
	bird-scaring device (line)	(Hawaii)	76
	line weight (60 g)		92
Melvin et al. 2001	paired streamer lines	N. Pacific	92
	line weighting	(Alaska)	47–76
	underwater line chute (1 m)		80
	night setting		+330
Ryan & Watkins 2002	underwater line chute (1–2 m)	sub-Antarctic	68
Gilman et al. 2003*a*	underwater line chute (9 m)	N. Pacific (Hawaii)	95
Boggs 2003	night setting	N. Pacific	93
	night setting with dyed bait	(Hawaii)	99
Gilman et al. 2003*b*[d]	underwater line chute (9 m)	N. Pacific	82
	underwater line chute (6.5 m)	(Hawaii)	87
	blue-dyed bait		60
	side setting		99
Løkkeborg 2003[e]	bird-scaring device (line)	N. Atlantic	98–100
	line shooter		60
	underwater line chute (1 m)		72–92

[a] *Adapted and updated from Gilman et al. (2005).*
[b] *The Japanese Research Fishing Agency has conducted tests of blue-dyed bait; nevertheless, numerical results have not been released (Gilman et al. 2005). Other experiments on underwater line-setting chutes and line weighting have been conducted by Barnes and Walshe (1997), O'Toole and Molloy (2000), Robertson et al. (2003), and Wienecke and Robertson (2004), but because their efficacy was reported as sink time, their results could not be included in the table.*
[c] *When available, these values are included as normalized for bird abundance.*
[d] *These measures were retested in 2006. Side setting of longlines had the lowest relative bycatch rates among the four measures tested.*
[e] *This includes results from three experiments (Løkkeborg 1998; Løkkeborg 2001; Løkkeborg & Robertson 2002).*

by Brothers et al. 1999; Melvin et al. 2004; Gilman et al. 2005).

Compliance was low during the initial years of implementation (Croxall & Nicol 2004). Recognizing the magnitude of seabird bycatch and observed population declines, CCAMLR closed fishing when birds were breeding and continued requiring that mitigation measures be used by all vessels at all times (Kock 2001; Croxall & Nicol 2004).

Although the basic set of required mitigation measures has remained the same, CCAMLR has sought higher performance standards since 1991 (CCAMLR Conservation Measure 25-02). Fishery license conditions now require scientific observers on every vessel and frequent inspections by South Georgia government fishery officers. Seasonal closures and improved compliance reduced seabird bycatch mortality to 640 in 1998 and 210 in 1999; it has not exceeded 30 since 2000 (Croxall & Nicol 2004; SC-CCAMLR 2005). The number of birds caught per 1000 hooks declined from 0.57 in 1992 and 1993, to 0.23 in 1997, and to 0.0003–0.0020 during 2000–2005 (Ashford et al. 1994; SC-CCAMLR 2005). From 1992 to 2005, the bycatch rate dropped over 99%.

Several factors contributed to such dramatic effectiveness. First, CCAMLR maintains an active dialog between scientists and industry, so industry was aware of, and worked to abate, bycatch problems. Second, compliance incentives were high. The Patagonian toothfish fishery is highly profitable, so the industry is keen to continue fishing and therefore follow license requirements. In addition, bait and hooks lost to seabirds are not available to catch fish, which creates an economic incentive to reduce seabird bycatch. Third, the longline fishing fleet off South Georgia includes no more than 19 vessels, facilitating effective monitoring and enforcement (SC-CCAMLR 2005). Finally, simultaneous use of several measures likely contributed to bycatch reduction success. Vessels failing to comply with every mitigation measure are still likely to use some measures. Although not every vessel fully complied at all times in South Georgia, seabird mortality level was negligible during 2000–2005 (SC-CCAMLR 2005).

Alaska

The demersal longline fishery in Alaska consists generally of two fleets targeting sablefish (*Anoplopoma fimbria*) in the Gulf of Alaska and Pacific halibut (*Hippoglossus stenolepsis*) and Pacific cod (*G. macrocephalus*) around the Aleutian Islands and in the Bering Sea. This fishery killed between 9,000 and 26,000 seabirds annually during 1993–2001 (NMFS 2006), mostly Northern Fulmars (*Fulmarus glacialis*, 69%) and gulls (*Larus* spp., 16%). The fishery also caught albatrosses (*Phoebastria* spp. 9%) and shearwaters (*Puffinus* spp., 4%; Melvin et al. 2001). The NMFS, working in collaboration with the fishing industry, first implemented bird avoidance measures in 1997 (U.S. Department of Commerce 1997*b*). Fishers were required to use one or more bycatch-reduction measures, including setting the gear subsurface, fishing at night, towing streamer lines, and using a towed buoy or comparable device. Vessels were required to use baited hooks that sink as soon as they enter the water, and discharge offal in a manner that reduces seabird bycatch (i.e., move the offal chute to the side of the vessel opposite gear deployment, or behind the haul station; U.S. Department of Commerce 1997*b*).

As in South Georgia, no preimplementation experiments were conducted. Nevertheless, in 1999 the NMFS, U.S. Fish and Wildlife Service, Pacific Fisheries Management Council, and researchers from the University of Washington initiated a 2-year program to test the effectiveness of bycatch deterrents (Melvin et al. 2001). In the sablefish fishery paired streamer lines reduced seabird bycatch by 92%. Adding weight to lines reduced seabird bycatch by 47% (without simultaneous surface deterrent such as streamer lines). In the Pacific cod fishery underwater lining tubes that set the gear 1 m below the surface reduced bycatch by 80%. Additional line weighting reduced bycatch by 76% (Melvin et al. 2001). In 2004 the Fisheries Service began requiring paired streamer lines of specified standard for vessels larger than 55 feet. The U.S. Fish and Wildlife Service makes free streamer lines available to fishing operators.

Estimated annual bycatch has dropped from between 9,000–26,000 birds in 1993–2001 to 4,000–6,000 in 2002–2004. Bycatch rates (birds per 10,000 hooks) dropped an average of 80% from 0.051–0.127 prior to mitigation measures to 0.015–0.017 after implementation (NMFS 2006).

The key component of the successful bycatch reduction in the Alaska demersal longline fishery is industry involvement from the conception stage all the way through to the regulatory stage. Researchers worked closely with fishers to identify practical solutions likely to reduce bycatch, test those solutions, and collaborate on legislation (Melvin & Parrish 2003).

Efficacy of Bird Deterrents

Despite the difficulties arising from lack of preimplementation data, evidence suggests that bycatch avoidance measures have reduced bycatch significantly in both Alaska and South Georgia. This is likely due to several factors: fishers had a suite of measures with which to comply (if they did not comply with one, they were more likely to comply with others); scientists, managers, and fishers have maintained an active dialog in implementation of these measures; and fishers have economic incentives to comply with regulations. It is unclear which measures have been most effective; nevertheless, this suite of measures has proven effective on implementation.

Lessons Learned

In each of the three case studies, three themes emerge: collaboration, monitoring, and compliance (via enforcement and incentives). Fishers, resource managers, and scientists worked together to develop gear technology or fishing practices that effectively reduced bycatch. Successful implementation depended on continued communication, education, and outreach through the implementation stages. In the example of the California pinger, an initial lack of compliance led to workshops and revised regulations that increased effectiveness dramatically. Similarly, in the Queensland prawn fishery, continued collaboration between researchers and industry and the flexibility in the regulations has steadily increased the use of TEDs and thus decreased bycatch of sea turtles. Finally, in the Alaska demersal longline fishery, fishers' involvement throughout every stage of mitigation development, testing, and implementation aided in successful bycatch reduction.

Our review was limited by the lack of comparable pre- and postmonitoring information in almost all cases. The only case for which complete data existed was the pinger case study. Although ample postimplementation data are available for the Australian prawn fisheries, the U.S. shrimp trawl fishery lacks directly observed postimplementation data. In the absence of direct bycatch observation, we made assumptions of TED effectiveness based on strandings data, which is not an accurate quantitative proxy for effectiveness. In addition, the seabird case study lacked preimplementation bycatch monitoring.

Postimplementation monitoring is critical for understanding why mitigation measures may lose effectiveness in operational fisheries. For pingers in the Gulf of Maine gear malfunction may account for some of the efficacy loss. In contrast, the increased pinger efficacy in the California gill-net fishery coincided with increased efforts by observers to monitor pinger functionality. In the U.S. TED example the lack of direct documentation of the number and sizes of turtles caught in nets with TEDs has hampered identification of problems with the devices. For example, in the United States, 17 years elapsed from when TEDs were first required to when they were designed to fully protect adult loggerheads due in part to a lack of observer data. Changes to the opening size of TEDs were made based mostly on data from stranded turtles (Epperly & Teas 2002).

Compliance, essential for bycatch reduction, depends heavily on enforcement and/or incentives. When enforcement is low, compliance and thus mitigation effectiveness is low, as in the Gulf of Maine harbor porpoise and Gulf of Mexico sea turtle examples. Nevertheless, in South Georgia, the small fleet size facilitated adequate enforcement and monitoring, resulting in high compliance and concomitant reduction in bycatch. Monitoring gear maintenance, compliance, and outreach is far more tractable in smaller fisheries. Smaller fisheries such as South Georgia and California–Oregon drift-net fisheries have experienced more success than larger fisheries such as the U.S. trawl and Gulf of Maine gill-net fisheries. The U.S. TED example also clearly indicates that regulations alone are insufficient to reduce bycatch to targeted levels. Given this finding, the U.S. requirement for TED certification from nations wanting to import shrimp to the U.S. is unlikely to succeed without monitoring and compliance standards.

These examples also point to the importance of incentives. In the seabird case study, economic incentives (bait loss to birds) may facilitate compliance. Potential loss of fishing access is a strong incentive. In the seabird examples compliance was facilitated by temporary or potential closures. For the highly profitable U.S. and CCAMLR demersal fisheries, the potential loss of fishing access likely explains some of the industry's cooperation and voluntary gear implementation.

Transferring the efficacy of mitigation measures from experimental field trials to operational fisheries has been met with varying degrees of success. In those fisheries where it has been successful, some common themes emerge: long-standing collaboration of the fishing industry, scientists, and resource managers; education and outreach; pre- and postimplementation monitoring; enforcement; and incentives. These key ingredients can lead to reduced bycatch of vulnerable species.

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