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REVIEW AND ASSESSMENT OF MITIGATION MEASURES TO REDUCE INCIDENTAL CATCH OF SEABIRDS IN LONGLINE, TRAWL AND GILLNET FISHERIES

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REVIEW AND ASSESSMENT OF MITIGATION MEASURES TO REDUCE INCIDENTAL CATCH OF SEABIRDS IN LONGLINE, TRAWL AND GILLNET FISHERIES

by
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FOOD AND AGRICULTURE ORGANIZATION OF THE UNITED NATIONS
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PREPARATION OF THIS DOCUMENT

This paper reviews technical and management mitigation measures that reduce the incidental catch of seabirds in longline, trawl and gillnet fisheries, and their fishery suitability in terms of efficiency and practical applicability.

This paper was prepared in support of effective implementation of the International Plan of Action for Reducing Incidental Capture of Seabirds in Longline Fisheries.

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ABSTRACT

Growing concerns have been raised about incidental capture of seabirds in various types of fisheries. Most attention has been given to bycatches of albatrosses in the longline fisheries of the southern Ocean. This report describes technical and management mitigation measures that have been tested in longline, trawl and gillnet fisheries, and critically reviews their fishery suitability in terms of efficiency and practical applicability. It is emphasized that studies based on observer data must be interpreted with caution, and the only way to determine the effectiveness of a mitigation measure is to apply an experimental approach including a control treatment without any mitigation device.

There is no single solution to mitigate incidental seabird mortality in longline fisheries, and this review gives strong evidence that the efficiency of a mitigation measure is specific to each fishery. However, there is potential for considerable reductions in seabird mortality rates in all longline fisheries by employing appropriate and effective mitigation measures. In the Northern Hemisphere, where northern fulmar is the dominant seabird captured, streamer lines have proved to be very efficient in demersal fisheries. In the Southern Hemisphere, night setting has shown to be an efficient mitigation measure, and this measure should be used in combination with other measures such as streamer lines and longlines with integrated weight when fishing in areas inhabited by nocturnal and diving seabirds.

Although few studies have been conducted in trawl fisheries, results indicate rare interactions between seabirds and trawl gear at times of no offal discharge. Studies reported to date suggest that no-discharge policy and ban of netsonde cables would virtually eliminate seabird mortality. During trawling carried out under offal discharge, streamer lines proved to be an efficient mitigation measure. Studies in gillnet fisheries are very scarce, and development of seabird mitigation measures for this gear type is in its infancy.

Future research on seabird mitigation measures in longlining should apply an experimental approach to fine-tune the most promising mitigation measures for each specific fishery. Mitigation measures have been tested in only a few trawl and gillnet fisheries, and this work needs to be expanded to other areas where interactions with seabirds occur. Promising measures have been identified for trawls but not for gillnet fisheries.

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INTRODUCTION

The general impacts of fishing activities on the marine ecosystem are gradually receiving more attention (Gislason, 1994). In addition to removing large biomasses of exploited marine species, fishing causes mortality of non-target species of benthos, fish, seabirds, sea turtles and marine mammals. Interactions between seabirds and fisheries have existed since humans first went to sea to catch fish. More recently, growing concerns have been raised about the numbers of seabirds that are incidentally killed in various types of fishing activities. Most attention has been given bycatches of albatrosses in the longline fisheries of the Southern Ocean (Brothers, 1991; Cherel, Weimerskirch and Duhamel, 1996; Weimerskirch, Brothers and Jouventin, 1997). Field and modelling studies have shown that many southern albatross populations are in decline, and longline-induced mortality is regarded to be an important factor contributing to this decline (Weimerskirch and Jouventin, 1987; Croxall *et al.,* 1990; Moloney *et al.,* 1994; Prince *et al.,* 1994; Poncet *et al.,* 2006).

Although reports on incidental capture of albatrosses, large petrels and other seabird species in longline fisheries are numerous (e.g. Brothers, 1991; Gales, Brothers and Reid, 1998; Løkkeborg, 1998; Brothers, Cooper and Løkkeborg, 1999; Boggs, 2001; Gilman, Boggs and Brothers, 2003), and this mortality may constitute a severe threat to many seabird populations, it is difficult to attribute population declines to a specific factor. The marine environment is subject to much natural variation, and thus provides a noisy background for observing changes that can be directly attributed to fishing activities (Gislason, 1994). Most populations undergo large natural fluctuations, which make it difficult to separate the effects of fishing from changes due to environmental factors and other anthropogenic events. Furthermore, accurate information on the numbers of birds killed is difficult to obtain (Wienecke and Robertson, 2002), and estimates of annual fishing-induced mortality are poor because bird captures are rare and observations are few. As an example, authors are often referring to the estimate by Brothers, 1991 of 44 000 albatrosses killed annually in the Southern Ocean by the Japanese tuna longline fishery alone (Moloney *et al.,* 1994; Cherel, Weimerskirch and Duhamel, 1996; Weimerskirch, Brothers and Jouventin, 1997). However, this estimate is an extrapolation based on only 45 birds observed caught in one single region and season.

Irrespective of the actual number of seabirds caught in a fishery and the consequent population level effects, it is not consistent with the principles of ecologically sustainable management for fisheries to take large numbers of seabirds (Løkkeborg and Robertson, 2002). The FAO Code of Conduct for Responsible Fisheries promotes the maintenance and conservation of biodiversity by minimizing fisheries impacts on non-target species. Fortunately, several mitigation measures capable of reducing the likelihood of seabird bycatches have been described (Brothers, Cooper and Løkkeborg, 1999; Sullivan *et al.,* 2006). As well as being efficient in minimizing bird capture, mitigation measures should be practical and easy to implement in commercial fishing, enforceable, cause no loss of target catch, and provide fishermen with incentives to employ them (Gilman, Boggs and Brothers, 2003; Gilman, Brothers and Kobayashi, 2005). In longlining, incidental seabird bycatch is a twofold problem as it also reduces gear efficiency and profitability due to the associated loss of baits to seabirds. Reduced seabird interactions should cause increased bait retention and thus provide the incentive of achieving higher target catch rates.

Several studies have been carried out to develop, test and improve different types of seabird avoidance methods. This work has partly been initiated and encouraged by FAO International Plan of Action for Reducing Incidental Catch of Seabirds in Longline Fisheries (IPOA–Seabirds). The objective of the IPOA–Seabirds is to encourage countries with longline fisheries where interactions with seabirds occur to adopt a national plan for reducing this problem. The twenty-seventh session of the Committee on Fisheries in 2007 agreed that the IPOA–Seabirds should be extended to other relevant fishing gear.

This paper describes technical and management mitigation measures developed to reduce the incidental catch of seabirds in longline, trawl and gillnet fisheries, and critically reviews their fishery suitability in terms of efficiency and practical applicability. The focus is on longline fisheries where most studies have been carried out, but trawl and gillnet fisheries are also included because these fishing practices may cause significant seabird mortality in some regions and promising mitigation measures have been developed and tested (Melvin, Parrish and Conquest, 1999; Sullivan, Reid and Bugoni, 2006; Sullivan et al., 2006).

CAUSES OF MORTALITY IN LONGLINE, TRAWL AND GILLNET FISHERIES

When longlines are set, the baited hooks float on the surface for a short while before they start sinking. During this period baited hooks are available to foraging seabirds attracted to the fishing vessel. Seabirds are killed during the line setting operation when they attack and seize baited hooks, become hooked in the bill or body and drawn underwater by the sinking longline. Seabird species capable of diving to several meters depth, may also seize baited hooks during the first part of the sinking phase. More seldom seabirds may become hooked when longlines are hauled (Brothers, Gales and Reid, 1999). Birds hooked during line hauling are less likely to sustain lethal injuries and may be released alive with careful handling.

In trawl fisheries, high levels of seabird mortality have been associated with collisions between seabirds and netsonde cables (Bartle, 1991; Weimerskirch, Capdeville and Duhamel, 2000). This cable is an electronic connection between the vessel and the echosounder on the headline of the trawl. Today the use of this equipment is banned in several regions. More recent works have demonstrated that contacts with the warp cables may also cause significant levels of seabird mortality (Sullivan, Reid and Bugoni, 2006). A third source of mortality is caused by birds diving into the trawl and becoming entangled in the meshes when they are trying to seize fish. This source of mortality is more frequent in trawl fisheries targeting small fish that are more easily ingested by seabirds (Weimerskirch, Capdeville and Duhamel, 2000).

In gillnet fisheries, mortality occurs when diving seabirds encounter gillnets and become entangled in the net. Seabird bycatch has been documented in coastal and high-seas fisheries, as well as in drift and demersal gillnet (Melvin, Parrish and Conquest, 1999; Trippel *et al.*, 2003). Seabirds may be caught also in gillnets set deeper than their maximum diving depth as seabirds may encounter nets as they are set or hauled.

CATEGORIES OF MITIGATION MEASURES

Mitigation measures for longline fishing have been classified somewhat differently, but can be divided into four main categories:

1. Avoid fishing in areas and at times when seabird interactions are most likely and intense (night setting, area and seasonal closures).
2. Limit bird access to baited hooks (underwater setting funnel, weighted lines, thawed bait, line shooter, bait-casting machines, side-setting).
3. Deter birds from taking baited hooks (streamer (bird-scaring) lines, acoustic deterrents, water cannon).
4. Reduce the attractiveness or visibility of the baited hooks (dumping of offal, artificial baits, blue-dyed bait).

A comprehensive review of seabird mitigation measures in place, being tested or recommended for reducing incidental catch of seabirds in longline fishing is given by Brothers, Cooper and Løkkeborg, 1999.

Mitigation measures tested in trawl fisheries are few. They are all based on the principle of deterring birds from coming into contact with the warp, paravane or netsonde cables, which are the parts of the trawl that cause the majority of seabird deaths (Weimerskirch, Capdeville and Duhamel, 2000; Sullivan, Reid and Bugoni, 2006).

Technological mitigation measures tested in gillnet fisheries are also few. Two methods have been proposed and tested to alert seabirds to the presence of gillnets and thereby avoid collision (Melvin, Parrish and Conquest, 1999). One method is to increase the visibility of the net (visual alerts), and the other method is to attach pingers to the net (acoustic alerts). Encounters with gillnets may also be reduced by setting nets deeper than the diving depth of seabirds.

DESCRIPTION OF MITIGATION MEASURES

Longline fisheries

This section gives a description of different mitigation measures. Only measures that have been developed, tested and proved to have potential in reducing incidental capture of seabirds are included. Additional mitigation measures that have been proposed but not been tested or proved inefficient are described by Brothers, Cooper and Løkkeborg (1999) and Bull (2007).

Avoid fishing in areas and at times when seabird interactions are most intense – As seabird mortality in longline fisheries is related to the feeding activity of the birds, mortality rates will vary with area and season, and have been shown to be higher close to breeding colonies (Moreno *et al.*, 1996; Nel, Ryan and Watkins, 2002) and during breeding seasons (Ashford and Croxall, 1998; Nel, Ryan and Watkins, 2002; Reid *et al.,* 2004). Avoiding fishing activities close to breeding colonies during the breeding season, i.e. area and seasonal closures, therefore reduces the number of foraging seabirds congregating around the fishing vessels.

Night setting – Most seabirds are visual feeders and forage during daylight hours. Therefore, setting longlines at night reduces the number of birds attacking baited hooks. Night setting also reduces the ability of seabirds to see and seize baits.

Streamer line (bird-scaring line, tori line) – A line attached to a high point at the stern and towed behind the vessel while longlines are set (Figure 1). The end of the line has a towed device (e.g. buoys) to create tension and streamers are attached to its aerial portion above the sinking longline. The movements of the streamers deter seabirds from attacking baited hooks.

Weighted lines – Longlines with added weights sink faster and thus reduce the time they remain close to the surface and are available for seabirds to seize baits. Extra weight can be added to longlines either by attaching (i.e. tying) external weights to the mainline, or by including strands of lead inside each of the strands of the mainline (integrated weight line).

Underwater setting funnel (chute) – A stern-mounted tube through which the baited hooks are set (Figure 2). This device delivers baited hooks underwater, thereby reducing the time they remain close to the surface and are visible and within the reach of seabirds. Both the mainline and the branchline are set through the underwater setting funnel developed for demersal longlining, whereas in pelagic longlining, only the branchline and the hook are fed through the device (named the “chute”). The chute designed for pelagic longline vessels deliver baited hooks deeper (4–5 m) than the funnel used by demersal vessels (1–2 m). A second emerging method for setting pelagic longlines is the underwater setting capsule. The baited hook is placed in a capsule that carries it underwater where it is released. The capsule is then returned on board to be loaded with the next hook.

Line shooter – This device is designed to set longlines without tension. During traditional setting, lines are set with tension, which is believed to delay line sinking and keep baits available to birds for longer compared to lines set with slack. A line shooter consists of opposing rubber and metal sheaves through which the line is pulled at a constant speed slightly faster than the vessel speed during line setting.

Bait-casting machine (bait thrower) – This device is used only in pelagic longlining to prevent entangling of the long branchlines with the mainline. Bait-casting machines throw baited hooks to the side far outside propeller wash and hull turbulence. Throwing baits into the propeller wash is likely to cause delayed line sinking.

Side setting – Side setting, as opposed to traditional stern setting, reduces the time baited hooks remain within the reach of seabirds due to two factors. First, side-set longlines are set to the side of the propeller wash thereby increasing the sink rate. Second, lines set at the side of the vessel enter the water several meters in front of the stern and thus commence sinking sooner and are deeper when they emerge clear of the vessel.

Strategic offal discharge – Homogenized offal is more easily accessible and thus attractive to seabirds than baits. Dumping of offal may therefore reduce incidental bird capture by attracting birds away from the baited longline to the area to the side of the vessel where the dumping occurs.

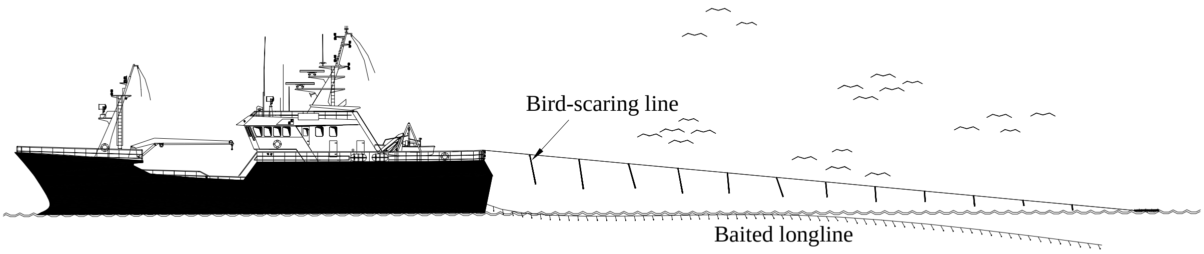

Figure 1. The streamer (bird-scaring) line (redrawn after Løkkeborg, 1998)

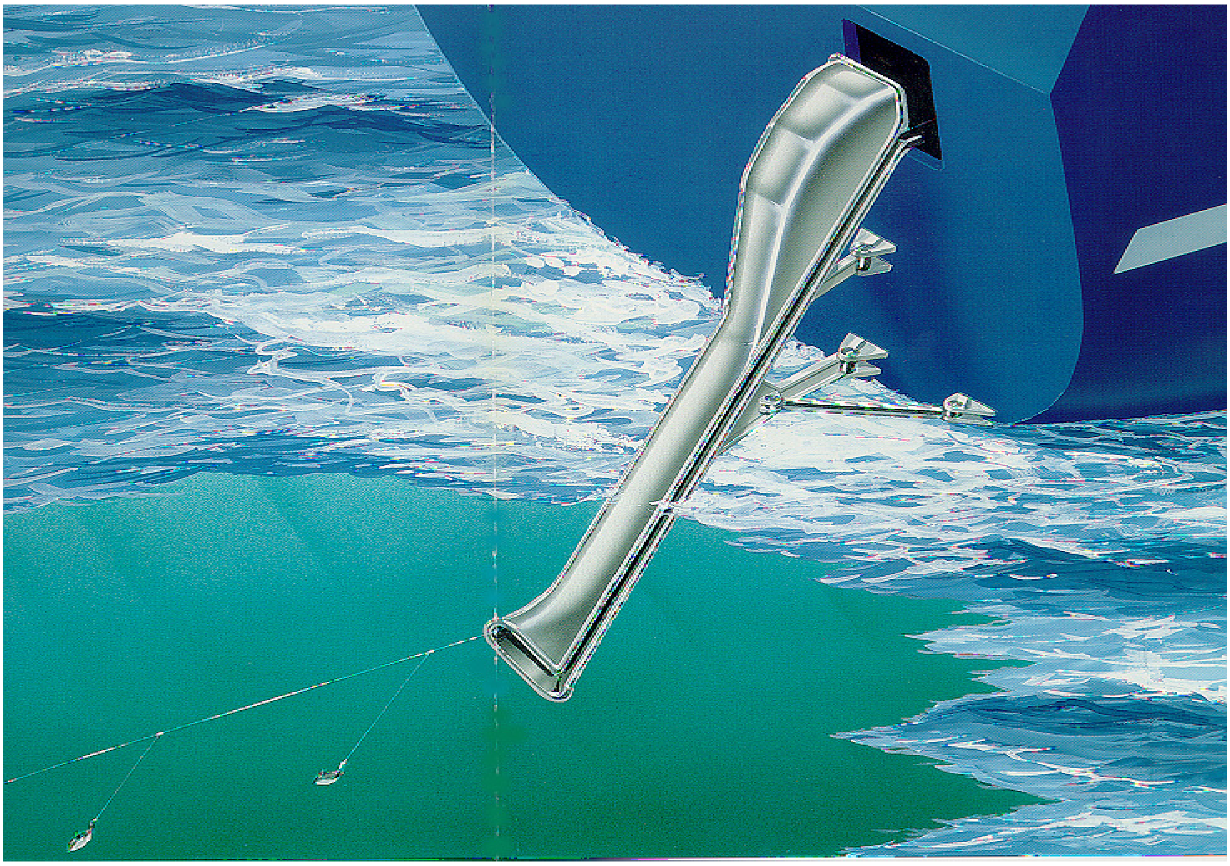

Figure 2. The setting funnel (redrawn after Løkkeborg, 1998)

Blue-dyed bait – Baits dyed blue are less visible to seabirds with blue ocean as background. These baits will become invisible to seabirds at shallower depth and therefore sooner than baits with clearer contrast.

Closure of areas and fishing time limitation – May affect the efficiency of the fishing operation. Therefore it is recommended that both, management mitigation measures and technical mitigation measures are introduced in a balanced matter. This mitigation method is only applicable in fisheries where line setting is short and allows dumping throughout the setting operation.

Description of mitigation measures in trawl fisheries

Studies to determine the effectiveness of seabird mitigation measures in trawl fisheries are scarce, and accordingly few mitigation devices have been developed and tested. This review has identified only three such devices, which all have been described and tested by Sullivan *et al.* (2006).

Streamer line – This mitigation method is similar to the streamer lines used on longliners. To adapt these for use on trawlers and deter seabirds from collision with the warp cables, streamer lines are suspended on each side of the warps.

Warp scarer – This device consists of a series of rings joined by a length of netting forming a hose around the aerial part of the warp. Streamers hang from each ring to the sea surface, deterring seabirds from colliding with the warp.

Brady baffler – The baffler is design to prevent seabirds scavenging for offal from congregating at the stern where the warp cables enter the water. It is attached to each of the two quarters of the stern gantry and consists of two horizontal steel arms, one aft of the stern and one outboard. Ropes with plastic cones at the seaward end hang from the arms.

Figures and detailed descriptions of these mitigation devices are given in Sullivan *et al.* (2006).

Description of mitigation measures in gillnet fisheries

Very few mitigation measures have been tested in gillnet fisheries. This review identified only two technological solutions and one case where gear operation was altered in an effort to reduce seabird bycatch (Melvin, Parrish and Conquest, 1999; Trippel *et al.,* 2003).

Visual alerts – Traditional gillnets are modified with visual alerts to increase their visibility, e.g. by dying the nets with an opaque colour. Seabirds should be able to detect these nets at longer distances and may thus avoid collision and entanglement however, increased visibility of gillnets may also lead to reduced catches.

Acoustic alerts – Acoustic pingers that emit a sound signal within the hearing frequency of seabirds are attached to traditional gillnets. The sound signal serves to scare off seabirds from gillnets.

Subsurface setting – Setting gillnets at greater depth could potentially reduce seabird interactions and bycatch.

METHODOLOGICAL CONSIDERATIONS

The effectiveness of different mitigation measures to reduce incidental catches of seabirds has been determined by using two approaches. One is based on observer data and relates seabird bycatch rates recorded by observers to their notes on factors such as type of mitigation measure used (e.g. streamer line), time of setting (day/night), lunar phase, season and area fished. The other approach applies an experimental design to compare seabird catch rates of longline sets using mitigation measures with those of sets with no mitigation device (control).

Unfortunately, there are few, if any, comprehensive studies in pelagic longline fisheries using an experimental approach to compare the effectiveness of different mitigation measures. The problem of applying an experimental approach to test mitigation measures in pelagic longlining is that seabird capture in most of these fisheries is a rare event, which also is the case for several demersal fisheries, and large numbers of hooks have to be set in order to obtain conclusive results. Some of the studies reviewed below therefore used number of contacts between baited hooks and seabirds or rate of bait loss as an alternative measure to evaluate the effectiveness of mitigation devices. Furthermore, an experimental approach should include a control treatment where lines are set without any mitigation device, which would increase the risk of catching endangered and threatened species such as albatrosses. This is the only way to determine the effectiveness of a mitigation measure, and one simply needs to catch and kill a few seabirds to develop the most effective measures that are capable of saving thousands of birds.

Due to the concern and problems discussed above, most studies in pelagic longline fisheries, and also several studies in demersal fisheries in the southern Ocean, are based on observer data. Seabird catch rates obtained from such data are affected by several variables, and some variables may be correlated to others, or their effect may be influenced by the presence of other variables. For example, analyses of observer data from Japanese tuna longline vessels operating in the Australian Fishing Zone (1991–1995) showed higher seabird catch likelihood when a bird-scaring line was in use than when not in use (Brothers, Gales and Reid, 1999). This unexpected result was due to the fact that use of bird lines are more prevalent in areas and seasons with typically higher seabird catch rates, as well as not being used at night when the catch rate is low. Thus, analyses of the effects of single variables may be problematic and even misleading, and any results of observer data analyses must be interpreted with caution.

Furthermore, fisheries observers usually collect data on seabird catches incidentally to their main work and normally do not record all sets (Brothers, Gales and Reid, 1999). Thus there is need for an appropriate level of observer coverage of dedicated seabird observers specifically tasked to collect reliable seabird bycatch data.

STUDIES ON MITIGATION MEASURES IN LONGLINE FISHERIES

Demersal longlining

Table 1 gives an overview of mitigation studies conducted in demersal longlining. The most promising and widely tested mitigation measure in demersal longlining is the streamer line. Comprehensive studies testing the efficiency of this device have been conducted on commercial vessels under typical fishing conditions in longline fisheries in Alaska and in the northeast Atlantic. The longline fisheries in these two regions are similar in terms of gear design, target species and seabirds caught (mostly northern fulmars [*Fulmarus glacialis]* and gulls). In Alaska, however, regulatory and conservation attention is focused on bycatch of the endangered short-tailed albatross (*Phoebastria albatrus*), whereas the northern Atlantic is not inhabited by albatrosses.

A two-year research programme (1999–2000) comparing seabird bycatch mitigation strategies have been carried out in the two major Alaska demersal longline fisheries; the sablefish (*Anoplopoma fimbria*) fishery and the cod (*Gadus marcocephalus*) fishery (Melvin *et al.*, 2001). This research programme tested single and paired streamer lines, weighted lines, setting funnel and line shooter. A total of 1.2 and 6.5 million hooks were set in the sablefish and cod fisheries, respectively, and 113 and 430 seabirds were caught. The primary seabird caught in both fisheries was northern fulmars, but short-tailed shearwaters (*Puffinus tenuirostris*) and Laysan albatross (*Phoebastria immutabilis*) were also caught.

Among the mitigation measures tested, paired streamer lines proved to be the most efficient solution. This device reduced seabird bycatch by 88–100 percent relative to controls with no deterrent. Thus paired streamer lines virtually eliminated the catch of surface foraging seabirds, and they were efficient in all years, regions and fleets despite the fact that seabird bycatches varied by orders of magnitude across years and among regions. Single streamer lines were slightly, but not significantly less effective than paired streamer lines, and reduced seabird bycatch by 71 percent and 96 percent in the cod and sablefish fisheries, respectively.

Table 1. Overview of studies to determine effectiveness of mitigation measures in demersal longline fisheries. The dominant seabird species caught are given (total number of birds in brackets). Data collection indicates whether the study applied an experimental design or was based on observer data (number of hooks recorded in brackets).

Area	Mitigation measures tested	Seabird species captured	Data collection	Reference
Gulf of Alaska, Bering Sea	Streamer line, weighted lines, setting funnel, line shooter	Northern fulmar, short-tailed shearwater, Laysan albatross, (543)	Experimental (7.7 mill)	Melvin *et al.*, 2001
Bering Sea	Streamer line, weighted lines	Northern fulmar, short-tailed shearwater, gulls, (394)	Experimental (13 mill)	Dietrich, Melvin and Conquest, 2008
Northeast Atlantic	Streamer line, setting funnel, line shooter	Northern fulmar, (254)	Experimental (700 000)	Løkkeborg, 1998, 2001; Løkkeborg and Robertson, 2002
Kerguelen, Indian Ocean	Night setting, offal dumping	White-chinned petrel, (38)	Experimental (174 000)	Cherel, Weimerskirch and Duhamel, 1996
Kerguelen, Indian Ocean	Night setting, offal dumping	White-chinned petrel, black-browed and grey-headed albatross, (957)	Observer data (1.6 mill)	Weimerskirch, Capdeville and Duhamel, 2000
Prince Edward Islands, Indian Ocean	Setting funnel, night setting,	White-chinned petrel, Indian yellow-nosed albatross, (114)	Experimental (5.1 mill)	Ryan and Watkins, 2002
Prince Edward Islands, Indian Ocean	Night setting	White-chinned petrel, grey-headed albatross, (1761)	Observer data (23 .2 mill)	Nel, Ryan and Watkins, 2002
South Georgia	Streamer line, area fished, lunar phase, hook size	White-chinned and southern giant petrel, black-browed and grey-headed albatross, (1428)	Observer data (5.3 mill)	Moreno *et al.*, 1996
South Georgia	Night setting, streamer line	Giant and white-chinned petrel, black-browed and grey-headed albatross, (98)	Observer data (206 720)	Ashford *et al.*, 1995
South Georgia	Streamer line	White-chinned petrel, (12)	Observer data (130 936)	Ashford and Croxall, 1998
Falkland Islands	Night setting, season	Black-browed albatross, (29)	Observer data (1.5 mill)	Reid *et al.*, 2004
Falkland Islands	Weighted lines	Black-browed albatross, (25)	Experimental (Not given)	Robertson, 2001
South Georgia	Weighted lines	Black-browed albatross, white-chinned petrel, (85)	Experimental (72 396)	Agnew *et al.*, 2000
New Zealand	Weighted lines	White-chinned petrel, sooty shearwater, (185)	Experimental (1.1 mill)	Robertson *et al.*, 2006
South Africa	Night setting, lunar phase	White-chinned petrel, (28)	Observer data (58 000)	Barnes, Ryan and Boix-Hinzen, 1997
Mediterranean	Night setting, lunar phase, season	Cory’s shearwater, (17)	Observer data (48 724)	Belda and Sanchez, 2001; Sanchez and Belda, 2003

Adding weight to the longlines reduced seabird bycatch relative to the control by 37 percent in the sablefish fishery and by 76 percent in the cod fishery. The setting funnel (tested only in the cod fishery) reduced seabird bycatch to similar level (79 percent) as that of line weighting. The line shooter caused increased rates of seabird bycatch.

A similar research program has been conducted in the northeast Atlantic on Norwegian commercial autoliners during four experimental cruises (Løkkeborg and Bjordal, 1992; Løkkeborg, 1998, 2001; Løkkeborg and Robertson, 2002). The results obtained in this programme are summarized and reviewed by Løkkeborg (2003). Three mitigation measures (streamer line, underwater setting funnel and line shooter) were tested, and a total of nearly 700 000 hooks were set. Almost all seabirds caught (254 in total) in these experiments were northern fulmars.

The mitigation measures tested in these experiments were all capable of reducing incidental catches of seabirds in the northeast Atlantic longline fishery. Also in these experiments, the streamer line proved to be the most efficient device, and virtually eliminated seabird catches. In the course of the experiments, only two birds were caught when a total of 185 000 hooks were set using the streamer line compared with 205 birds for controls with a similar number of hooks and with no mitigation device (99 percent reduction). The two birds were hooked under strong side wind that will bring the streamer line out of its ideal position right above the baited longline.

The underwater setting funnel reduced seabird bycatch by 72 percent and 92 percent in the two cruises where this device was tested. Differences in pitch angle due to the loading of the vessel and thus differences in the submerged depth of the funnel are the most likely explanation for this difference in performance (Løkkeborg, 2001). Seabird bycatch was reduced by 59 percent for longlines set with the line shooter, although this difference was not statistically significant (Løkkeborg and Robertson, 2002).

The Patagonian toothfish (*Dissostichus eleginoides*) fishery is the third important demersal longline fishery to draw conservation concern due to its interactions with seabirds. In an experiment conducted in Kerguelen waters (South Indian Ocean), the effect of dumping offal during line settings was investigated (Cherel, Weimerskirch and Duhamel, 1996). Lines were set from the right side of the stern and homogenized offal was piped overboard from the left side. Only one seabird was caught during 41 longline settings with concomitant release of homogenized offal compared with 33 birds (31 white-chinned petrels [*Procellaria aequinoctialis*], 2 grey-headed albatrosses [*Diomedea chrysostoma*] during 28 settings without the release of offal (98 percent reduction). Mortality rate was reduced by 62 percent when lines were set at night compared with lines set during daylight hours. At night, the mortality rate was 75 percent lower when the powerful decklights were off.

Seabird mortality data were collected by trained observers on board four longliners operating in Kerguelen waters during four successive fishing seasons, 1994–1997 (Weimerskirch, Capdeville and Duhamel, 2000). White-chinned petrel was the dominant species caught (879 of a total of 957 birds) followed by black-browed albatross (*Diomedea melanophris*) (35) and grey-headed albatross (31). Night setting reduced mortality of white-chinned petrels by 81 percent from 0.91 birds/1 000 hooks during the day to 0.17 birds/1 000 hooks at night. Only one of a total of 78 albatrosses was caught on longlines set at night. Consequently, total seabird mortality decreased considerably in this fishery after day setting was banned. Dumping of offal during line setting reduced the mortality of white-chinned petrels by 54 percent.

The effectiveness of an underwater setting funnel in reducing incidental mortality of seabirds was investigated separately for day and night sets in the Patagonian toothfish fishery off the Prince Edward Islands (Ryan and Watkins, 2002). The bycatch rates using the setting funnel were three times lower than when the funnel was not used both for night and for day sets. Seabird bycatch rates were lower at night than during the day both for sets using the funnel and for sets without the funnel. The relative efficiency of these mitigation measures was, however, different for petrels and albatrosses. The results indicated that night setting was most effective for reducing incidental catch of albatrosses, whereas the setting funnel was the more efficient measure for petrels.

Factors affecting seabird bycatch levels in the Patagonian toothfish fishery around the Prince Edward Islands were analysed based on observers' data collected over a four-year period (1996–2000) (Nel, Ryan and Watkins, 2002). Nearly all seabirds killed were caught during their breeding seasons. Albatrosses and giant petrels (*Macronectes* sp.) were caught almost exclusively during day sets, whereas catch rates of white-chinned petrels (by far the most frequently hooked species) were similar during day and at night. During the course of the study, seabird bycatch rates decreased from 0.19 to 0.034 birds per 1 000 hooks, mainly due to implementation of mitigation measures (primarily the requirement to set lines only at night) and movement of the fleet farther away from the islands.

Moreno *et al*. (1996) analysed observer data reporting nearly all of the incidental capture of seabirds in the Patagonian toothfish fishery around South Georgia (Southwest Atlantic) during the 1995 season. These analyses were based on 5.3 millions hooks set and 1428 seabird killed, mainly white-chinned petrel (77.8 percent), southern giant petrel (*Macronectes giganteus*) (10.8 percent) and black-browed albatross (8.1 percent). The authors identified four factors related to the incidental mortality, but unfortunately, figures on the magnitude of these effects are not given. Vessels operating closer to South Georgia had higher incidental mortality than vessels fishing further off the island. Mortality rates were less than 0.1 birds per 1 000 hooks for vessels using streamer line compared to more than 0.3 birds for vessels without streamer line. In night sets, longlines set around the time of a full moon resulted in significantly more birds being caught than those set during the new moon phase. A significant inverse relationship was shown between seabird mortality and hook size (gap), and the authors suggested that hooks larger than 30 mm in width should be used to reduce incidental mortality.

Seabird interactions with longline operations targeting Patagonian toothfish around South Georgia were recorded by scientific observers (Ashford *et al.*, 1995). A total of 83 birds (85 percent of the overall total) were caught during four sets conducted in daylight compared to 15 birds caught on 16 sets made at night. The only seabird species caught at night was white-chinned petrel, whereas six species of albatrosses and petrels were caught in daylight settings. Although quantifiable data were lacking, mortality rates seemed to be higher when a streamer line not meeting CCAMLR specifications (e.g. the streamers did not reach the surface of the water) was used compared to a streamer line made to these specifications. The authors concluded that nighttime setting most effectively reduced seabird mortality in this study, which would confine the effect to white-chinned petrels only.

A similar study was conducted in this fishery during the 1997 season onboard a longliner using the Spanish double-line system (Ashford and Croxall, 1998). Only 12 seabirds (9 white-chinned petrels) were recorded caught giving an average mortality rate of 0.099 birds/1 000 hooks. This rate was substantially lower than that of other vessels fishing simultaneously around South Georgia and that of the study by Ashford *et al*. (1995) carried out in the 1994 season. The low seabird mortality was explained by the fishing operations being performed according to CCAMLR specifications, i.e. night time setting, decklights off, streamer line, weighted lines and no offal discarded during setting. Under these conditions, no significant increase in seabird mortality was found for experimental settings without employing streamer line. Eleven of the 12 seabirds caught were recorded before 1 May giving a rate of 0.12 and 0.02 birds/1 000 hooks before and after 1 May, respectively. This seasonal decline in mortality rates may be linked to the end of the breeding season for white-chinned petrels and black-brown albatross (the other species caught) on South Georgia (Ashford and Croxall, 1998). Also in this study nighttime setting is suggested as the most efficient mitigation measure.

Reid *et al*. (2004) analysed mortality data collected by seabird observers onboard toothfish longliners operating in Falkland Islands waters during the 2001/02 season. A total of 29 seabirds (27 black-browed albatross, 2 white-chinned petrels) were recorded caught, of which 26 (90 percent) occurred during the breeding season. No birds were observed caught on hooks set at night despite the fact that 38 percent of observed hooks were set during the night. The total mortality rate during the 2001/02 season was estimated at 0.016 birds/1 000 hooks, which is markedly lower than previously reported for the same region. This decline was thought to be the result of more effective use of mitigation measures.

Robertson (2001) measured longline sink rates to derive a line weighting regime that had the potential to eliminate incidental capture of albatrosses by autoline vessels targeting Patagonian toothfish. Longlines with 6.5 kg weights at 35 m and 50 m intervals sank fast, 0.44 and 0.33 m s^{-1} respectively, providing limited opportunity for seabirds to take baited hooks. Asymptotic longline sink rates at 0.10–0.15 m s^{-1} were achieved with weight spacing of 70 m. For autoline vessels using similar gear characteristics as in this experiment and 6.5 kg weights spaced < 50 m (or alternatively 4 kg per 40 m, both giving sink rates > 0.3 m s^{-1}), very low seabird catch rates would be expected when fishing with an effective streamer line (Robertson, 2001). In a similar study, longlines with integrated weight (6–10 mm in diameter, 113–219 g/m in weight) were shown to sink around 2.5 times faster than conventional unweighted lines (5.5–11.5 mm, 36–113 g/m) (Robertson *et al.*, 2003).

Experiments were carried out in the toothfish fishery at South Georgia to examine the effects of different weighting regimes on seabird mortality (Agnew *et al.*, 2000). To increase the likelihood of catching birds and thereby increasing the statistical power of the experiment, longlines were set during the day and a total of 85 birds were caught. The Spanish-rigged longline system (double line method) was used and weights of 4.25, 8.5 and 12.75 kg attached at 40 m intervals were compared. Weights of 8.5 kg gave an 80 percent reduction in bird mortality compared to 4.25 kg (0.8 versus 4.0 birds per 1 000 hooks, respectively). However, 12.75 kg at 40 m intervals gave no further significant reduction.

The potential of longlines with integrated weight to reduce incidental catch of white-chinned petrel and sooty shearwater (Puffinus griseus) were investigated in 2002 and 2003 in the New Zealand ling (Genypterus blacodes) autoline fishery (Robertson *et al.*, 2006). These seabird species are among the most difficult to deter from baited hooks. White-chinned petrels forage day and night (Weimerskirch, Capdeville and Duhamel, 2000) and are capable of diving to at least 13 m (Huin, 1994). Sooty shearwaters are agile flyers and have deep diving abilities (67 m depth; Weimerskirch and Sagar, 1996). Lines with integrated weight (50 g/m beaded lead core, sink rate: 0.24 m s^{-1}) yielded a 94–99 percent reduction in capture of white-chinned petrels and a reduction of 61 percent for sooty shearwaters in comparison to unweighted conventional lines (sink rate: 0.11 m s^{-1}). No albatrosses were caught in these experiments except a single Salvin’s albatross [*Thalassarche salvini*].

Observations on seabird interactions with a longline fishery for hake (*Merluccius* sp.) were made during three 4-day trips on the shelf off South Africa (Barnes, Ryan and Boix-Hinzen, 1997). Greater shearwater (*Puffinus gravis*) and cape petrel (*Daption capense*) were the most abundant seabirds attending the vessels, however, the white-chinned petrel was the only species caught during longline setting. Out of the eight recorded variables that could influence seabird mortality rates, only time of setting and moonlight were important in explaining the variation in the catch rate. The longlines were set at night, and sets completed before the increase in white-chinned petrel activity occurring 2.5 hours prior to sunrise caught less birds than later sets. Thus light intensity explained most of the variation in white-chinned petrel catch rate in this study.

Factors affecting seabird mortality rates in the western Mediterranean were studied based on observations during 105 setting and hauling operations (Belda and Sanchez, 2001; Sanchez and Belda, 2003). Most of the incidental captures of seabirds (mainly Cory’s shearwater Calonectris diomedea) occurred around sunrise, and all capture that occurred before sunrise were in nights with moonlight. Also, about 80 percent of the attempts by seabirds to take bait occurred around sunrise. Accordingly, setting of longlines at night or at mid-day was suggested as an efficient mitigation measure to reduce bait loss and seabird mortality in the western Mediterranean. Incidental captures of seabirds were also related to the breeding cycle with most captures taking place during the chick rearing stage.

Pelagic longlining

Most studies on seabird interactions in pelagic longlining have been conducted in Australian and New Zealand waters (Table 2). Analyses of observer data from Japanese tuna longline vessels operating in the Australian Fishing Zone from 1991 to 1995 showed that fishing season and fishing area strongly influenced seabird catch likelihood (Brothers, Gales and Reid, 1999). Birds were 6.9 times more likely to be caught during summer than winter, and for example the catch likelihood for northeastern

Table 2. Overview of studies to determine effectiveness of mitigation measures in pelagic longline fisheries. The dominant seabird species caught are given (total number of birds in brackets). Data collection indicates whether the study applied an experimental design or was based on observer data (number of hooks recorded in brackets).

Area	**Mitigation measure tested**	**Seabird species captured**	**Data collection**	**Reference**
Australia	Season, area, night setting, lunar phase, thawed bait	Not identified	Observer data (several mill.)	Brothers, Gales and Reid, 1999b
Australia	Season, area, night setting, lunar phase, thawed baits, bait thrower	Not identified, (577)	Observer data (3.3 mill)	Klaer and Polacheck, 1998
Australia	Streamer line, bait throwing	Black-browed, shy and wandering albatross, (45)	Observer data (108 662)	Brothers, 1991
New Zealand	Area, night setting	Grey petrel, wandering, black-browed and southern buller’s albatross, (320)	Observer data (2.3 mill)	Murray *et al.*, 1993
Hawaii	Streamer line, weighted lines, dyed baits	Laysan and black-footed albatross	Experimental (6378)	Boggs, 2001
New Zealand	Setting chute	Sink rates were determined. Effects on seabird capture were not addressed.	Experimental (40)	O’Toole and Molloy, 2000
Hawaii	Setting chute	Laysan and black-footed albatross, (25)	Experimental (10 043)	Gilman, Boggs and Brothers, 2003

Australia was only 11 percent of that in Tasmania. Fewer birds were caught on hooks set at night than those set during the day, with a reduction in catch likelihood of 85 percent. Moreover, birds were 3.6 times more likely to be caught on night set hooks set in bright moonlight condition than on those set when there was no moon light. Due to the problems associated with observer data discussed above, these analyses did not demonstrate reductions in seabird catch rates when either bird scaring lines or bait throwers were in use. When analysing data for the summer season alone, sets with thawed baits showed significantly lower seabird catch likelihood than sets using frozen baits.

A subset of Australian observer data from 1992 to 1995 was analysed in an effort to partly overcome the problems discussed above by for example excluding data from areas with very low seabird catch rates (Klaer and Polacheck, 1998). Also in this analyses time of day, area fished and season were the environmental factors that most affected seabird mortality. The seabird catch rates were 79 percent lower at night than during the day, and night sets during the new moon had 82 percent lower probability of catching seabirds compared to sets made during the full moon. The catch rates in Southern Australia were 9 times higher in Tasmania, and birds were 3 times more likely to be caught during summer than winter. Bait thawing and use of a bait thrower were the most significant mitigation measure, whereas the effect of using bird-scaring line could not be determined because this measure was used in all sets included in the analyses. Both thawing the bait and using a bait thrower reduced seabird catch rates by about 50 percent.

Brothers (1991) collected and analysed more detailed information than normally obtained from observer data. This study showed that bait loss to seabirds was reduced by 69 percent using bird-scaring line. The distance from the port side of the ship that baited hooks were thrown also influenced rate of bait loss. Baited hooks thrown more than 7 m out from the port side of the ship had 80 percent lower bait loss than those thrown less than 7 m.

Murray *et al.* (1993) also collected more detailed information based on observer data from Japanese tuna longline vessels operating in the New Zealand region in 1988–1992. The data analysed comprised 785 longline sets that caught a total of 320 seabirds. Like in Australian waters, capture rates differed between fishing areas. A finer-scale analysis using smaller areas showed that the vulnerability of species differed with fishing areas. The effect of time of day on seabird catch rates differed between areas and distribution of seabirds. In the south, where nearly all birds caught were albatrosses, 73 percent of the birds were caught in daylight. In the north, most birds caught were petrels, and here 42 percent of the birds were caught at night and 44 percent were caught within 1.5 hours of dawn or dusk.

Interestingly, Murray *et al.* (1993) estimated total annual seabird mortality by extrapolating the seabird catch rates in the observer data to the total effort of the Japanese tuna fleet. This analysis indicated that total seabird mortality in New Zealand waters declined from 3 652 in 1988 to 360 in 1992, probably as a result of progressive introduction of mitigation measures with an increased use of bird lines and night fishing.

The Hawaii longline swordfish fishery, which uses shallow-set pelagic longlines, was closed for four years as a result of concerns over incidental capture of sea turtles. The fishery was re-opened in 2004, and is now subjected to strict management measures (e.g. restricted annual effort, 100 percent observer coverage). Boggs (2001) used an experimental approach to determine the effectiveness of streamer lines, addition of weight to the bait and dyeing the bait blue. To prevent seabird mortality, hooks were replaced with net pins to hold the bait, and contact rates between albatrosses and baits were recorded. A contact was defined as an albatross grasping a bait in its beak. To increase the rate of bird encounters, experiments were conducted in daylight near the Northwestern Hawaiian Islands which comprise the primary breeding colonies of black-footed (*Phoebastria nigripes*) and Laysan albatrosses. Baits with added weight and baits dyed blue both reduced the number of contacts with the two albatross species by about 90 percent compared with the control. The streamer line reduced contacts between baits and albatrosses by about 70 percent. Assuming that albatross mortality is proportional to the number of times birds make contact with the bait, this study demonstrated that the three mitigation measures tested have the potential of significantly reducing mortality in the Hawaii longline fishery for swordfish.

The principle of underwater setting methods is to limit seabird access to baited hooks. Time depth recorders (TDRs) were used to determine sink rate of baited branchlines set through a setting chute and branchlines set by the conventional method of hand-throwing (O'Toole and Molloy, 2000). At 100 m astern of the vessel, which was the point where the bird scaring line came in contact with the water, the mean depth of branchlines set through the chute was 8.7 m compared to 5.9 m for branchlines set by hand-throwing. The sink rates were similar for both setting methods, but branchlines set through the chute were on average 2.8 m deeper at any given distance astern the vessel than those that were hand-thrown. Branchlines emerged from the chute at a mean depth of 6.5 m (range: 2.5–10 m), indicating that the potential of the chute to reduce incidental capture is promising (O'Toole and Molloy, 2000). This is deeper than the maximum diving depth of several albatross species (Prince, Huin and Weimerskirch, 1994; Hedd *et al.*, 1997).

The efficiency of the underwater setting chute in reducing seabird mortality has been tested in the Hawaii longline tuna fishery (Gilman, Boggs and Brothers, 2003). The chute tested was 9 m long, and when deployed, 5.4 m of the chute was underwater. In terms of seabird contact rate per 1 000 hooks, the chute was 98 percent effective at reducing albatross contacts with baited hooks compared to the control. Moreover, the chute eliminated seabird capture as no bird were observed caught during setting with the chute, whereas 25 albatrosses (22 Laysan and 3 black-footed albatrosses) were caught without the chute deployed. Bait loss was significantly lower when setting through the chute than when setting without the chute (10 percent versus 31 percent), resulting in savings of 21 percent of bait when using the chute. This suggests that Hawaii tuna longline vessels would benefit from increased tuna catches by employing the chute, which comprises an important economic incentive for fishermen to use mitigation measures.

EVALUATION OF MITIGATION MEASURES IN LONGLINE FISHERIES

Streamer line

CCAMLR was the first management body to implement a conservation measure that required all longline vessels fishing in its convention area to use a streamer line while setting longlines (Conservation Measure 29/X adopted by CCAMLR in 1991). The streamer line has since then become the most commonly applied seabird mitigation measure in longline fisheries throughout the world (Melvin *et al.*, 2004).

All studies applying an experimental approach to test the performance of streamer lines have shown that this mitigation device is very efficient in reducing seabird bycatch and seabird attacks on bait both in demersal (Table 3; Løkkeborg, 1998, 2001; Melvin *et al.*, 2001; Løkkeborg and Robertson, 2002) and pelagic longline fisheries (Brothers, 1991; McNamara *et al.*, 1999 (cited in Gilman, Brothers and Kobayashi, 2005); Boggs, 2001). Several works testing streamer lines are inconclusive, however, these studies were based on observer data, as opposed to a rigourous experimental design, and consequently confounded by a wide array of factors (Murray *et al.*, 1993; Ashford *et al.*, 1994, 1995; Ashford and Croxall, 1998; Klaer and Polacheck, 1998; Brothers, Gales and Reid, 1999).

When proper and consistent streamer line design and performance were ensured, this mitigation measure reduced the mortality of surface-foraging seabirds by as much as 96-100percent compared to a control of no deterrent (Løkkeborg 1998; 2001; Melvin *et al.*, 2001; Løkkeborg and Robertson, 2002). In an experiment in the Alaskan Pacific cod fishery, the streamer line completely eliminated the bycatch of surface-foraging birds, and the only seabird caught were the short-tailed shearwater, which is a diving bird (Melvin *et al.*, 2004). Streamer lines are likely to be less efficient in reducing bycatch of diving seabirds as birds may still reach baited hooks beyond the aerial portion of streamer lines. This deficit may be solved or at least significantly reduced by using weighted longlines in combination with streamer lines. Paired streamer lines in combination with integrated weight lines were shown to reduce bycatch of short-tailed shearwaters by 97 percent compared to control lines of no mitigation measure (Dietrich, Melvin and Conquest, 2008).

Streamer lines can also be less efficient when operated in strong crosswinds (Løkkeborg 1998; Brothers, Gales and Reid, 1999; Melvin *et al.*, 2001). Under such conditions, the streamer line can be blown to the side of the longline leaving baited hooks exposed to seabirds. Reduced efficiency under crosswind conditions may partly be counteracted by attaching the streamer line to the windward side of the vessel or by using paired streamer lines. Although differences in seabirds catch rates between single and paired streamer lines were small and not significant, Melvin *et al.*, 2001 recommended the use of paired streamer lines in the Alaska and Bering Sea demersal fisheries. This recommendation was based on behavioural evidence demonstrating that paired streamer lines resulted in virtually no albatross attacks on baits, whereas single streamer lines failed to eliminate albatross attacks. Paired streamer lines are, however, not operationally practical on small tuna longliners because the longer branchlines frequently tangle with the streamer lines.

Accordingly, aerial distance and position relative to sinking hooks are the most critical components of streamer line performance. The former is related to seabird foraging and diving behaviour, and the latter is affected by wind direction and wind speed. How these two components affect streamer line performance and efficiency should be given a research priority and given special attention when prescribing streamer line performance standards.

Night setting

Setting longlines at night, i.e. avoid line setting during daylight hours, has proved to be a very efficient mitigation method, in particular for albatrosses. However, some seabird species (e.g. white-chinned petrel) forage at night, and these species are vulnerable to hooks also set at night, although at a lower risk. Night setting was shown to be much more efficient in reducing incidental catch of albatrosses than white-chinned petrel in all studies that reported capture of both groups of seabirds (Table 3; Murray *et al.*, 1993; Ashford *et al.*, 1995; Weimerskirch, Capdeville and Duhamel, 2000; Nel, Ryan and Watkins, 2002; Ryan and Watkins, 2002).

In order to maximize the efficiency of setting longlines at night, it is important to ensure that the decklights are off. Cherel *et al*. (1996) demonstrated that the capture rate at night was four times higher when the decklights were on. Also, the efficiency of this mitigation measure has been shown to be lower for longlines set in bright moonlight condition than for those set during the new moon (Moreno *et al.*, 1996; Barnes, Ryan and Boix-Hinzen, 1997; Klaer and Polacheck, 1998; Brother, Gales and Reid, 1999; Belda and Sanchez, 2001). Thus, longline operations in areas inhabited by white-chinned petrels and night setting during full moon require additional mitigation measures to effectively reduce seabird captures.

Area and seasonal closure

Seabird mortality rates have been shown to be higher close to breeding colonies and during breeding seasons (Moreno *et al.*, 1996; Ashford and Croxall, 1998; Nel, Ryan and Watkins, 2002; Reid *et al.*, 2004). Seasonal fishing closure is therefore regarded to be a fundamental factor in reducing seabird bycatch in CCAMLR fisheries. This measure is applied during the breeding seasons in high risk areas of CCAMLR waters such as South Georgia, and is under consideration in Australia’s eastern tuna and billfish fishery. In high risk areas where area closures are not applied during the breeding seasons, such as around Kerguelen and Crozet Islands, bycatch of seabirds remains high despite the use of other mitigation measures (CCAMLR, 2005a).

Weighted lines

Externally attached weights must be tied and removed every time the line is set and hauled, and this is a laborious and time consuming process not without risk to crew members. For example, the weighting regime for vessels using autoline systems required by the CCAMLR conservation measure 25-02 (5 kg at 50 to 60 m intervals for non-integrated weight longlines; CCAMLR, 2005b) implies that one tonne of weight are needed to set a 10 km line. This problem has been solved by the development of lines with strands of lead included inside each of the strands of the rope, giving it an integral weight distributed evenly along its length. These lines are more practical in use and acceptable to fishermen (i.e. high level of industry support). However, longlines with integrated weight are designed for autoliners, and vessels using the Spanish system of longline fishing (double line method) have to use attached weights and comply with the CCAMLR conservation measure for this method (8.5 kg at 40 m intervals).

Table 3. Seabird bycatch reductions for different mitigation measures tested in demersal and pelagic longline fisheries.

Mitigation measure	Effectiveness	Seabird species	Area	Reference
Streamer line	88-100%	Northern fulmar	Gulf of Alaska	Melvin *et al.*, 2001
	71-94%	Northern fulmar	Bering Sea	Melvin *et al.*, 2001
	98-100%	Northern fulmar	Northeast Atlantic	Løkkeborg, 2003
Night setting	41%	White-chinned petrel	Indian Ocean	Cherel, Weimerskirch and Duhamel, 1996[a]
	85%	White-chinned petrel	Indian Ocean	Cherel, Weimerskirch and Duhamel, 1996[b]
	81%	White-chinned petrel	Indian Ocean	Weimerskirch, Capdeville and Duhamel, 2000
	99%	Albatrosses	Indian Ocean	Weimerskirch, Capdeville and Duhamel, 2000
	87%	Albatrosses, giant petrel	Indian Ocean	Nel, Ryan and Watkins, 2002
	100%	Albatrosses, giant petrel	South Georgia	Ashford *et al.*, 1995
	100%	Black-browed albatross	Falkland Islands	Reid *et al.*, 2004
	85%	Not identified	Australia	Brothers, Gales and Reid, 1999[c]
	79%	Not identified	Australia	Klaer and Polacheck, 1998[c]
	79%	Albatrosses	New Zealand	Murray *et al.*, 1993[c]
Weighted lines	37%	Northern fulmar	Gulf of Alaska	Melvin *et al.*, 2001
	76%	Northern fulmar	Bering Sea	Melvin *et al.*, 2001
	80%	Black-browed albatross, white-chinned petrel	South Georgia	Agnew *et al.*, 2000
	94-99%	White-chinned petrel	New Zealand	Robertson *et al.*, 2006
	61%	Sooty shearwater	New Zealand	Robertson *et al.*, 2006
Setting funnel	79%	Northern fulmar	Bering Sea	Melvin *et al.*, 2001
	72-92%	Northern fulmar	Northeast Atlantic	Løkkeborg, 1998, 2001
	67%	White-chinned petrel	Indian Ocean	Ryan and Watkins, 2002
	100%	Laysan albatross	Hawaii	Gilman, Boggs and Brothers, 2003[c]
Line shooter	+54%	Northern fulmar	Bering Sea	Melvin *et al.*, 2001
	59%	Northern fulmar	Northeast Atlantic	Løkkeborg and Robertson, 2002
Bait-casting machine	50%	Not identified	Australia	Klaer and Polacheck, 1998[c]
Offal discharge	98%	White-chinned petrel	Indian Ocean	Cherel, Weimerskirch and Duhamel, 1996
	54%	White-chinned petrel	Indian Ocean	Weimerskirch, Capdeville and Duhamel, 2000

[a] Decklights on.
[b] Decklights off.
[c] Pelagic longline fisheries

Experiments testing the effect of adding external weights are few, and reductions in bycatch achieved with this measure varied from 37 percent to 80 percent (Table 3; Agnew *et al*., 2000; Melvin *et al* 2001). Unfortunately, only one study has been carried out to test lines with integrated weight, and this experiment gave promising results for a demersal autoline fishery (Robertson *et al*., 2006). Although few experiments have been carried out, there is reason to believe that weighted lines as a single mitigation measure do not have the potential to give satisfactory bycatch reductions in most fisheries. However, line weighting in combination with other mitigation measures (e.g. streamer line, underwater setting, side setting) is likely to be highly efficient in reducing seabird mortality.

In addition to reducing the incidental capture of seabirds, weighted longlines may also give increased target catch rates as they reach the seabed more rapidly. The release rate of attractants from baits declines rapidly during the first 2 hours of immersion in seawater (Løkkeborg, 1990), and longlines with sink rate of 0.16 m s^{-1} (conventional lines) would take 1 h 44 min to reach fishing depth at 1000 m compared to 55 min for a line weighted to sink at 0.3 m s^{-1} (Robertson *et al*., 2003). Thus, to maximize bait attractiveness it is advantage to use longlines that sink fast. In addition, lines with integrated weight have superior handling attributes making gear easier to deploy and retrieve relative to traditional unweighted longlines (Robertson *et al*., 2006).

Underwater setting

Studies on underwater setting funnels are few and inconclusive, although these works all demonstrated reduced seabird bycatch rates (Table 3; Løkkeborg, 1998, 2001; Melvin *et al*., 2001; Ryan and Watkins, 2002; Gilman, Boggs and Brothers, 2003). The depth at which the device delivers the baited hooks and the diving capability of the seabird species inhabiting the fishing ground under consideration are the most obvious explanations to the inconsistency in the results obtained with this setting method. The underwater chute developed for pelagic fisheries delivers baited hooks at depths of several metres, and in waters not inhabited by seabirds that are proficient at diving to greater depths (e.g. white-chinned petrel, flesh-footed shearwater (*Puffinus carneipes*), sooty shearwater), this device would have great potential to reduce incidental capture of seabirds to insignificant numbers (see O’Toole and Molloy 2000; Gilman, Boggs and Brothers, 2003). However, the sink rates and thus the performance of the chute is likely to be affected by line weighting, line tension (i.e. with/without line shooter) and chute position relative to the propeller wash, and studies to assess the effects of these factors should be undertaken.

The setting funnel has been tested in demersal longline fisheries in Alaska, Norway and South Africa giving reductions in mortality rate from about 67 to 92 percent. The baited lines were delivered into the water at only 1–2 m depth. During rough seas, when the vessel is front heavy and due to the effect of the propeller wash, baited hooks emerged close to the sea surface making them available even to surface seizing seabirds. Thus there is potential for significant improvements of this mitigation device. Also, underwater setting devices used in combination with weighted longlines should further reduce the time and area baited hooks are within the reach of seabirds.

Line shooter

Experiments testing line shooter are scarce, and more research is needed. Results showing significant reductions in seabird capture when setting with a line shooter have not been reported. Future studies should include experiments testing the line shooter in combination with underwater setting devices and weighted lines. This combination of mitigation methods may prove to be efficient in reducing the time baited hooks are within the reach of seabirds.

Bait-casting machine

Only one of the works reviewed here tested the performance of bait-casting machine, and this device was shown to reduce seabird bycatch by 50 percent (Klaer and Polacheck, 1998). In addition, Brothers (1991) showed that baited hooks thrown more than 7 m out from the side of the vessel had 80 percent higher bait retention than those thrown less than 7 m. Empirical data to evaluate this mitigation measure are therefore too scarce, and more research is needed. When bait thrower is used in combination with streamer lines, it is important to adjust the throw distance to ensure that the baited hooks land on the surface under the streamers and to vary the distance according to wind conditions.

Strategic offal discharge

Dumping of offal proved to be very efficient (98percent) in the study carried out by Cherel, Weimerskirch and Duhamel (1996) in Kerguelen waters, whereas analyses of observer data indicated a 54 percent reduction in seabird mortality (Weimerskirch, Capdeville and Duhamel, 2000). However, using this method needs to be carefully considered as offal dumping attracts more seabirds to the fishing vessel. This mitigation method is only applicable in fisheries where line setting is short and where catches of fish are sufficient to allow dumping throughout the setting operation.

The use of offal is not applicable in fisheries such as tuna longlining where line setting lasts for several hours and there is little offal to discharge. Also, the CCAMLR conservation measure 25–02 prohibits dumping of offal during longline setting, and requires offal to be retained onboard or discharged on the opposite side of the vessel to that where longlines are hauled.

The proposed method of dispensing fish oil behind fishing vessels has similar limitations. Dripping shark liver oil on the ocean surface was shown to be effective in reducing both seabird numbers and dives on baits in a pelagic fishery in northern New Zealand where flesh-footed shearwater dominated the seabird assemblage (Pierre and Norden, 2006).

Blue-dyed bait

The performance of this mitigation measure has only been tested in the study by Boggs (2001), who recorded contact rates between albatrosses and baits. Although contact rates were reduced by 90 percent, this method is operationally difficult to use. Dying the baits cause extra work to the fishermen, and is not possible in autolining where pieces of bait are cut from whole fish at the moment they are baited and set.

STUDIES ON MITIGATION MEASURES IN TRAWL FISHERIES

An overview of studies examining interactions between seabirds and trawl fisheries is given in Table 4. Only two of these studies determined the effects of mitigation measures on seabird mortality rate.

Observer data were collected from four of the former Union of the Soviet Socialist Republics (USSR) vessels in the squid trawl fishery in New Zealand waters (Bartle, 1991). A total of 279 seabirds (236 white-capped albatrosses [*Diomedea cauta steadi*], 30 sooty shearwaters) were observed caught by monitoring 897 tows. At least 83 percent and probably nearer 92 percent of the seabirds were killed by collision with the netsonde monitor cable. The netsonde cable used to be applied in New Zealand waters only by trawlers of the former USSR (Bartle, 1991), but is now banned.

Similar results were obtained from data collected by trained fishery observers onboard three Ukrainian trawlers targeting Patagonian toothfish and mackerel icefish (*Champsocephalus gunnari*) on the shelf of Kerguelen (Williams and Capdeville, 1996; Weimerskirch, Capdeville and Duhamel, 2000). One of the trawlers used a netsonde cable, and most of the mortality recorded was observed on this vessel, where the cable caused all albatross deaths. White-chinned petrels were killed in highest numbers, and they were observed caught either in the meshes near the headline of the trawl or in the codend. This type of mortality was higher on the trawlers fishing for mackerel icefish (18 birds) than on the toothfish trawlers (one bird), which accounted for 54 percent of the trawl hauls examined (Williams and Capdeville, 1996). The icefish is smaller than the toothfish and thus easily ingested by the birds making trawlers targeting icefish attractive to seabirds. Netsonde cables are now banned in the CCAMLR area including the Kerguelen waters (Weimerskirch, Capdeville and Duhamel, 2000).

The Australian trawl fishery for Patagonian toothfish around Macquarie Island, Heard and McDonald Islands is a relatively new fishery, and there are only two vessels licensed to operate in these areas. Wienecke and Robertson (2002) analysed the observations of seabird interactions with this fishery from 1997 to 2000. The seabird assemblage was dominated by cape, white-chinned and giant petrels at Heard and McDonald Islands (HIMI), and by giant petrels and black-browed albatrosses at Macquarie Island (MI). During 15 cruises (10 at HIMI and 5 at MI), a total of 883 shots and 1 043 hauls were observed. Very low proportion of the seabird observations involved direct contacts with the fishing gear (warps and nets), and most contacts (98 percent) were slight and did not cause any apparent injury. During the 15 cruises, only 18 seabirds were observed to suffer serious injuries or were likely to have died. Given the large number of bird observations (almost 200 000), these results show that commercial trawlers are able to operate at HIMI and MI without causing significant seabird mortalities. Rare interactions between seabirds and fishing gear were ascribed to the current licence conditions and operational procedures such as a no-discharge policy, ban of netsonde cables and dimmed lighting at night.

Specifically tasked seabird observers recorded seabird interactions during 157 days onboard finfish trawlers and eight days onboard squid trawlers operating in Falkland Islands' waters (Sullivan, Reid and Bugoni, 2006). The vast majority of contacts between seabirds and finfish trawls were contacts between birds (cape petrel and black-browed albatross) on the waters and the warp cable, of which most resulted in no apparent injury. Seabirds had negligible contacts with the warps when there was no offal discharge. All mortalities recorded were caused by the warp and paravane cables, 70 and 3 respectively (mainly black-browed albatross). All seabird deaths occurred at times of offal discharge, suggesting that eliminating factory discharge would virtually eliminate mortality.

Three mitigation measures (paired streamer lines, warp scarer, Brady baffler) were tested under commercial fishing operations on a finfish trawler in Falkland's waters (Sullivan *et al.*, 2006). Mortalities were rare with 86 percent of trawl hauls having no observed mortality. All three mitigation measures gave lower seabird mortality than the control (no mitigation measure). No seabirds were killed when the streamer lines were used, and only one bird was killed with the warp scarer employed. The rates of seabird contacts with the warp were also reduced with all three mitigation devices compared with the control treatment. Contact rate was significantly lower with the streamer lines than the warp scarer, which again resulted in significantly lower contact rate than the Brady baffler. With a significant relationship between seabird mortality and contacts with the warp identified (Sullivan, Reid and Bugoni, 2006), the authors concluded that the contact rate data suggested a performance hierarchy of the three mitigation devices. The streamer lines and warp scarer both performed substantially better the Brady baffler, while streamer lines were slightly better than the warp scarer.

STUDIES ON MITIGATION MEASURES IN GILLNET FISHERIES

Visual and acoustic alerts were tested to reduce seabird bycatch (primarily common murre [*Uria aalge*] and rhinoceros auklet [*Cerorhinca monocerata*] in the coastal sockeye salmon [*Onchorhunchus nerka*] drift net fishery in Puget Sound [Washington, United States of America]; [Melvin, Parrish and Conquest, 1999]). The traditional gillnets used in this fishery are 200 meshes in depth (18.3 m) and made from monofilament nylon (0.5 mm in diameter), which is virtually invisible under water. These gillnets were compared to experimental nets with the upper 20 and 50 meshes, respectively, replaced with white multifilament nylon twine (number 18). This configuration made the upper 1.8 and 4.6 m, respective, of the net highly visible. Nets with 20 visible meshes in the upper panel reduced murre bycatch by 45 percent and maintained catching efficiency for salmon, whereas auklet bycatch was not reduced. Nets with 50 visible meshes reduced both murre (40 percent) and auklet (42 percent) bycatches, however this modification also reduced the catch rate of salmon by more than half.

The acoustic alert tested was pingers attached to the floatline every 50 m. The pingers emitted a 1.5 kHz (±1 kHz) signal every 4 s at 35–40 dB above background noise level (Melvin, Parrish and Conquest, 1999). Pingers reduced murre bycatch by 50 percent and maintained salmon catch rates, but they did not reduce auklet bycatch; i.e. pingers and 20 mesh visible panels gave similar results.

A potential method to reduce the bycatch of echolocating cetaceans is to increase the sound reflecting properties of gillnets. This mitigation measure was tested in the demersal gillnet fishery in Bay of Fundy (Canada), and its effect on seabird bycatch was also determined (Trippel *et al.*, 2003). Traditional monofilament nylon (0.6 mm in diameter) gillnets were compared to nets in which the strands contained fine barium sulphate particles and were dyed pale blue to mask the white opaque colour of the barium sulphate. There was a significant reduction of seabird bycatch (> 98 percent greater shearwater) in the reflective nets. Eleven seabirds were caught in 72 reflective nets (0.15 birds per net) compared to 94 seabirds in 121 control nets (0.78 birds per net). The reduction was explained by the increased visibility of the blue opaque net. There was also a significant reduction in harbour porpoise (*Phocoena phocoena*) bycatch in reflective nets, whereas there was no difference in catches of commercial fish species (mainly gadoids) between control and reflective nets.

Table 4. Overview of studies to investigate interactions between seabirds and trawl fisheries. The dominant seabird species killed are given (total number of birds in brackets). Data collection indicates whether the study applied an experimental design or was based on observer data (number of trawl hauls recorded in brackets).

Area	Mitigation measure tested	Seabird species killed	Data collection	Reference
New Zealand	No measures were tested.	White-capped albatross, sooty shearwater, (279)	Observer data (897)	Bartle, 1991
Macquarie Island, Australia	No measures were tested.	No mortality	Observer data (198)	Williams and Capdeville, 1996
Kerguelen, Indian Ocean	No measures were tested.	White-chinned petrel, (24)	Observer data (1035)	Williams and Capdeville, 1996; Weimerskirch, Capdeville and Duhamel, 2000
Macquarie, Heard and MacDonalds Islands, Australia	No measures were tested.	Cape and white-chinned petrel, (few)	Observer data (1043)	Wienecke and Robertson, 2002
Falkland Islands	Level of offal discharge	Black-browed albatross, (73)	Observer data (565)	Sullivan, Reid and Bugoni, 2006
Falkland Islands	Streamer line, warp scarer, Brady baffler	Black-browed albatross, (18)	Experimental (78)	Sullivan *et al.*, 2006

Melvin, Parrish and Conquest (1999) also investigated how fishing time (i.e. dawn, day, dusk) affected salmon and seabird catches in the coastal drift net fishery in Puget Sound. Both salmon catch and seabird bycatch were highest at dawn. However, precluding sunrise fishing gave only a small reduction (5 percent) in catching efficiency for salmon, whereas pronounced reductions in both auklet and murre bycatches were obtained.

In the Japanese high-seas drift gillnet fishery for flying squid (*Ommastrephes bartrami*), seabirds entanglements were compared between nets submerged 2 m below the surface and traditional surface nets (Hayase and Yatsu, 1993, cited in Melvin, Parrish and Conquest, 1999). Seabird bycatch was significantly reduced in submerged nets, however, fishing efficiency was reduced by up to 95 percent for these nets.

CONCLUSIONS

There is potential for considerable reductions in seabird mortality rates in all longline fisheries by employing appropriate and effective mitigation measures. Analyses of observer data over a period of several years have shown clear reductions in seabird bycatch rates in many fisheries (Murray *et al.*, 1993; Agnew *et al.*, 2000; Gilman, Boggs and Brothers, 2003; Reid *et al.*, 2004). In the toothfish fishery around South Georgia, for example, the bycatch rate has been reduced from 0.66 birds/1 000 hooks in 1993 to 0.0003 birds/1 000 hooks in 2003 as a result of implementation and increasing compliance with the CCAMLR conservation measure 25-02 (Reid *et al.*, 2004). Similar analyses indicated that total seabird mortality in the tuna fishery in New Zealand waters declined by an order of magnitude from 3 652 birds in 1988 to 360 birds in 1992 (Murray *et al.*, 1993).

There is no single solution to mitigate incidental seabird mortality in longline fisheries. The current review gives strong evidence that the efficiency of a mitigation measure is specific to each fishery. In particular, effectiveness of a given mitigation device is influenced by the seabird species assemblage at the fishing ground considered (surface versus diving foragers, diurnal versus nocturnal foragers). Also type of longline gear is likely to be an important factor (demersal versus pelagic longline, single- versus Spanish-rigged demersal longline).

Some conclusions, however, can be drawn based on the studies conducted to date. In the Northern Hemisphere (Atlantic Ocean and Pacific Ocean), where northern fulmar is the dominant seabird captured, streamer lines have proved to be very efficient in demersal fisheries. As the Pacific Ocean and the Bering Sea are inhabited by endangered and threatened species such as albatrosses, additional care should be taken by using paired streamer lines and/or weighted longlines in the longline fisheries carried out in these regions.

In the Southern Hemisphere, night setting has shown to be an important and efficient mitigation measure. Although night setting alone may still reduce bycatch of nocturnal species such as white-chinned petrel, this measure has to be used in combination with other measures when fishing in areas inhabited by nocturnal seabirds and when fishing in bright moonlight condition. Based on conclusions from a wide range of studies, it is reason to believe that the combination of streamer lines and longlines with integrated weight would greatly reduced incidental bycatch of nocturnal and diving seabirds, which are among the most difficult to deter from baited hooks.

Although few studies have been conducted in trawl fisheries, the results reported to date indicate rare interactions between seabirds and trawl gear at times of no offal discharge. These studies therefore suggest that no-discharge policy and ban of netsonde cables would virtually eliminate seabird mortality. Furthermore, no seabirds were killed when streamer lines were used during trawling carried out under factory discharge and in the spring when albatross density peaks (Sullivan *et al.*, 2006). However, the longline studies demonstrated that seabird interactions are specific to each fishery, and therefore more studies need to be conducted in other areas and trawl fisheries.

Studies in gillnet fisheries are even more scarce, and development of seabird mitigation measures for this gear type is in its infancy. This review has identified only one study where a mitigation method proved to be efficient in reducing seabird bycatch while maintaining target species catch rates (Trippel *et al.*, 2003).

Future research needs

Future research on seabird mitigation measures in longlining should apply an experimental approach to fine-tune the most promising mitigation measures for each specific fishery. Research on streamer lines should compare the attack or dive rate of seabird species as a function of the aerial extent of the streamer line in order to optimise designs for southern hemisphere fisheries in particular. Research is also needed to compare single and paired streamer line performance and to develop streamer line designs that protect baited longlines set in crosswinds.

Studies on weighted longlines are few, and future research should focus on this promising mitigation method. The concept of integrated weight is designed for multifilament longlines, and alternatives to adding external weights to monofilament and pelagic longlines (e.g. weighted swivels) should be a research priority. Line weighting regime, appropriate sink rate and combination of other mitigation measures need to be determined for a specific fishery. Preliminary results from experiments testing side setting in Hawaii longline fisheries are promising (Gilman, Boggs and Brothers, 2003; cited in Gilman, Brothers and Kobayashi, 2005), and future research should also include this mitigation measure. Currently there are several studies being conducted to improve and fine-tune the most promising mitigation methods.

Finally, to solve the global problem of seabird mortality in longline fisheries, broad use of effective mitigation measures in all fisheries that have a problem with seabird bycatch is essential. To achieve this goal, it is important to provide fishermen with incentives for voluntary use of seabird avoidance methods, and the longline industry is expected to respond most strongly to economic incentives (Gilman, Boggs and Brothers, 2003). Reduced seabird interactions and increased bait retention should provide the economic incentive of achieving higher target catch. Therefore, data on bait loss and fish catch rates need to be collected in future experiments in order to demonstrate increased profitability by using seabird mitigation measures. Furthermore, the ideal seabird mitigation method should also be practical, safe and convenient for fishermen to employ, and easy for managers to enforce.

Mitigation measures have been tested in only a few trawl and gillnet fisheries, and this work needs to be expanded to other areas where interactions with seabirds occur. Promising measures have been identified for trawl but not for gillnet fisheries.

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