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A review of methodologies aimed at avoiding and/or mitigating incidental catch of protected seabirds

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A REVIEW OF METHODOLOGIES AIMED AT AVOIDING AND/OR MITIGATING INCIDENTAL CATCH OF PROTECTED SEABIRDS

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Abstract

Information on methods aimed at mitigating incidental mortality resulting from fisheries interactions have been released in a variety of local, national and international media. Recent published reviews in the field of bycatch mitigation have typically had a species or fishing method focus. This report presents the results of the seabird component of a global review of mitigation methods aimed at reducing mortalities of protected seabirds, marine mammals and reptiles and corals due to interactions with fishing gear in New Zealand fisheries and fisheries that operate using similar methodologies. The application of these mitigation methods to New Zealand fisheries were assessed, recommendations for the fisheries management made, and areas for further research in New Zealand identified. Factors influencing the appropriateness and effectiveness of a mitigation device include the fishery, vessel, location, seabird assemblage present and time of year (i.e. season). As such, there is no single magic solution to reduce or eliminate seabird bycatch across all fisheries. Realistically a ***combination of measures*** is required, and even within a fishery there is likely to be ***individual vessel refinement*** of mitigation techniques in order to maximise their effectiveness at reducing seabird bycatch. Retention or strategic management of offal and discards are recommended as the most effect measure to reducing seabird bycatch in longline and trawl fisheries. Other recommended methods for both demersal and pelagic longlining include paired bird-scaring lines, line-weighting and night-setting (in some fisheries). Along with offal and discard management, paired bird-scaring lines and reducing the time the net is on (or near) the surface are likely to be the most effective regime at this point to mitigate seabird interactions with the warp cables and net respectively. However urgent investigation is needed into more effective measures at reducing seabird interactions with the trawl nets.

Keywords: seabirds, fisheries, bycatch, mitigation

1. Introduction

FISHERIES AND SEABIRD BYCATCH

In New Zealand, seabirds have been recorded caught in longlines, trawl, set nets and pots (NPOA 2004; Robertson et al. 2004a). Worldwide, a total of 61 seabird species have been recorded as killed by longlining operations on at least one occasion (Brothers et al. 1999a). In New Zealand, 13 albatross and 17 petrel species have been recorded as having been caught during commercial longline and trawl fishery operations since 1996 (NPOA 2004). Incidental mortality though interactions with fisheries operations has been linked with a global declines of some albatross and petrel species (Croxall et al. 1990; Brothers 1991; Weimerskirch et al. 1997; Weimerskirch et al. 1999; Lewison & Crowder 2003). Given that nearly half of the world's 125 petrel species and 16 of the 21 albatross species are classified as threatened (BirdLife_International 2000), effective measures to mitigate against seabird bycatch (including fishing gear modification) need to be investigated in order to reduce the impact of these fisheries operations on global seabird populations.

Longlining

Longline gear can be set throughout the water column, on the seabed (demersal longlining), floated off the bottom at various fishing depths (semipelagic longlining) or suspended from floats drifting freely at the surface (pelagic longlining) (Brothers et al. 1999a). Pelagic and demersal longlining operations differ in the gear used: compared to demersal fisheries, pelagic fisheries use longer snoods, have multiple buoys at the surface and use whole baits. The longer snoods on the pelagic gear increases the chances of seabird takes during hauling. These differences in gear mean that different mitigation measures may be required between pelagic and demersal longline fisheries.

When compared to drift-netting, longlining is perceived as a relatively environmentally friendly fishing method in terms of being target species and size-selective, and does not directly damage the sea floors (Brothers et al. 1999a; Brooke 2004). However the versatility of this fishing method has resulted in a large number of vessels having the potential to catch seabirds; ranging from small open boats operating in shallow coastal waters, to large ocean-going vessels operating on high-seas fishing grounds at depths down to 3000 m (Brothers et al. 1999a). Although no observations describing the nature of seabird interactions in longline fisheries 20 or 30 years ago exist, it is likely that the factor of sink rate was not then as acute, because gear in the past was heavier (Brothers et al. 1999a). Furthermore, the mechanisation of fishing operations has greatly expanded the scope of these operations (Brothers et al. 1999a).

From 1993, the use of tori lines became mandatory for all tuna longline fishing vessels (foreign and domestic) in the New Zealand Exclusive Economic Zone (EEZ) (Regulation 36A of the Fisheries (Commercial Fisheries) Regulations 1993) (Duckworth 1995).

Trawling

Trawl operations induce a lower reported, though still substantial, seabird mortality than longliners (Bartle 1991a; Weimerskirch et al. 2000) and incidental mortality may be substantially higher than recorded from birds landed on deck.

The early reporting of seabird mortalities occurring through collisions or entanglements with net monitor (=net sonde) cables on trawl vessels (Bartle 1991b; Duhamel 1991) led to a ban on the use of these cables in several Southern Hemisphere trawl fisheries including the New Zealand domestic trawl fisheries (1992), Australia’s Heard Island and Macquarie Island trawl fisheries (1996), and trawl fisheries managed by the Convention on the Conservation of Antarctic Marine Living Resources (CCAMLR) (1994) (Wilson et al. 2004).

Net-related mortality has been recorded more frequently for the pelagic (or mid-water) trawling method compared to demersal trawling (Sullivan et al. 2004b). The difference in time the net stays at the surface in these two gear types is likely to account for the variation in mortality rates: pelagic nets remaining at or near the surface for extended periods, whereas demersal nets are weighted to sink quickly (Sullivan et al. 2004b).

The size of trawl fisheries target fish may influence the level of seabird bycatch. Weimerskirch et al. (2000) noted that trawl fisheries targeting the smaller mackerel icefish (*Chamsocephalus gunnari*) incurred higher seabird mortalities than that in the Patagonian toothfish (*Dissostichus eleginoides*) fishery. They concluded that this may be due to the icefish vessels being more attractive to seabirds as the target species of this fishery is smaller and easily ingested by the birds.

Drift nets

Due to their indiscriminate and destructive nature, drift nets were globally banned on the high seas in the early 1990s (Montevecchi 2002; Brooke 2004). Much of the fishing effort that used drift nets subsequently shifted focus to longlining (Brothers et al. 1999a).

SEABIRDS

Understanding the biology and foraging behaviour of the seabird species that a mitigation method is being designed to avoid catching is an essential first step in the conception of the technique and assessing the likelihood of its effectiveness (Sánchez & Belda 2003).

The assemblage of seabirds attending fishing vessels will differ depending on the number of fishing vessels present in the same fishing grounds, the location, time of day and season (Weimerskirch et al. 2000). Interaction of different seabird species with fishing gear will be influenced by their feeding method, dive depth abilities and seabird size. The smaller birds (e.g. terns, storm petrels and auklets) are unable to swallow such large food items as longline baits, and as such are rarely found captured in this way (Brothers et al. 1999a). Scavenging seabirds particularly, have large gapes and are thus able to swallow large food items whole, making them liable to get caught on longline hooks (Brothers et al. 1999a).

Biology

Seabirds such as albatrosses and petrels are long-lived, monogamous, have delayed maturity, high adult survival, a long breeding life, and relatively low reproductive rates (generally one egg/chick per season per breeding pair). As a result of these factors, seabird populations can only increase slowly under highly favourable environmental conditions (unless they are at carrying capacity) (Furness 2003). Therefore, any additional factors increasing the rate of adult mortality will have a strong negative impact on population dynamics and the species as a whole.

Most seabirds (particularly albatrosses and petrels) exhibit strong mate and site fidelity, generally returning to the same site (often the same nest) to breed with the same mate in successive seasons. Within a pair, both birds share parental duties including feeding the chick. As such, if one parent dies during a breeding season, the widowed parent is unable to sufficiently feed the chick. Furthermore, there is often a lag-period following the death of a partner before the widowed bird will next breed, as it must find a new mate and form a pair bond before breeding will commence.

Foraging behaviour

The foraging ecology of many seabird species is still largely unknown, along with the degree to which each seabird species relies on visual and olfactory cues to locate food (Verheyden & Jouventin 1994; Nevitt 1999; Brooke 2004; Nevitt et al. 2004). Such information would be beneficial to the design of many mitigation devices.

Both diving and scavenging seabirds present at fishing vessels are susceptible to interactions with fishing gear. Divers are capable of diving considerable distances to retrieve baited hooks, thus exposing them to being hooked. Larger birds, for example the wandering albatross (*Diomedea exulans*), do not have the same diving capabilities, instead they harass the diving birds when they come to the surface and attempt to take the retrieved bait and hook (Cherel et al. 1996).

The Southern Ocean is home to many of the most capable diving seabirds, namely shearwaters and some petrels. Studies of *Puffinus* shearwaters have found that the maximum dive depths of these species ranges between 35.4–70.6 m (Weimerskirch & Cherel 1998; Keitt et al. 2000; Burger 2001; Aguilar et al. 2003). White-chinned petrels (*Procellaria aequinoctialis*), a common bycatch species, has a recorded maximum dive depth of 12.8 m (Huin 1994). Grey-headed (*Thalassarche chrysostoma*) and black-browed (*T. melanophrys*) albatrosses are also skilled divers and are therefore able to catch sinking baits underwater (Prince et al. 1994). It is these species (*Puffinus*, *Procellaria* and the small albatrosses) that generally account for a large percentage of seabird mortality in the longline and trawl fisheries (Brothers 1991; Murray et al. 1993; Robertson et al. 2004a).

Some seabird species partition their foraging ranges according to sex or breeding status, leading in some cases to bycatch events having a species-specific sex or age bias (Bartle 1990; Croxall & Prince 1990; Ryan & Boix-Hinzen 1999). These biases in bycatch rates can in turn cause age or sex biases in the population, which has further implications on the productivity and hence population size of the species.

Seabirds are capable of foraging considerable distances; some albatross and petrel species are known to travel hundreds of kilometres on single foraging trips (Jouventin & Weimerskirch 1990; Weimerskirch & Cherel 1998). Such large foraging ranges increases the number of vessels birds are vulnerable to beyond those fishing adjacent to the breeding colonies.

Some seabirds are attracted to vessels because they have learnt that it can be a source of food through scavenging offal and bait. Removing the source of food either directly (i.e. 'discards') or indirectly (i.e. bird-scaring lines etc) should in the long-term discourage seabirds from following vessels (Weimerskirch et al. 2000).

SEABIRD–FISHING GEAR INTERACTIONS

When devising new, or modifying existing, gear for reducing incidental captures, measuring gear selectivity and monitoring for potential adverse impacts are necessary (Bache 2003). Understanding the circumstances that lead to the death of birds in a fishery is essential to determine how future mortalities can be prevented. Describing these circumstances will provide a clearer understanding of how and when a mitigation measure can reduce mortality (Brothers et al. 1999a; Bache 2003).

Longlining

Seabirds may become entangled on the line or caught during line setting and hauling (primarily with pelagic gear) (Brothers et al. 1999a). Brothers & Foster (1997) observed three situations in which baited hooks on longlines pose a threat to seabirds following astern of the vessel: (1) as the hooks were cast into the water and before sinking; (2) if the hooks float on or near the surface as a result of current or tide action during their soak time; or (3) when hooks with unused bait were hauled back aboard the vessel. Therefore, reduction in seabird bycatch through modifications to fishing practices and/or equipment can be achieved through the following processes: preventing baited hooks being visible to birds; preventing access to baited hooks; reducing the potential of hooks to kill birds that take them; and decreasing the incentive for birds to follow longline vessels (Brothers et al. 1999a).

Trawl

Seabirds interactions with trawl gear include collisions with the net monitoring (net sonde) cable and trawl warps, or birds becoming tangled in the net (whilst attempting to feed) during setting and hauling when the net is at the surface (Weimerskirch et al. 2000; Barton 2002; Wienecke & Robertson 2002; Hooper et al. 2003; Sullivan et al. 2004b). Hooper et al. (2003) identified four types of seabird entanglement that may occur with trawl nets: (1) plunge diving through the large meshes; (2) pecking at enmeshed fish during which procedure the neck is squeezed as the meshes close; (3) feet becoming jammed as meshes close as birds 'ride' the net; (4) wings becoming caught at the 'wrist' as meshes close.

Gillnets

Most seabird captures in gillnet fisheries are of diving species, which most often get caught in the nets when diving for prey (Melvin et al. 1999).

Other fisheries

No information could be found regarding the mechanisms of capture for purse seine, jig and troll fisheries.

SUCCESSFUL MITIGATION

Gilman et al. (2003) listed the following criteria as being important for seabird mitigation method(s): (1) reduce seabird mortality to insignificant levels; (2) not cause increases in bycatch of other sensitive species; (3) require minimum alteration of traditional fishing practices and provide operational benefits; (4) be simple for crew to employ and not increase safety hazards to crew; (5) increase fishing efficiency; and (6) be feasibly enforced when limited resources for enforcement are available.

Bycatch mitigation may take the form of area/seasonal closure of fishing grounds, modifications to fishing gear, and new fishing practices and equipment (Brothers et al. 1999a). While area/seasonal closures have occurred, or have been suggested, the greatest potential in terms of fisher response and support lies with the alternatives (Brothers et al. 1999a; Melvin et al. 1999; Kock 2001; Gilman et al. 2003a).

SCOPE AND OBJECTIVES OF PROJECT

The development of techniques to avoid and mitigate incidental mortality of seabirds and marine mammals resulting from fisheries interactions is a growing field internationally. Recent published reviews in the field of bycatch mitigation have typically had a species or fishing method focus, or a combination (Fertl & Leatherwood 1997; Brothers et al. 1999a; Tasker et al. 2000). However, a comprehensive review across fishing methods and species has not yet been published.

The aim of this project was to conduct a global review of methodologies designed at avoiding and/or mitigating incidental catch of seabirds. The review focuses on interactions between fishing gear and these species in New Zealand fisheries and fisheries that operate using similar methodologies to New Zealand fisheries. This review collates and synthesises published, unpublished, internet-based, and anecdotal information on methodologies for the avoidance of incidental catch of seabirds in fisheries that share characteristics with New Zealand fisheries (including longline, purse seine, jig, set net/gillnet, troll, and trawl). Material reviewed included mitigation and avoidance methods that have been proposed but not tested, tested but demonstrated to be unsuccessful, or tested and demonstrated to be successful. The applications of these methods to New Zealand fisheries were assessed and areas for further research in New Zealand identified. This report therefore seeks to consolidate the experience and information gathered worldwide in the field of bycatch mitigation and avoidance and evaluate these for application in New Zealand, as well as serving as a means to assess past lessons learnt and therefore avoid any future attempts at reinventing the wheel.

2. Methods

Material (post-1990) investigating mitigation measures to reduce seabird bycatch was obtained from various forms of media including peer-reviewed journals, unpublished reports, magazine articles, conference papers, websites, government and Non-government Organisations' literature. Relevant factors were extracted from the material and recorded in detailed tables (Appendix 1) for each fishery for which information could be found. Based on the information provided in the original source material (and captured in the Appendix), the influence of mitigation measures on bycatch and target fish catch rates are summarised for longline, trawl and gillnet fisheries. No information was found regarding bycatch mitigation measures for purse seine, jig or troll fisheries. Thus the results section of this report is divided into longline, trawl and gillnet sections, within each of which the relevant mitigation methods are reviewed.

For the context of this paper, bycatch is defined as the non-target species that are obtained whenever fishing gear is not perfectly selective (Terry 1995), and mitigation measures are defined as the modification to fishing practices and/or equipment that reduces the likelihood of seabird incidental catch (Brothers et al. 1999a). A contact is defined as an event during which a seabird comes into contact with gear near baited hooks (Gilman et al. 2003b). A capture is based on a count of the number of seabirds hauled aboard, and not the number of seabirds observed caught during setting (Gilman et al. 2003b).

3. Results

MITIGATION METHODS RELEVANT TO MULTIPLE FISHERIES

Offal and discard management

METHOD:
The presence of offal is probably a major factor affecting seabird numbers attending vessels (Weimerskirch et al. 2000; Robertson & Blezard 2005). Seabirds feed on the offal discharged and subsequently associate the vessel with food. Therefore, offal discharge reinforces the behaviour of birds to attend vessels (Weimerskirch et al. 2000). Managing offal and discards through retention or strategic dumping may reduce seabird bycatch.

RESULTS:
Weimerskirch et al. (2000) analysed fisheries observer data from demersal trawlers and longliners around the Kerguelen Exclusive Economic Zone (EEZ). The release of offal from longliners had a positive influence on the total number of birds attending, especially on the number of large species and white-chinned petrels. On the trawlers, offal discharge affected the presence of some species, but did not significantly influence the total number of birds attending trawlers. In comparison, results from a study using specifically tasked seabird observers on demersal trawl fisheries around the Falkland Islands (and the associated high

seas) reported increasing contact rates with fishing gear with increasing levels of offal discharge (Sullivan et al. in press). Furthermore, all seabird mortalities occurred at times of factory discharge (Sullivan et al. in press).

Analysis of New Zealand Fisheries observer data collected during the summer of 2004/05 on the Auckland Islands squid fishery for the purpose of determining the factors that influence warp strike, found that offal discharge as the single most important factor affecting interaction between seabirds and fishing gear (Abraham 2005). Furthermore, analysis of New Zealand Fisheries observer data collected from squid trawlers during the 2002/03, 2003/04 and 2004/05 seasons showed that the discharge of offal had a significant ($p = 0.012$) influence on seabird bycatch: lower bycatch was recorded when offal was not discharged during the fishing operation (Conservation Services Programme unpubl. data).

COST/PROBLEMS:

- Possible logistical implications of offal retention due to vessel storage capacity .

BENEFITS:

- The general consensus is that retention of offal reduces seabird bycatch rates (Abraham 2005; Robertson & Blezard 2005; Sullivan et al. in press).

Area/seasonal closures

METHOD:
Areas where high levels of seabird bycatch have been recorded, or where the range of an endangered species overlaps with a fisheries operation, are closed to fishing effort for a specific season or period.

RESULTS:
The restriction of fisheries operating in CCAMLR waters to fishing only during the winter months has resulted in a decline in the incidental mortality of seabirds from approximately 0.2 birds/1000 hooks in 1995 to <0.025 birds/1000 hooks in 1997 (SC-CAMLR 1995; SC-CAMLR 1998).

While investigating methods to reduce seabird bycatch in the coastal salmon drift gillnet fishery in Puget Sound (Washington), Melvin, Parrish et al. (1999) recorded temporal variation in seabird bycatch and abundance over different temporal scales (interannually, within fishing seasons, and over the day). Due to a reduction in effort (i.e. total sets) to meet the quota, it was estimated that a 43% reduction in seabird could be achieved by limiting fishery openings to periods of high salmon abundance.

COST/PROBLEMS:

- While area/season closures may be beneficial in some circumstances, it is unlikely to be adequate as a mitigation measure for general use (Brothers et al. 1999a).
- Knowledge regarding seasonal/annual variability in patterns of species abundance is required to accurately allocate seasonal/area closures (Melvin et al. 1999).

BENEFITS:

- Seasonal and area closures have been shown to reduce seabird bycatch (SC-CAMLR 1995; SC-CAMLR 1998; Melvin et al. 1999).

Longlining

The different gear configurations used in pelagic and demersal longlining mean that not all mitigation measures are appropriate for both fishing methods. Table 1 lists some of the major mitigation measures reviewed in this document, and their applicability to demersal or pelagic longline fisheries.

TABLE1. APPROPRIATE (✓) MIGATION METHODS FOR DEMERSAL AND PELAGIC LONGLINE FISHING.

MITIGATION	PELAGIC	DEMERSAL
Bait	✓	
Bait-casting	✓	
Bird-scaring	✓	✓
Blue-dyed	✓	
Brickle	✓	✓
Capsule	✓	
Chute	✓	
Funnel		✓
Line shooter		✓
Line	✓	✓
Night-setting	✓	✓
Offal	✓	✓

CONCEALED BAIT

Underwater setting devices

During setting, these devices deliver baited hooks from the ship to below the water surface in order to avoid being taken by seabirds. To date, studies have shown mixed results in terms of the efficiency of underwater setting devices to reduce seabird bycatch. However, as development progresses, the devices are showing some promise as mitigation methods. The effectiveness of the different methods is influenced by sea conditions, stage of a fishing trip (i.e. beginning or end, which dictates vessel load distribution), propeller turbulence (on bait retention), and seabird assemblages attending the vessel. These factors vary between fishing grounds, and as such the capabilities of underwater setting devices need not be identical to achieve similar levels of effectiveness (Brothers et al. 1999a).

Funnel (lining tube)

METHOD:
Mustad underwater setting funnel is a commercially available underwater setting device (Brothers et al. 1999a). In contrast to other underwater setting devices, both the mainline and branchlines are fed through the funnel. Furthermore, this device delivers the groundline one metre below the surface in the propeller wash – much shallower than the pelagic chutes (E. Melvin pers. comm.).

RESULTS:
The funnel has been trialled in demersal longline fisheries in South Africa, Alaska and Norway under normal fishing operations, all of which noted a reduction, sometimes significant, in seabird bycatch when the funnel was used (Løkkeborg 1998; Løkkeborg 2001; Melvin et al. 2001b; Ryan & Watkins 2002). Despite these reductions, in some cases, the number of birds being caught while using the funnel was still relatively high (Løkkeborg 1998). Therefore, results from studies to date have found the funnel's performance to be inconsistent at reducing seabird capture.

COST/PROBLEMS:

- Suitable for demersal longline fisheries only (Brothers et al. 1999a).
- Can increase bait loss (Løkkeborg 1998), which can result in reduced catch rates (Ryan & Watkins 2002).
- Underwater setting tubes are expensive to fit (approximately UK£40,000) (Brooke 2004).
- The line would periodically jump out of the slot that runs along the side of the tube, rendering the tube useless as a seabird deterrent for that entire set (Melvin et al. 2001b).
- During high seas and when the vessel was front heavy, the bottom of the funnel was lifted out of the water during setting, resulting in the depth of the setting funnel decreasing and therefore making baited hooks available to seabirds (Løkkeborg 1998).
- Uncertain if it has the ability to set at sufficient depths in rough weather, particularly in the Southern Ocean in the presence of pursuit diving species such as the white-chinned petrel (Brothers et al. 1999a).

BENEFITS:

- Løkkeborg (2001) noted that catch rate for target fish species was higher.
- Reduction in seabird bycatch compared to when no deterrent was used (Løkkeborg 1998; Løkkeborg 2001; Melvin et al. 2001b; Ryan & Watkins 2002).

Chute

METHOD:
The earlier versions of the chute system relied on a paravane mechanism; a combination of water injection and venturi force accelerate baited hook passage down the chute (Brothers et al. 1999a). Later versions have had weights slipped into the hollow cavity down the length of the chute to hold the chute in the water (J. Molloy pers. comm.).

RESULTS:
The concept of the chute and early developmental trials in New Zealand (Barnes & Walshe 1997; Molloy et al. 1999). Brothers et al. (2000) undertook a comprehensive development trial off the waters of Tasmania. During this trial, modifications were made to the chute which demonstrated its capacity to minimise seabird interactions during line setting in pelagic longline fishing. However these results needed to be tested under normal fishing conditions.

Gilman, Brothers et al. (2003) tested the efficiency of a 6.5 m and 9 m chute in the Hawaii pelagic longline tuna and swordfish fisheries. The 6.5 m and 9 m chutes deployed baited hooks 2.9 m and 5.4 m underwater respectively (Gilman et al. 2003b). Both chutes were found to be effective at reducing seabird captures: 6.5 m chute - 0.01 captures/1000 hooks/bird for tuna gear; 9 m chute - 0.05 and 0.03 captures/1000 hooks/bird for tuna and swordfish gear respectively. Expressed as contact rate per 1000 hooks per albatross (normalised for albatross abundance), the chute was 95% effective at reducing albatross contacts with fishing gear compared to the control. Based on bait retention and hook setting interval, vessels would experience a gain in efficiency of between 14.7% and 29.6% when using the chute versus setting conventionally, when albatrosses were abundant behind the vessel (Gilman et al. 2003a).

During at-sea trials (with no control) under normal fishing operations in the Australian East Coast tuna and billfish pelagic longline fishery, high bycatch rates (1.081 birds/1000 hooks) were reported while using the chute (B. Baker pers. comm.). The majority (97%) of the birds caught were flesh-footed shearwaters (*Puffinus carneipes*).

COST/PROBLEMS:

- The chutes trialled in Hawaii performed inconsistently and was inconvenient due to manufacturing flaw and design problems (Gilman et al. 2003b).
- Slower hook setting rate with the chute compared to normal setting (Gilman et al. 2003a).
- Relatively expensive - US$5,000 for the hardware, plus additional cost of installation (Gilman et al. 2003b).
- Use of the chute in large swells caused fouled hooks and tangled gear (Gilman et al. 2003b).
- Requires a lot of deck space to stow (Gilman et al. 2003b).
- High bycatch (1.081 birds/1000 hooks) recorded while using the chute in Australian trials (B. Baker pers. comm.).

BENEFITS:

- Reduced seabird contacts and captures in Hawaii (Gilman et al. 2003b).
- May increase fishing efficiency due to increased bait retention (Gilman et al. 2003b).

Capsule

METHOD:
Since it's original conception in New Zealand by Dave Kellian, the capsule has gone through two design phases (Smith & Bentley 1997; Brothers et al. 2000). A weighted transportation capsule clamps the baited snood until the capsule reaches its determined depth. At this point the carry-over action of the capsule and retrieval action releases the bait (Smith & Bentley 1997). Baits set by the capsule can be delivered to a pre-selected depth which can be varied; cycle time is dependent upon the depth selected (Brothers et al. 2000). The most recent development to the method of deployment and retrieval of the capsule is a track that transports the capsule (J. Molloy pers. comm.).

RESULTS:
Development trials have been undertaken on pelagic longliners in New Zealand and Australian waters (Smith & Bentley 1997; Brothers et al. 2000). Despite design flaws being identified in these trials, the capsule noticeably lowered bird activity in the area immediately behind the vessel in comparison to hooks set manually, and no diving attempts were made. During the Australian trial, the capsule was capable of setting hooks at sufficient depth to avoid seabird interactions (excluding those occasions when tangles occurred). Brothers, Chaffey et al. (2000) noted that the majority of tangles were the result of the branchline catching on the capsule as it returned, or due to the hook catching on the ball.

COST/PROBLEMS:

- Suitable for pelagic longline systems only (Brothers et al. 1999a).
- Further development required to solve problems with tangling (Brothers et al. 2000).
- Relatively expensive.

BENEFITS:

- Versatility in the depths at which baits can be delivered (Brothers et al. 1999a).
- Compact and easily fitted to any size vessel, irrespective of associated gear configuration (Brothers et al. 1999a).
- Birds generally remained further astern roaming more widely (Brothers et al. 2000).

Bait casting/throwing machine

METHOD:

Bait-casting machines (BCMs) are used in pelagic longlining to mechanically cast the baited branchlines, placing them in the water at a distance from the longline in order to minimise line tangles (Brothers et al. 1999a).

RESULTS:

The utility of the BCM as a means of reducing seabird deaths was not fully tested during the trials conducted in the Southeastern Indian Ocean by Brothers (1993). Brothers (1993) noted that the effectiveness of the BCM is reliant on a number of factors, including using thawed baits and the deployment of properly constructed bird-scaring lines (BSLs) and poles (one for the port side throwing and one for the starboard side throwing).

Studies using observer data from Japanese longliners fishing in the Australian Fishing Zone (AFZ) and New Zealand EEZ, both recorded lower seabird bycatch rates when using a BCM compared to not using one (Duckworth 1995; Klaer & Polacheck 1998).

COST/PROBLEMS:

- The original bait-casting machines (Gyrocast) were designed with functions to mitigate seabird bycatch as well as labour saving; however such machines proved expensive to produce ($A20,000). Subsequent cheaper models were produced with only the labour saving functions (Brothers et al. 1999a).
- Applicable to pelagic longlining only (Brothers et al. 1999a).

BENEFITS:

- Possible increase in fishing effort or maintaining present fishing effort but reduced actual work due to reduced cycle time (Brothers 1993).
- Baits are not lost from hooks during machine throwing (Brothers 1993).

Blue-dyed bait

METHOD:

Thawing and dyeing bait blue is thought to reduced the seabirds’ ability to see the bait through camouflage (Gilman et al. 2003b), thus reducing interactions with fishing gear. However, Lydon & Starr (2005) proposed an aversion response by seabirds as the possible mechanism for reducing the attractiveness of blue-dyed baits to the birds.

RESULTS:
When blue-dyed bait was tested in the Hawaii swordfish pelagic longline fishery, Boggs (2001) recorded significantly lower contact rates for Laysan (*Phoebastria immutabilis*) and black-footed albatross (*P. nigripes*) compared to the control treatment (undyed bait). However, a subsequent comparative study of mitigation methods in this and the tuna fishery found that blue-dyed bait was less effective (significantly in some cases) at avoiding bird interactions than side-setting and the underwater chute (Gilman et al. 2003b). When combining the effects of bait retention and hook setting rates on fishing efficiency for seabird avoidance treatments employed using tuna gear, blue-dyed bait had the third highest fishing efficiency and would produce a gain in efficiency of 45.2% over fishing with the 6.5 m chute (Gilman et al. 2003b).

In a comparative study of Japanese Southern bluefin tuna pelagic longline vessels fishing off of Capetown, Minami & Kiyota (2004) recorded a lower seabird bycatch when using blue-dyed bait compared to using a BSL. During this study, one vessel recorded a reduction in catch rate of the target species when using blue-dyed bait.

Two blue-dyed bait pilot trials have been undertaken in New Zealand on pelagic longliners (Lydon & Starr 2005; DOC unpubl. report). Both studies recorded bird captures on undyed bait sets, but none when using dyed bait; however these results were not significant. Furthermore, Lydon & Starr (2005) observed a contrast in seabird behaviour around the longline between the two bait types (dyed and undyed) on six of the seven longline sets; while apparently indifferent to the blue-dyed bait in the first six sets, seabirds actively attacked both bait types on the final set.

Lack of blue-dyed bait trials in demersal fisheries may be due to the fact that they deploy many more hooks and as such use considerably more bait, making this approach less practical for the demersal fishery compared to the pelagic fisher (E. Melvin pers. comm.).

COST/PROBLEMS:
- Currently pre-dyed bait is not sold commercially, making the thawing and dying of bait impractical and inconvenient for the crew (Gilman et al. 2003b).
- Insufficient in minimizing bird mortality (Gilman et al. 2003b).
- May not be employed consistently by different crew (Gilman et al. 2003b).
- Variable results with regards to fishing efficiency (Manami & Kiyota 2004).
- Birds may habituate to the blue-dyed bait rendering it ineffective as a long-term mitigation solution (Lydon & Starr 2005).
- Reduction in target species catch rate has been recorded when using blue-dyed bait (Manami & Kiyota 2004).
- To date trialled only on pelagic longline vessels.

BENEFITS:
- Relatively inexpensive, approximately US$14 per set or US$1.00 per 100 squid (Gilman et al. 2003b).
- Safe to use.
- Catch rates of fish were greater in the Hawaiian tuna longline fishery when blue-dyed bait was used (Gilman et al. 2003a).

Side-setting

METHOD:
By setting fishing gear from the side of the vessel, the bait is thought to be sufficiently deep (i.e. out of seabird reach) by the time it reaches the stern (Gilman et al. 2003b; Sullivan 2004).

RESULTS:
A comparative at-sea trial in the Hawaii swordfish and tuna pelagic longline fisheries, found side-setting more effective at reducing seabird contacts and captures (in both fisheries) than blue-dyed bait or underwater setting chutes (9 m and 6.5 m) (Gilman et al. 2003b). To increase the efficiency of side-setting, a bird curtain was deployed when this method was used. There were no statistically significant differences between contact and capture rates for the three different side-setting positions (a short distance from the stern, port or starboard side) tested using tuna gear. When combining the effects of bait retention and hook setting rates on fishing efficiency for seabird avoidance treatments employed using tuna gear, side setting had the second highest fishing efficiency and would produce a gain in efficiency of 52.7% over fishing with the 6.5 m chute.

In New Zealand, side-setting was used at-sea on the Daniel Solander while fishing for ling; a total of six voyages were undertaken, each 6-7 weeks duration during which setting was from the side (P. Ballantyne pers. comm.). Four of the six voyages were observed by Ministry of Fisheries observers (generally two observers per trip). Seabird bycatch appeared to be reduced; however the line became tangled around the propeller on the third voyage while side-setting. Operational difficulties were encountered, with the side-setting depending on the prevailing weather and how the vessel set the gear in relation to the conditions. This was overcome, to some extent, by extending the line away from the vessel 1.5 m in a tube and also lowering the line closer to the water. Time loss was also a consideration in some conditions. In the case of Daniel Solander a change to side-setting was not too difficult as the line setting machinery was mounted forward in the vessel.

Sullivan (2004) reported that this method (=mid-ship setting) has been used in some demersal fisheries, and that seabird interactions with baited hooks were negligible on these vessels. In comparison, some side-setting demersal fishing vessels in Alaska have caught seabirds (E. Melvin pers. comm.).

COST/PROBLEMS:

- Some costs associated with initial alterations to vessel's deck design for side setting (Gilman et al. 2003a).
- Bird curtain (estimated cost US$50) recommended to be used concurrently when side-setting (Gilman et al. 2003a).
- Potential increased safety risk to crew member clipping branchlines (Gilman et al. 2003a).
- When side setting in heavy weather it may be unavoidable to have the swell come on to the side of the boat; this may potential cause discomfort to crew, particularly on smaller boats (Gilman et al. 2003a).
- The line became tangled around the propeller in the New Zealand trials, however this was overcome by extending the line away from the vessel 1.5 m in a tube and also lowering the line closer to the water (P. Ballantyne pers. comm.)
- Potential benefits of side-setting for reducing seabird bycatch may be limited to larger vessels (i.e. if bait sinks out of the range of seabirds at 80 m astern and the gear is

moved 10 m forward of the stern, this yields a saving of lonely 10 m) (E. Melvin pers. comm.).

BENEFITS:

- Shown to be effective at reducing seabird interactions and mortality in some fisheries (Gilman et al. 2003a).
- Practicable for crew to use (Gilman et al. 2003a).
- Crew in the Hawaiian trials perceived this method as causing fewer gear tangles compared to conventional stern setting (Gilman et al. 2003a).
- Requires a nominal amount of initial expense to employ (Gilman et al. 2003a).
- No additional effort required to implement the method once the initial conversion is made (Gilman et al. 2003a).
- Potential to increase fishing efficiency through the effects of bait retention and hook setting rates (Gilman et al. 2003a).
- Potentially effective at reducing seabird interactions on a wide range of longline vessel deck designs (Gilman et al. 2003b).
- No incidences of gear being fouled in the propeller while side-setting from any of the three positions in the Hawaiian trials (Gilman et al. 2003a).

Night-setting

METHOD:

Night-setting may reduce seabird mortality either because fewer birds are active at night, thus reducing the numbers of seabirds exposed to fishing operations, or because the birds have more difficulty seeing the baited hooks (Murray et al. 1993; Cherel et al. 1996; Barnes & Walshe 1997; Belda & Sánchez 2001). Night-setting is particularly beneficial if slow sinking baits are being set (Brothers et al. 1999a).

RESULTS:

Belda & Sánchez (2001) investigated the influence of the time of setting on seabird bycatch in the Mediterranean demersal and pelagic longline fisheries. Significant differences were found in the number of seabirds caught at different hours weighted by the number of hooks set at each hour for both fisheries: birds were more abundant in setting operations taking place during sunrise (demersal fishery) and in the hours previous to sunset (pelagic fishery) (Belda & Sánchez 2001).

In the Patagonian toothfish longline fishery in the Kerguelen EEZ, Weimerskirch et al. (2000) reported night-setting significantly reduced the overall number of birds caught (0.91±1.72 birds/1000 hooks during the day, 0.17±0.82 birds/1000 hooks at night). This significant reduction in bycatch was observed for white-chinned petrel and all albatross species except the wandering albatross. In the demersal (Spanish system) Patagonian toothfish longlining fishery around the Falkland Islands, Reid & Sullivan (2004) recorded no birds being caught in the night sets.

Studies using observer data from Japanese longliners fishing in the AFZ and New Zealand EEZ, both recorded lower seabird bycatch rates when setting at night compared to during the day (Duckworth 1995; Klaer & Polacheck 1998). Klaer & Polacheck (1998) noted that seabird bycatch was five times greater during the day sets (0.252 birds per 1000 hooks) compared to night sets (0.022 birds per 1000 hooks).

Associated with night-setting is the influence of moon phase on seabird abundance and bycatch rates; the chance of catching seabirds during the full half-phase of the moon is greater than during the new half-phase (Ashford & Croxall 1998; Klaer & Polacheck 1998; Baird & Bradford 2000).

Shiode et al. (2001) investigated the influence of night-setting on target species catch rates in the Japanese Southern bluefin tuna longline fishery. Using data from Japanese Real Time Monitoring Program, fluctuations (both increases and decreases) in target catch rate were recorded in relation to night setting ratios.

COST/PROBLEMS:

- Crew safety may be compromised due to reduced lighting levels under which to work (Brothers et al. 1999a).
- Concerns regarding the possibility of a negative impact on target fish catch rates. Fluctuations (both increases and decreases) in target catch rate have been recorded (Shiode et al. 2001).
- Possible lowering of the bycatch rate of one suite of seabird species (diurnal feeders) at the expense of another (crepuscular/nocturnal feeders) (Brothers et al. 1999a).
- Night setting has limited potential as a comprehensive approach, particularly in high latitude fisheries there is little to no night for part of the year, and coupled with full moon limitations (Brothers et al. 1999a).

BENEFITS:

- Suitable for both bottom and pelagic longline fisheries (except for fisheries in high latitudes during the summer) (Sánchez & Belda 2003).
- Can be used in both large and small vessels (Sánchez & Belda 2003).
- Night-setting has been found to be an effective mitigation measure to reduce seabird incidental capture in a range of locations and fisheries (Duckworth 1995; Klaer & Polacheck 1998; Reid & Sullivan 2004).

DETERRENT

Bird-scaring line

Bird-scaring line devices are known by a variety of names, including: streamer lines (paired and single), tori lines, tori pole streamers, bird lines and bird scarers. This review encompasses all such devices, but refers to them collectively throughout the text as bird-scaring lines (BSLs).

METHOD:
Brothers et al. (1999) define a BSL as any device that when deployed astern during line setting deters birds from taking baited hooks. Brothers (1995) describes a BSL that is correctly constructed and correctly used as a conspicuous moving fence, which creates an impassable barrier excluding seabirds from the area of the water where the baited hooks enter. BSL design differs between fisheries: in the Southern Hemisphere tuna pelagic longline and demersal fisheries, the BSL are generally lines with suspended streamers, whereas those used in the Alaskan fisheries are a line with towed objects such as a buoy bag (Brothers et al. 1999a). The main components of a BSL are the line, streamer lines and mounting pole (or

high point for attachment) (Brothers 1995). A mechanised deployment and retrieval reel is not essential, but does eliminate bird line tangles and manual labour (Brothers 1995).

RESULTS:
A reduction, significant in most cases, in seabird contacts and captures have been noted in a number of studies testing BSLs in the Norwegian commercial demersal longline fishery (Løkkeborg & Bjordal 1992; Løkkeborg 1998; Løkkeborg 2001; Løkkeborg & Robertson 2002; Løkkeborg 2003), Hawaiian pelagic swordfish longline fishery (Boggs 2001), Chilean demersal Patagonian toothfish Spanish-style longline fishery (Ashford & Croxall 1998), Alaskan demersal longline fishery (Melvin et al. 2001b), Japanese Southern bluefin tuna pelagic longline fisheries (Manami & Kiyota 2004) and the New Zealand pelagic tuna longline and demersal ling autoline fisheries (Imber 1994; Smith 2001).

Trials in the New Zealand ling (*Genypterus blacodes*) demersal autoline fishery on the Chatham Rise found that the aerial section of the BSL appeared to keep all seabird species except cape pigeons (*Daption capense*) away from the longline (Smith 2001). Smith (2001) described the BSL as having most effect on the larger seabird species, especially *Diomedea* albatrosses. This is in part reflected in the species composition of the 12 birds (0.0093 seabirds per 1000 hooks set) caught during the trial: 10 grey petrels (*Procellaria cinerea*), one Chatham albatross (*Thalassarche eremita*) and one cape pigeon.

Løkkeborg (2001) tested an advanced and a simple BSL in the Norwegian demersal longline fishery: both types of BSL significantly reduced seabird bycatch (no BSL – 1.06 birds per 1000 hooks; simple BSL – 0.03 birds per 1000 hooks; advanced BSL – 0.00 birds per 1000 hooks), reduced bait loss and significantly increased the catch rate of the target species.

Both the paired-BSLs (flying streamer lines from both the port and starboard side of the vessel) and single-BSLs trialled by Melvin, Parrish et al. (2001) in the Alaskan demersal longline fishery reduced seabird bycatch; however the paired-BSL was found to be the more effective of the two designs (no BSL – 0.094 birds per 1000 hooks; single-BSL – 0.006 birds per 1000 hooks; paired-BSL – 0.00 birds per 1000 hooks).

Observer data analysed for both New Zealand domestic and Japanese tuna longlining in the New Zealand EEZ, found that the presence or absence of a BSL had no statistically significant effect on seabird bycatch rates during either the day or night (Duckworth 1995; Baird & Bradford 2000).

A number of factors have been shown to influence the effectiveness of a BSL, including weather conditions, quality and mounting height (Duckworth 1995; Løkkeborg 1998; Brothers et al. 1999a). Correct mounting height of a BSL is critical for achieving maximum effectiveness; it increases the distance of hooked bait protection and prevents the fishing longline interfering with the bird line (Keith 1998; Brothers et al. 1999a).

COST/PROBLEMS:

- Commercially-produced BSLs range in cost from $A200−300. A mounting (“tori”) pole may be a further associated cost (Brothers et al. 1999a).
- The design of a BSL must be refined on individual vessels in order to achieve maximum effectiveness at reducing seabird bycatch. For example, the placement of streamers on the BSL is dependent on the length of the aerial section and the height of the attachment point on the vessel or pole (Brothers 1995; Keith 1998).

BENEFITS:

- In most situations, BSLs significantly reduce seabird interactions with fishing gear and mortality (Løkkeborg & Bjordal 1992; Imber 1994; Ashford & Croxall 1998; Løkkeborg 1998; Boggs 2001; Løkkeborg 2001; Melvin et al. 2001b; Smith 2001; Løkkeborg & Robertson 2002; Manami & Kiyota 2004).
- Reduced bait loss has been recorded when using a BSL, which may result in an increase in target species catch rates (Løkkeborg 1998; Løkkeborg 2001).
- Deployment is relatively quick and easy.
- BSLs are the most cost effective deterrent and are applicable to most longline and trawl fisheries (E. Melvin pers. comm.).

Brickle curtain

METHOD:
A protective curtain positioned around the hauling bay to reduce hook-ups by deterring birds from approaching too close to the hauling bay (Sullivan 2004). The curtain consists of a series of lines hanging seaward from a rope positioned around the hauling bay (Sullivan 2004).

RESULTS:
Anecdotal evidence indicates that the Brickle curtain can effectively discourage birds from seizing baits in the hauling area (Brothers et al. 1999a). With regards to the Falkland Islands longline fisheries, Sullivan (2004) noted that some species (particularly black-browed albatross and cape petrels) can become habituated to the curtain when used over long periods; therefore they are best used periodically (i.e. when there are high densities of birds around the hauling bay) in order to remain effective as a mitigation method.

COST/PROBLEMS:

- Possible habituation by birds to the curtain (Sullivan 2004).

BENEFITS:

- Suitable for pelagic and demersal longline fisheries (Brothers et al. 1999a).
- Low cost for materials (Brothers et al. 1999a).
- Safe for the crew to use (Brothers et al. 1999a).
- No negative impact on target fish catch rates or non-bird bycatch (Brothers et al. 1999a).

Fish oil

METHOD:
Oil is extracted from fish bycatch species and dispensed over the stern of the vessel, creating a slick in the water over the longline (Pierre & Norden 2006).

RESULTS:
At-sea trials (preliminary and under normal fishing operations) of school shark (*Galeorhinus galeus*) liver oil in the snapper pelagic longline fishery in the Hauraki Gulf of New Zealand resulted in a significant reduction in the numbers of seabirds and the numbers of dives on baits, compared to the seawater and canola oil (Pierre & Norden 2006). This method was effective in a mixed species inshore seabird community numerically dominated by flesh-footed shearwaters (*Puffinus carneipes*).

COST/PROBLEMS:

- Unknown effect on ecosystem of introducing large amounts of fish oil into the marine environment (Pierre & Norden 2006).
- Unknown effect of fish oil on feather surface of the birds (Melvin et al. 2004; Pierre & Norden 2006).
- Unknown potential for habituation over time (Pierre & Norden 2006).

BENEFITS:

- Produced from fish bycatch or discards (Melvin et al. 2004; Pierre & Norden 2006).
- Proven to significantly reduce the numbers of seabirds and the numbers of dives on baits (Pierre & Norden 2006).
- No significant differences between the total numbers of fish, or the numbers of the target fish species, captured on longlines deployed while using shark liver oil compared to the seawater control (Pierre & Norden 2006).

Water cannon

METHOD:

A high pressure hose is used to shoot water over the setting area in order to scare birds from the area where the baited hooks enter the water.

RESULTS:

Trials conducted on Japanese pelagic longliners tested various combinations of nozzle tips, flow stabilizers, and emission angles and mixing ice particles to maximize the range of the water jet (Kiyota et al. 2001). Observations from the trial indicated that seabirds avoided the water jet and did not try to fly under the water curtain, but the water jet was deteriorated by cross wind. Also, the use of this device during cold windy conditions adversely affected the crew and as such was switched off during these instances (Brothers et al. 1999a).

COST/PROBLEMS:

- The effectiveness of the water jet system is limited and insufficient to avoid incidental takes of seabirds by itself (Kiyota et al. 2001).
- Risks to crew safety and comfort (Brothers et al. 1999a).

BENEFITS:

- Able to be used by pelagic and demersal longline fisheries (Brothers et al. 1999a).

Acoustic deterrents

METHOD:

Any noise used to deter birds away from the vessel. Methods used include firing a shotgun, canons, hitting the steel hull, or commercial devices that emit high frequency and loud noises or distress calls (Brothers et al. 1999a).

RESULTS:

Anecdotal observations have reported acoustic deterrents as being effective at temporarily scaring birds away (Crysell 2002). However, no detectable response was found during a trial in which seabirds at a breeding colony were subjected to high-frequency and loud noise as well as distress calls (Brothers et al. 1999a).

COST/PROBLEMS:

- Birds may habituate to the noise, making acoustic deterrents ineffective as long-term mitigation measures (Brothers et al. 1999a).
- Noise may not repel birds over distances sufficient to reduce bycatch (especially deep-diving species).

BENEFITS:

- Temporarily scares birds (Brothers et al. 1999a).

Magnetic deterrents

METHOD:
Commercially available magnetic devices claim to interfere with receptors that birds have for detecting magnetic fields (Brothers et al. 1999a).

RESULTS:
The magnetic device was trialled at-sea on a Japanese tuna longliner within the AFZ, and near a shy albatross (*Thalassarche cauta*) breeding colony in Tasmania (Brothers et al. 1999b). The device did not significantly affect the catch of seabirds during the at-sea trials, and there was no apparent effects in the behaviour of birds at the breeding colony (Brothers et al. 1999b).

COST/PROBLEMS:

- Unlikely to offer protection to the 100 m or more astern required with present line-setting methods (Brothers et al. 1999a).

Electric deterrents

METHOD:
The Super DC pulse system is a device designed to produce an electric pulse field in the water in order to deter birds.

RESULTS:
Kitamura et al. (2001) tested the Super DC pulse system on adult mallards in an experimental tank, observing the bird's behaviour under various levels of voltage and pulse stimulation. The mallards jumped out of the tank at 400–500 V. The feasibility study for producing electric fields in the open water concluded that carrying the huge generator on a southern bluefin tuna fishing vessel required to produce an effective electric pulse field was impractical in terms of cost, space and safety (Kitamura et al. 2001).

COST/PROBLEMS:

- Impractical as a mitigation measure in terms of cost, space and safety (Kitamura et al. 2001).

INCREASED SINKING SPEEDS

Integrated and line weights

METHOD:
Increasing line sink rates are likely to decrease the chance of interactions between seabirds and fishing gear, and consequent incidental mortality of seabirds during fishing. Adding weights to the fishing gear (either the branchlines or the mainline), or integrating weight into the line, may achieve a faster line sink rate (measured by time depth recorders).

Line weighting studies can be categorised as those investigating line sink rates of various weighting and spacing regimes, and those which investigate the effectiveness of reducing seabird bycatch by these different regimes. Both types of studies are described below in order to provide approximate guidelines for useful weighting regimes.

RESULTS:
Brothers et al. (2001) tested the effect of line weighting (20 g, 40 g and 80 g swivels) on sink rate and bycatch on 10 pelagic longline vessels within the AFZ. The fastest sink rates were recorded for hooks with 80 g at 0 m or 1 m (0.68 and 0.71 m/s respectively). A baited hook with no weight attached sank 43% slower than a baited hook with an 80 g weight. Irrespective of how much weight was added, hooks sank more rapidly in the first 4 m than they did to 10 m. Vessels with faster line sink rates were recorded as having lower seabird bycatch rates than those with slower line sink rates.

In their study on a Southern bluefin tuna pelagic longline vessel off the southeast coast of the South Island, Anderson & McArdle (2002) recorded the depth of a baited hook after 30 seconds on an unweighted branchline (5.57 m), a monofilament branchline with a 60 g lead swivel (13.44 m), and a branchline composed of lead core cord (7.27 m). Based on these sink rates it was concluded that the addition of a 60 g weight removes the baited hooks from the recorded diving range of white-chinned petrels, shy albatross, black-browed albatross, grey-headed albatross and light mantled sooty albatross (*Phoebetria palpebrata*), but not sooty shearwaters (*Puffinus griseus*) (Anderson & McArdle 2002).

Boggs (2001) tested the effectiveness of attaching 60 g swivel weights 3.7 m above the bait in the Hawaii-based pelagic longline swordfish fishery. Contact rates were significantly lower for weighted lines compared to unweighted lines: expressed as contact rate per bird per 100 branchlines, the weights were 93% and 91% effective for black-footed and Laysan albatrosses respectively.

Two external line weighting regimes (38 g swivels and 60 g swivels placed 7.3 m and 5.5 m from the hook respectively) were trialled (no control) under normal fishing operations in the Australian East Coast tuna and billfish pelagic longline fishery (B. Baker, pers. comm.). Recorded bycatch rates 0.167 and 1.04 birds/1000 hooks for the 38 g and 60 g trials respectively. The majority of birds caught were flesh-footed shearwaters.

Robertson (2000) tested different line weighting regimes (6.5 kg every 30, 50, 70, 100, 140 and 200 m) on a Patagonian toothfish autoline demersal longline vessel fishing on the Patagonian shelf near the Falkland/Malvinas Islands. As expected, sink time increased as weight spacing increased; however, sink rates to any depth did not vary greatly with weight spacings >70 m. Sink rates with weight spacings of 35 and 50 m were greatest close to the surface.

Smith (2001) analysed line sink rates using external weighting (2.5 kg and 5 kg) and no weighting on a New Zealand ling demersal autoline fishing vessel working on the Chatham Rise. Line sink rate varied significantly between sampling positions; however, the maximum line weighting regime (5 kg per 400 m) was not found to accelerate line sink rate on the vessel, suggesting that weights would need to be added at much closer intervals (e.g. 40 m) (Smith 2001).

Results from a study investigating weight regimes (4.25, 8.5 and 12.75 kg attached at 40 m intervals) on a Spanish-rigged demersal longline for the toothfish fishery around South Georgia, reported a significant reduction in seabird mortality when 8.5 kg was used compared to 4.25 kg, but no further significant reduction when 12.75 kg was used (Agnew et al. 2000).

Melvin, Parrish et al. (2001) reported the effect of weighted gear on seabird bycatch to be variable when tested in the Alaskan cod (10 lb/90 m) and sablefish (0.5 lb/11 m) demersal longline fisheries. In the first year of the trial, adding weight to gear significantly reduced seabird bycatch relative to no deterrent by 37% and 76% for the sablefish and cod fisheries respectively. However, in the second year of the trial, the addition of weights did not improve the already high bycatch reduction of paired-BSLs (Melvin et al. 2001b).

The effectiveness of integrated weight (IW) (50g lead/m) in reducing white-chinned petrel and sooty shearwater mortality was tested in the New Zealand ling demersal autoline longline fishery off of Solander Island, New Zealand (Robertson et al. 2004b). When using IW compared to unweighted (UW) line, a 98.7% and 93.5% reduction in mortality of white-chinned petrels was recorded during 2002 and 2003 respectively. For sooty shearwaters, a 100% and 60.5% reduction in mortality was recorded during 2002 and 2003 respectively. Catch rates of ling and non-target fish species were not affected by use of IW lines (Robertson et al. 2004b).

Using two different vessels, Robertson, Smith et al. (2004) recorded line sink rates of UW silver line, IW silver line and IW polyester line in the New Zealand ling demersal autoline longline fishery off of Solander Island (NZ) and the Patagonian toothfish demersal longline fishery around Heard Island. While there was no difference in sink rates between vessels, there was a statistically significant difference between line types; the mean sink rate for UW silver was 0.109 ± 0.022 m/s, IW silver was 0.239 ± 0.018 m/s and IW polyester was 0.272 ± 0.022 m/s. However, adding external weights to unweighted lines resulted in a sink profile similar to IW lines.

COST/PROBLEMS:

- Concern for crew safety when using added external weights (Brothers et al. 2001; Melvin et al. 2001b; Anderson & McArdle 2002).
- Use of lead weighting (either external or integrated) increases the risk of this potentially harmful compound accumulating in the marine environment.
- Increased cost due to the extra swivels/weights (Brothers et al. 2001).
- Attaching external weights close to the hook may incur an extra cost due to increased loss of weights when lines are cut by bycatch (especially sharks) (Brothers et al. 1999a).
- Variable results regarding the effectiveness of line weighting were recorded in the Alaskan demersal longline fishery (Melvin et al. 2001b).

BENEFITS:

- Reduced seabird bycatch in demersal and pelagic longline fisheries (Agnew et al. 2000; Boggs 2001; Robertson et al. 2004b).
- Lead core line is safe for crew to use (Anderson & McArdle 2002).
- Appropriate weighting can keep hooks in the right depths for longer, so improving catch potential in both demersal and pelagic fisheries (Brothers et al. 2001; Melvin et al. 2001b).
- Catch rates of target and non-target fish species were not affected by use of IW lines (Robertson et al. 2004b).

Line shooter

METHOD:

Setting a demersal longline under tension may result in hooks remaining on the surface and accessible to seabirds for a longer period (Sullivan 2004). A line shooter sets the line without tension, enabling the line to set closer to the vessel and perhaps increase the sink rate (Melvin et al. 2001b; Løkkeborg & Robertson 2002). This device consists of a pair of hydraulically operated wheels that pull the line through the auto-baiter, delivering the line slack into the water.

RESULTS:

The results of the Mustad line shooter trials in the Norwegian and Alaskan demersal longline fisheries have shown remarkably varying results with regards to reducing seabird bycatch (Melvin et al. 2001b; Løkkeborg & Robertson 2002). Løkkeborg & Robertson (2002) reported a reduction (though not significant) in the number of seabirds caught when using a line shooter (32 birds caught using no mitigation device, 13 in sets with the line shooter). Lines set with the shooter reached 3 m depth in 22.6±4.1 s (15% faster), compared to 26.6±7.3 s without the shooter. However, sinking rates were similar beyond 3 m depth (Løkkeborg & Robertson 2002). In contrast, Melvin, Parrish et al. (2001) reported total seabird (including short-tailed shearwaters *Puffinus tenuirostris*) catch per unit effort significantly increased by 54% when a line shooter was used compared to sets made with out the shooter.

Observations were made on the Avro Chieftain while using a line setter in the Ross Sea in conjunction with IWL, with the aim of trying to sink the IWL at the CCAMLR requirement of 0.3 m/sec, without putting weights on. Sink rates were monitored as per CCAMLR requirements. Using bottle test sink rates, the sink rates were found to exceed 0.7 m/sec (over twice the required CCAMLR sink rate at that time) and getting up to 2 m/sec. More accurate sink trials were to be conducted in order to assess the profile of the sink rate using TDRs, however these were never done as CCAMLR altered the sink rate to one that was achievable without using the line setter when using IWL (M. McNeill pers. comm.).

COST/PROBLEMS:

- Using a line shooter was shown to increase seabird bycatch in the Alaskan cod demersal longline fisheries (Melvin et al. 2001b).
- Requires additional crew to set gear (Melvin et al. 2001b).
- Results of trials using line shooters have been variable (Melvin et al. 2001b; Løkkeborg & Robertson 2002).

BENEFITS:

- Target fish catch rate did not vary when using a line shooter compared to not using one (Løkkeborg & Robertson 2002).

Bait condition

METHOD:

The condition of the bait (frozen/thawed, swim-bladder inflated/deflated) can influence its buoyancy and therefore availability to birds (Brothers et al. 1999a).

RESULTS:

Results from an experiment assessing the sink rates in a tank of stationary salt water found that bait size (large versus small), bait condition (frozen versus thawed), and bait species (mackerel scad *Decapterus macarellus,* chub mackerel *Scomber japonicus*, Japanese pilchard *Sardinops melanostichus* and squid *Todarodes pacificus*) had significant effects on sink rates (Brothers et al. 1995). Bait condition had the most powerful effect, with thawed baits sinking and frozen baits floating. Fish with inflated swim bladders were the exception, floating even when they were thawed. The sink rate of bait with inflated swim bladders may be solved by adding a 20 g lead sinker or swivel to a baited hook (Brothers et al. 1995).

Analyses of observer data from New Zealand domestic and Japanese pelagic tuna longlining in the New Zealand EEZ and for Japanese pelagic longliners fishing in the AFZ, have reported reduced seabird bycatch (only in the summer for the AFZ data) when using thawed bait compared to using frozen or poorly thawed bait (Duckworth 1995; Klaer & Polacheck 1998; Brothers et al. 1999b).

Contrary to previous studies, Anderson & McArdle (2002) study using squid baits, recorded partially thawed baits sinking faster than thawed baits. These results provide further support for Brothers et al. (1995) suggestion that sink rates may vary between bait species.

COST/PROBLEMS:

- Compared to frozen baits, thawed baits pull off the hooks more easily when they are thrown from the ship (Brothers et al. 1999a).
- Many vessels have inadequate thawing facilities, which lead to inconsistency in the thaw state of bait (Brothers et al. 1999a).
- Possible costs of installing thaw racks which incorporate a sprinkler system (Brothers et al. 1999a).
- Applicable only to pelagic longlining.

BENEFITS:

- Compared to frozen baits, thawed baits are easier to apply to hooks (Brothers et al. 1999a).
- Remove discomfort for crew through handling thawed rather than frozen bait (Brothers et al. 1999a).
- Observer data recorded a reduction in bycatch when using thawed bait compared to frozen or partially thawed bait (Duckworth 1995; Klaer & Polacheck 1998; Brothers et al. 1999b).
- Bait size (large versus small), bait condition (frozen versus thawed), and bait species had significant effects on sink rates (Brothers et al. 1995).

Concepts not trialled

Methods designed to conceal bait include the Bait Spider, smart lures, and hull-integrated underwater setting (Anonymous 1998; Brothers et al. 1999a; Anonymous 2000). Deterrent methods that have not been trialled include the Hose, the 'Brigette Bardot' laser gun, the Ultrasonix electronic protection bird scarer, and emitting smoke from refuse disposal incinerators (Brothers et al. 1999a; Crysell 2002). Frozen block bait or glazed bait have been suggested as methods for improving sink rates (Anonymous 2000).

Trawling

WARP CABLE AND THIRDWIRE PROTECTION

Falkland Island's Warp Scarer

METHOD:
A device attached to the warps to create a protective area around the warp. This consists a series of ring style devices (joined by a length of square netting) with rollers installed to allow easy cable adjustment (including allowance of cable splices) (Sullivan et al. 2004b). From each ring a rope with reflective tape hangs to the sea, to scare birds from the warp (Sullivan et al. 2004b). The warp scarer is deployed after shooting the net and retrieved prior to hauling (Sullivan et al. 2004b).

RESULTS:
During a trial in the Falkland Islands pelagic finfish trawl fishery, lower mortality rates (per hour) were recorded for the Warp Scarer (0.06) compared to the control (no mitigation device; 0.76) (Sullivan et al. 2004b). Furthermore, in comparison to the control, the Warp Scarer significantly reduced total contacts (6.14 contacts/hour compared to 58.34 contacts/hour) and heavy contacts (0.93 contacts/hour compared to 17.46 contacts/hour). The one mortality recorded during the Warp Scarer trial occurred during shooting (i.e. before the device was deployed).

COST/PROBLEMS:
- Seabird mortalities may occur as the device is deployed after shooting and retrieved before hauling (Sullivan et al. 2004b).
- Approximately US$800 (Sullivan et al. 2004b).
- Concerns for crew safety due to the requirement of a crew member to reach outboard of the stern of the vessel during deployment (Sullivan et al. 2004b).

BENEFITS:
- Significant reduction in heavy and total seabird contacts with the trawl warps (Sullivan et al. 2004b).
- Requires little storage space (Sullivan et al. 2004b).
- No costs associated with fitting (Sullivan et al. 2004b).
- Easy to maintain and replace (Sullivan et al. 2004b).

Bird-scaring lines

METHOD:
In order to provide protection over both warp cables on a trawler, Sullivan et al. (2004) used two BSLs: one attached to a side arm that reached 2 m outboard from the stern of the vessel on the side with the discharge chute, and the other line attached to the rail in the centre of the fantail (the deck level above the trawl deck). On trawlers, BSLs are generally deployed after shooting and retrieved prior to hauling (Sullivan et al. 2004b).

RESULTS:
No mortalities were recorded during BSL trials in Falkland Islands pelagic finfish trawl fishery, compared to 0.76 mortalities per hour for no mitigation device. Mortalities were recorded for black-browed albatross, southern giant petrels (*Macronectes giganteus*) and cape petrel (Sullivan et al. 2004b). Total contact rates were significantly reduced when using the BSL (1.00 contacts/hour) compared to no BSL (58.34 contacts/hour), and so too were heavy contacts (BSL – 0.29 contacts/hour; no BSL –17.46 contacts/hour) (Sullivan et al. 2004b).

Observations were collected anecdotally by Melvin et al. (2004) to determine the relative merits of single- and paired-BSLs in the Bering Sea pollock (*Theragra chalcogramma*) trawl fishery. Short-tailed shearwaters and northern fulmar (*Fulmarus glacialis*) were the most abundant seabirds throughout the trial. In most configurations, BSLs virtually eliminated seabird air and water contacts with the third wire: 16.04 contacts/hour were recorded with no deterrent, compared to 0.8 contacts/hour with the paired-BSLs and 4.72 contacts/hour with the single-BSL.

Observations and data collected from vessels in the South Georgia icefish trawl fishery did not indicate a significant reduction in bycatch while using BSLs (Hooper et al. 2003).

COST/PROBLEMS:
- Approximately US$40 (Sullivan et al. 2004b).
- Mortalities may occur when the device is deployed after shooting and retrieved before hauling (Sullivan et al. 2004b).
- When using BSLs as a third wire deterrent, more work is needed to make them track predictably and minimize the potential for fouling on gear during haulbacks (Melvin et al. 2004).

BENEFITS:
- Require little storage space (Sullivan et al. 2004b).
- No costs associated with fitting (Sullivan et al. 2004b).
- Easy to maintain and replace (Sullivan et al. 2004b).
- Deployment only requires buoys to be thrown in to the water (Sullivan et al. 2004b).
- The use of two BSLs appears to provide protection of both warp cables (Sullivan et al. 2004b).
- BSLs are the most cost effective deterrent and are applicable to most longline and trawl fisheries (E. Melvin pers. comm.).
- BSLs have been shown to reduce seabird mortalities (Melvin et al. 2004; Sullivan et al. 2004b).
- BSLs are relatively inexpensive compared to other mitigation methods.

Boom array and buoy line

METHOD:
A boom with lines attached that extended to the water and a buoy on a line attached to the rail (Melvin et al. 2004).

RESULTS:
During a pilot test of the boom array and buoy lines in the Bering Sea pollock trawl fishery, no contacts were recorded when either method were deployed; however, the buoy was less effective than the boom at keeping birds from nearing the warp (Melvin et al. 2004)

BENEFITS:
- The multiple lines of the boom array excluded birds from a broader swath of the plume, could be maintained in the area outboard of the wire, and could be permanently deployed with no negative effect on deck crew operations (Melvin et al. 2004).

Snatch block

METHOD:
In order to have the third wire enter the water as close to the stern as possible, it was run through a snatch block directly below the third wire block (see Figure 1 in Melvin, Dietrich et al. 2004).

RESULTS:
Observations were collected anecdotally by Melvin et al. (2004) to determine the relative merits of the snatch block in the Bering Sea pollock trawl fishery as a third wire mitigation method. The contact rate was lower when the snatch block (1.0 contacts/hour) was used compared to no deterrent (16.04 contacts/hour).

COST/PROBLEMS:
- Retrofitting of the vessel would be required (Melvin et al. 2004).

BENEFITS:
- Based on limited observations, Melvin et al. (2004) believe the concept has strong merit as a method to reduce seabird contacts with the third wire.

Third wire scarers

METHOD:
Scarer devices (four options) were attached directly to the third wire (see Figures 2 and 4 in Melvin, Dietrich et al. 2004).

RESULTS:
Anecdotal observations made by Melvin et al. (2004) in their pilot tests in the Bering Sea pollock trawl fishery, reported that all but one (trial 2) third wire scarer were effective at reducing seabird strikes.

COST/PROBLEMS:
- In general, all the third wire scarers that were tested were difficult to deploy and manage (Melvin et al. 2004).

- The devices created potential unsafe conditions for the deck crew (Melvin et al. 2004).
- When retrieving the devices during haul back, care had to be taken to keep them clear of fouling the third wire block (Melvin et al. 2004).

BENEFITS:

- Appeared to be effective at reducing seabird strikes.

Bird baffler

METHOD:

The bird baffler (originally devised by Keith Brady in New Zealand) consists of a tower fitted to each of the two quarters of the stern gantry. Two steel arms (one aft of the stern and one outboard), with ropes and plastic cones at the seaward end are lowered from each tower (Sullivan et al. 2004b).

RESULTS:

During a trial in the Falkland Islands pelagic finfish trawl fishery, lower mortality rates (per hour) were recorded for the Brady Baffler (0.07) compared to the control (no mitigation device; 0.76) (Sullivan et al. 2004b). Mortalities were recorded for black-browed albatross, southern giant petrels and cape petrel. While the baffler reduced heavy contacts compared the control (9.71 contacts/hour and 17.46 contacts/hour respectively), the rates of total contacts did not differ significantly between the two (44.78 contacts/hour and 58.34 contacts/hour respectively) (Sullivan et al. 2004b).

To date, there are no published studies from New Zealand trawl fisheries proving that bird bafflers significantly reduce seabird bycatch and interactions with fishing gear. New Zealand Ministry of Fisheries observer data collected from the Auckland Island squid trawl fishery (2004/05) recorded a reduction in heavy bird contacts with the warps when a bird baffler was used; however because this observed baffler effect was largely associated with vessels, it may be an artefact (Abraham 2005). Analysis of New Zealand Ministry of Fisheries observer data for squid trawling over three seasons (2002/03, 2003/04, 2004/05) has shown that the use of bird bafflers as a mitigation measure does not significantly reduced seabird bycatch (p = 0.767) (Conservation Services Programme unpubl. data). Furthermore, there is great variability in the design and deployment of bird bafflers in this fishery (W. Norden pers. comm.).

COST/PROBLEMS:

- Approximately US$4,800 plus fitting (Sullivan et al. 2004b).
- Did not provide as much protection to the warp cables as BSLs or the Warp Scarer (Sullivan et al. 2004b).
- The use of bird bafflers as a mitigation measure over three years of fishing in the New Zealand squid trawl fishery did not significantly reduce seabird bycatch (Conservation Services Programme unpubl. data).
- Great variability in the design and deployment of bird bafflers, possibly influencing the effectiveness.

BENEFITS:

- Reduction in heavy seabird contacts and mortalities recorded during trials at the Falkland Islands compared to using no mitigation device (Sullivan et al. 2004b).

- The device can be set at the beginning of a fishing trip and retrieved at the end of the trip or in extreme weather (Sullivan et al. 2004b).

Fish oil

METHOD:
Oil is extracted from bycatch fish species and dispensed over the stern of the vessel, creating a slick in the water behind the vessel.

RESULTS:
Melvin et al. (2004) collected anecdotal observations regarding the effectiveness of pollock oil as a seabird deterrent in the Bering Sea pollock trawl fishery. The pollock oil appeared to dramatically exclude seabirds from the discharge plume for a considerable distance (>100 m) behind the vessel for at least 30 minutes post-application; before the oil was applied, 13 birds per minute were feeding at the periphery and 1.5 from within the plume; post-application, 1.2 birds per minute fed from the periphery and 0 birds fed in the plume (Melvin et al. 2004).

COST/PROBLEMS:
- Unknown effect on ecosystem of introducing large amounts of fish oil into the marine environment (Melvin et al. 2004; Pierre & Norden 2006).
- Unknown effect of fish oil on feather surface of the birds (Melvin et al. 2004; Pierre & Norden 2006).
- Discharge of fish oil is prohibited in the United States under the Clean Water Act (1972), requiring an application for a waiver to do research to further investigate the use of fish oil as a mitigation method to reduce seabird bycatch in the United States.
- Unknown potential for habituation over time (Pierre & Norden 2006).

BENEFITS:
- Produced from fish bycatch or discards (Melvin et al. 2004; Pierre & Norden 2006).
- Birds appeared to be excluded from the discharge plume for a considerable distance (>100 m) behind the vessel for at least 30 minutes post-application (Melvin et al. 2004).

NET PROTECTION/MODIFICATION

Net binding

METHOD:
The aim of net binding is to reduce the time during which seabirds may interact with the gear by preventing the net from lofting and the mesh opening as the tension created by the vessel is lost due to waves and swell action, and increasing the sink rate of the net (Sullivan et al. 2004c). While the net is sinking, the bindings are broken and the net spread as a result of the force of the water moving through the doors (Sullivan et al. 2004c).

RESULTS:
Sullivan et al. (2004) trialled net binding in the South Georgia icefish (*Champsocephalus gunnari*) trawl fishery. Despite seabird numbers being low during the trial, eight birds were caught on control trawls (three white-chinned petrels were entangled in the 200 mm mesh on

a single shot), while no birds were caught during the binding trial. The binding remained in place as the net was deployed down the trawl ramp and as it extended astern. However, when the tension on the net was increased as the bridle and sweeps were paid away, many of the bindings broke and the net spread across the water's surface (Sullivan et al. 2004c). Despite these problems, it was noted that the net appeared to sink faster than under normal operational conditions, and the bound sections of the net appeared to prevent meshes from opening and lofting (Sullivan et al. 2004c).

COST/PROBLEMS:

- The bindings broke, possibly due to them being too weak due to the shaved section, and/or a stronger binding is required (Sullivan et al. 2004c).

BENEFITS:

- Fewer birds were caught during when the net was bound (Sullivan et al. 2004c).
- The net may sink more quickly to fishing depths.

Net weighting

METHOD:

Weights can be added to the net to increase the sink rate or reduce the surface time of the net upon deployment (Hooper et al. 2003).

RESULTS:

Observations and data were collected from three vessels in the South Georgia icefish trawl fishery, each trialling different methods of weighting the net (Hooper et al. 2003). The results of the study did not provide clarification as to which weighting regime was most appropriate; the different net designs possibly confounding results (Hooper et al. 2003). Nevertheless, the use of footrope weighting resulted in the codend submerging immediately on shooting, and as such was suggested as a likely avenue to undertake future experimental work.

COST/PROBLEMS:

- Findings were inconclusive regarding the most appropriate weighting design (Hooper et al. 2003).

BENEFITS:

- The codend immediately submerged on shooting when the footrope weighting was used (Hooper et al. 2003).

Night-setting

METHOD:

Night-setting may reduce seabird mortality either because fewer birds are active at night, thus reducing the numbers of seabirds exposed to fishing operations, or because the birds have more difficulty seeing the fishing gear (Murray et al. 1993; Cherel et al. 1996; Barnes & Walshe 1997; Belda & Sánchez 2001).

RESULTS:

Analyses of Australian Fisheries Management Authority observer data from Australian trawlers operating around Macquarie Island and Heard and McDonald Islands showed no significant differences in the recorded contacts per hour during the night compared to during the day (Wienecke & Robertson 2002).

Observations and data collected from vessels in the South Georgia icefish trawl fishery showed that significantly more birds were caught on night shots (7 out of 37 shots) compared to day shots (3 out of 145 shots); however, there was no significant difference between the number of birds being caught during day or night hauls (Hooper et al. 2003). It was noted that even though the probability of catching birds was lower in the day, the number of birds caught was higher during the day compared to night (Hooper et al. 2003). Furthermore, a higher proportion of birds caught during the day time were albatrosses. Hooper et al. (2003) advocated that further work was required in order to obtain a better understanding of the patterns of day and night catches observed in this study.

COST/PROBLEMS:

- No conclusive data proving the effectiveness of night-setting in South Georgia and Australian trawl fisheries.

Concepts not trialled

Based on observations and data collected from vessels in the South Georgia icefish trawl fishery, Hooper et al. (2003) believed that different species are vulnerable to different mesh sizes: 120–200 mm mesh for white-chinned petrels, and 200–800 mm mesh for grey-headed and black-browed albatross. To prevent birds from approaching this vulnerable part of the net, Hooper et al. (2003) suggested placing a small mesh top chafer over the area. While the data did not statistically support the concept, Hooper et al. (2003) believed that net cleanliness does have some effect on the likelihood of catching birds.

Gillnets

Visual alerts

METHOD:
Modify fishing gear to incorporate visual alerts on to the nets in order to decrease the chances of entanglement of seabirds.

RESULTS:
Trials were undertaken in the coastal salmon drift gillnet fishery in Puget Sound (Washington) to test traditional monofilament nets modified with visual alerts at one of two depths (upper 20 and 50 meshes) (Melvin et al. 1999). Relative to monofilament controls, common murre (*Uria aalge*) bycatch was reduced by 40% and 45% in the 50-mesh and 20-mesh visual alert nets respectively; where as rhinoceros auklet (*Cerorhinca monocerata*) bycatch was reduced only in 50-mesh nets (42%).

COST/PROBLEMS:

- 50-mesh visible panels significantly reduced the rate of sockeye catch by more than half (Melvin et al. 1999).

BENEFITS:

- 20-mesh visible panels maintained fishing efficiency for sockeye (Melvin et al. 1999).
- 20-mesh and 50-mesh visible panels significantly reduced common murre bycatch by 45% and 40% respectively (Melvin et al. 1999).
- 50-mesh visible panels reduced rhinoceros auklet bycatch by 42% (Melvin et al. 1999).

Pingers

METHOD:
Modify fishing gear to incorporate acoustic alerts on to the nets in order to decrease the chances of entanglement of seabirds.

RESULTS:
Trials were undertaken in the coastal salmon drift gillnet fishery in Puget Sound (Washington) to test traditional monofilament nets modified with acoustic alerts (pingers) (Melvin et al. 1999). Compared to the traditional monofilament net, pingers reduced common murre bycatch at rates by 50%, but had no significant effect on rhinoceros auklet bycatch.

COST/PROBLEMS:

- Pingers did not reduced rhinoceros auklet bycatch (Melvin et al. 1999).

BENEFITS:

- Pingers did not compromise fishing efficiency (Melvin et al. 1999).
- Pingers significantly reduced common murre bycatch at rates by 50% (Melvin et al. 1999)

Time of setting

METHOD:
By obtaining an understanding of the patterns of abundance of both target and bycatch species, fishing operations can be adjusted (i.e. time of setting) to minimise chances of bycatch events while not reducing target species catch rates (Melvin et al. 2001a)

RESULTS:
Melvin, Parrish et al. (2001) found that in the coastal salmon drift gillnet fishery in Puget Sound (Washington), the time of day significantly influenced both target species catch rates (sockeye salmon $p < 0.001$) and seabird entanglements (rhinoceros auklets $p < 0.001$; common murres $p < 0.001$). Compared to during the day, common murre entanglements were higher at both dawn and dusk, while both sockeye salmon catch and auklet entanglements were highest at dawn (Melvin et al. 2001a).

COST/PROBLEMS:

- An extensive knowledge of the temporal patterns (often variable) of seabird and target fish species abundances is required.

BENEFITS:

- Potential to alter target fish species and non-target species catches rates (Melvin et al. 2001a).

Subsurface drift gillnet

METHOD:
Increasing the depth that the net is set could potentially reduce bycatch and interactions between seabirds and fishing gear.

RESULTS:
Hayase & Yatsu (1993) found that in the Japanese high-seas drift gillnet fishery for flying squid (*Ommastrephes bartrami*), seabird (including sooty and short-tailed shearwaters) entanglements were significantly reduced in nets submerged 2 m below the surface compared to surface nets. There was no significant difference in the bycatch rate of other non-target species (northern fur seal *Callorhinus ursinus*, small cetaceans and sea turtles) when subsurface nets were used, however fishing efficiency was reduced by up to 95% (Hayase & Yatsu 1993).

COST/PROBLEMS:
- Fishing efficiency was reduced by up to 95% when subsurface nets were used (Hayase & Yatsu 1993).

BENEFITS:
- Seabird entanglements were significantly reduced when subsurface nets were used (Hayase & Yatsu 1993).

COMPARATIVE STUDIES

Longline

Boggs (2001) assessed the efficiency of blue-dyed bait, line weighting and BSL as mitigation measures in the Hawaiian swordfish pelagic longline fishery. All of the deterrent treatments had significantly lower contact rates for black-footed albatross and Laysan albatross than the control treatment; however statistical tests did not indicate that any of the deterrents was significantly better than any other. The effectiveness of the deterrents was calculated as the percent reduction in contact rates in comparison with control results. Expressed as contact rate per bird per 100 branch lines, the BSL was 75% and 77% effective, the blue-dyed bait 95% and 94% effective, and weights 93% and 91% effective for black-footed albatross and Laysan albatross respectively.

A comparative assessment between four experimental mitigation devices (6.5 and 9 m underwater setting chute, side-setting, blue-dyed bait) was undertaken in the Hawaiian tuna and swordfish pelagic longline fishery (Gilman et al. 2003a). Based on mean contact and capture rates, side-setting was the most effective (significantly) treatment tested in this trial when used with both Hawaii longline tuna and swordfish gear. Blue-dyed bait was less effective (significantly in some cases) at avoiding bird interactions than side-setting and the underwater chute (Gilman et al. 2003a).

At-sea trials under normal fishing conditions showed a significant difference in the effectiveness of reducing seabird bycatch in north Atlantic demersal autoline longline fishery when using a BSL and the Mustad underwater setting funnel; lines set without any devices caught 99 birds (1.75 birds per 1000 hooks), lines set through the funnel caught 28 birds (0.49 birds per 1000 hooks), and lines set with the BSL caught two birds (0.04 birds per 1000 hooks) (Løkkeborg 1998).

Løkkeborg (2001) trialled a simple BSL, an advanced BSL and the Mustad underwater setting funnel under normal fishing operations in the north Atlantic demersal longline fishery. The advanced BSL was the most effective at reducing seabird bycatch: 74 birds were caught (1.06 birds per 1000 hooks) when no mitigation measure was used, compared to six birds (0.08 birds per 1000 hooks) when using the underwater setting funnel, two birds (0.03 birds per 1000 hooks) when using the simple BSL, and zero birds when using the advanced BSL. Løkkeborg (2001) noted that catch rate for target fish species was higher when either mitigation measure was used.

Løkkeborg & Robertson (2002) compared the efficiency of three mitigation measures (BSL, line shooter, BSL + line shooter) during at-sea trials under normal fishing operations in the north Atlantic demersal longline fishery. The line shooter had no significant effect on seabird captures, either alone or in combination with the BSL. For the BSL there was a significant difference in seabird captures both between the BSL and the control, and between the BSL + line shooter and the line shooter. As such, Løkkeborg & Robertson (2002) advocated that BSLs as the most feasible and effective mitigation measure in the north Atlantic demersal longline fishery.

Melvin, Parrish et al. (2001) tested BSLs (single, paired, paired + weight), external line weighting and the Mustad line shooter as methods to reduce seabird bycatch in two (sablefish and cod) Alaskan demersal longline fishery. Among all deterrents tested, paired BSLs proved to be the most comprehensive solution to seabird bycatch and maintaining fishing efficiency; paired BSLs successfully reduced seabird bycatch in all years, regions, and fleets, and were robust in a wide range of wind conditions and required little adjustment as physical conditions changed (Melvin et al. 2001b).

In a comparative study of Japanese Southern bluefin tuna longline vessels fishing off of Capetown, Minami & Kiyota (2004) recorded a lower seabird bycatch when using blue-dyed bait compared to using a BSL. However, when used in combination, the blue-dyed bait and the BSL reduced the incidental take of seabirds to one tenth of the unmitigated seabird take (Manami & Kiyota 2004).

Trawl

Sullivan et al. (2004) compared the effectiveness of the Falkland Islands Warp Scarer, BSLs and the Brady Baffler. The results indicated a performance hierarchy based on contact rates: the BSLs and Warp Scarer performed substantially better than the Baffler, with the BSL showing a small, but significant, improvement on the Warp Scarer (Sullivan et al. 2004b). Significantly more total and heavy contacts were recorded while the Baffler was in use than either the BSL or Warp Scarer.

Melvin et al. (2004) conducted a pilot test during which observations were made regarding the relative merit of the mitigation methods as seabird deterrents for future testing in the Bering Sea pollock fishery. The methods included fish oil, BSLs (paired and single), a snatch block, third wire scarers (four designs), a boom array-warp deterrent and a buoy line. From these tests, Melvin et al. (2004) concluded that BSLs and the snatch block were the most likely to reduce seabird contacts with the third wire in this fishery, while merit in the boom array-warp deterrent was also noted.

Gillnet

Trials undertaken in the coastal salmon drift gillnet fishery in Puget Sound (Washington) involved modifying nets to include visual and acoustic alerts to traditional monofilament nets (Melvin et al. 1999). Nets with 50-mesh visible panels successfully reduced the bycatch of major seabird species, but resulted in a reduced sockeye salmon catch rate by more than half. Use of the 20-mesh panels were equally successful in reducing bycatch of the major seabird species, while maintaining fishing efficiency. Similarly, pingers reduced murre bycatch without compromising fishing efficiency (Melvin et al. 1999).

4. Discussion

MITIGATION STUDIES

Melvin & Robertson (2000) discussed the difficulties in evaluating mitigation research and making comparisons between studies. Goals, methodologies and sampling protocols are rarely similar across studies, sample sizes are rarely adequate to make robust comparisons, and controlled studies conducted aboard fishing vessels are few. Melvin & Robertson (2000) suggested that the following criteria should be incorporated into research programmes testing seabird bycatch deterrents in longline fisheries, however these criteria will benefit trawl fisheries mitigation research too:

- A single, common goal: to reduce seabird bycatch significantly without reducing the catch rate of the target species or increasing the bycatch of other non-target species.
- Compare deterrent strategies to a standard: either a control of no deterrent or some other rational measure.
- Collaborate with fishers and conduct research on active fishing vessels.
- Use consistent measures of bird interactions (such as abundance and attacks) and bird catch per unit effort and explore the relationship among them.

While much information can be obtained from data collected by observer programmes, because of its method of collection, there are limitations imposed on its use (i.e. this work is done without controls, time restraints are placed on the observer to do other tasks, and the observer is not necessarily trained at seabird identification). Controlled studies do require comparatively more resources compared to the use of observer programme data, however they are necessary in order to draw robust conclusions from the data collected and conduct comparisons between studies. Previously, research through controlled studies has been rare; however with the growth and development of bycatch mitigation research internationally, an increasing proportion of recent studies in longlining mitigation have incorporated the above criteria, and as such the same should be done in the emerging field of trawling research (Melvin et al. 2001b; Gilman et al. 2003a; Løkkeborg 2003; Robertson et al. 2004b; Sullivan et al. 2004b).

Despite a number of studies in this review not fulfilling the above criteria, there was sufficient information to provide recommendations for mitigation measures to reduce seabird captures in the New Zealand fisheries.

Factors influencing the appropriateness and effectiveness of a mitigation device include the fishery, vessel, location, seabird assemblage present and time of year (i.e. season). As such, there is no single magic solution to reduce or eliminate seabird bycatch across all fisheries. Realistically a ***combination of measures*** is required, and even within a fishery there is likely to be ***individual vessel refinement*** of mitigation techniques in order to maximise their effectiveness at reducing seabird bycatch.

MITIGATION METHODS FOR MULTIPLE FISHERIES

Offal and discard management

The presence of offal has been shown to influence seabird numbers attending vessels, the species present, and interactions with fishing gear in both trawl and longline fisheries in New Zealand and overseas (Weimerskirch et al. 2000; Robertson & Blezard 2005; Sullivan et al. in press). The most important observation made in several studies was that all mortalities occurred at times of offal discharge (Robertson & Blezard 2005; Sullivan et al. in press). Results from a Ministry of Fisheries warp strike project have also shown that in the New Zealand squid trawl fishery, the warp injury and death rate is higher when offal is discharged compared to when it is not discharged (Abraham 2005). These results clearly indicate that further research is required into the effect of offal discharge in seabird contact and bycatch rates in New Zealand and overseas, and that offal management is likely to be an effective way to mitigate incidental capture in both trawl and longline fisheries.

Area/seasonal closures

Temporal variation in seabird abundance at vessels, contact and bycatch rates have been documented, with the majority of birds being caught during the breeding seasons (Melvin et al. 1999; Weimerskirch et al. 2000; Robertson et al. 2004a). In New Zealand waters, area closures would be particularly beneficial in areas close to major seabird breeding colonies. Seasonal closures would need to incorporate the breeding seasons of both summer- and winter-breeding seabirds.

LONGLINING

Recommended methods

Based on the reviewed material, a combination of BSLs, line weighting, night setting (in some fisheries), and retention of offal during fishing operations is likely to be the most effective regime at mitigating seabird bycatch in New Zealand demersal and pelagic longline fisheries.

Studies have reported BSLs effectively reducing (significantly in most cases) seabird contacts and mortalities in both pelagic and demersal longline fisheries in New Zealand and overseas waters (Løkkeborg & Bjordal 1992; Imber 1994; Ashford & Croxall 1998; Løkkeborg 1998; Boggs 2001; Løkkeborg 2001; Melvin et al. 2001b; Smith 2001; Løkkeborg & Robertson 2002; Løkkeborg 2003; Manami & Kiyota 2004). Contrary to the majority of studies, Duckworth (1995) and Baird & Bradford (2000) reported that the presence or absence of a BSL had no statistically significant effect on seabird bycatch rates when analysing observer data for both New Zealand domestic and Japanese tuna longlining in the New Zealand EEZ. The use of observer data for these two studies may limit the quality of the data compared to the contolled studies.

Factors shown to influence the effectiveness of a BSL include the seabird assemblage present, fishing grounds, target fish species, fishing method, vessel size, time of day/year, weather conditions, BSL quality and mounting height (Duckworth 1995; Løkkeborg 1998; Brothers et al. 1999a). Correct mounting height is critical for achieving maximum effectiveness; it increases the distance of bait protection and prevents interference with the longline (Keith 1998; Brothers et al. 1999a). Therefore, individual vessel refinement of BSLs is likely to be necessary in order to achieve maximum effectiveness.

BSLs fulfil many of the criteria necessary for a successful mitigation measure, including: reduced seabird bycatch rate, reduced bait loss which may lead to a possible increase in target fish catch rates (Løkkeborg 2001), easy and relatively quick to deploy and retrieve, reasonably priced, and can be used in both demersal and pelagic longline fisheries.

External and integrated line weighting have been shown to increase line sink rates and hence decrease the chance of incidental seabird mortality in both pelagic and demersal longline fisheries in New Zealand and overseas waters (Agnew et al. 2000; Robertson 2000; Boggs 2001; Brothers et al. 2001; Melvin et al. 2001b; Robertson et al. 2004b). A number of variables affect line sink rate, including both environmental (e.g. weather conditions, swell height) and equipment (e.g. propeller wash and turbulence) factors; identifying the variables that are most influential to sink rates will be necessary to design a line-weighting regime that will achieve faster line sink rates (Smith 2001).

With regards to external weighting on pelagic longlines, the line sinks faster the closer the weight is to the hook (Brothers et al. 2001; Anderson & McArdle 2002). There is an abundance of proficient diving seabird species in New Zealand and Australian waters, and to date prescribed weight regimes to achieve sink rates of 0.26–0.30 m/s for pelagic longlines in these waters include using an 80 g within 3 m of the hook, a 60 g weight 1–2 m from the hook, or a 40 g weight at the hook (Brothers et al. 2001; Anderson & McArdle 2002).

The recent trial of IW (50g lead/m) in the New Zealand ling demersal autoline longline fishery off Solander Island (New Zealand), recorded a significant reduction in sooty shearwater and white-chinned petrel captures over two consecutive seasons (Robertson et al. 2004b). These result were encouraging given that both these species are highly proficient divers and a regular bycatch species in New Zealand longline fisheries (Robertson et al. 2004a). Furthermore, catch rates of ling and non-target fish species were not affected by use of IW lines (Robertson et al. 2004b).

Bait condition (thawed and with deflated swim bladders) is a further mitigation measure that should be used in pelagic longline fisheries, but in combination with other measures (Brothers et al. 1995; Brothers et al. 1999a).

Future research

Underwater setting devices have shown to be more effective at reducing bycatch in Northern Hemisphere seabird assemblages than those in the Southern Hemisphere (Gilman et al. 2003a). The composition of Southern Hemisphere seabird assemblage includes proficient divers, therefore a device is required that consistently achieves setting depths to 10 m. Ryan & Watkins (2000) noted structural limitations of the tube-type setting devices such as the funnel (particularly those that are stern-mounted), which may not enable them to be built to the lengths necessary to prevent the incidental capture of species such as white-chinned petrels which are able to dive to depths of at least 10 m. Increasing setting depths to avoid diving seabirds, has the adverse affect of increasing fishing cycle time. Furthermore, the chute, funnel and capsule all exhibited inconsistencies in line setting performance and reducing bycatch. Therefore, further development and at-sea trials under normal fishing operations are required before these devices reach their full potential (perhaps not sufficient to reduce Southern Hemisphere seabird bycatch) and therefore ready for commercial use. In terms of future advances in effective underwater systems, they should be considered in the vessel design (i.e. hull integrated underwater setting system) rather than an afterthought (E. Melvin pers. comm.).

While Melvin, Parrish et al. (2001) found single-BSLs reduced seabird bycatch relative to no mitigation measure in the Alaskan demersal longline fishery, paired-BSLs were even more effective (no BSL – 0.094 birds per 1000 hooks; single-BSL – 0.006 birds per 1000 hooks; paired-BSL – 0.000 birds per 1000 hooks). As such, it would be beneficial to trial paired-BSLs in New Zealand longline fisheries to test their effectiveness relative to single-BSLs.

For the time of setting to be used as a mitigation measure, it is first necessary to have knowledge of the seabird species implicated in attacking lines and their foraging habits (i.e. time of day, dive depths etc). Therefore, while night-setting may provide additional protection, further studies are required in New Zealand waters to determine the potential impact of this measure on night-foraging species such as the white-chinned petrel (Brooke 2004). Weimerskirch et al. (2000) reported a significant reduction in the bycatch rate of white-chinned petrels when lines were set at night compared to during the day. However, given the relatively high numbers of both grey and white-chinned petrels in New Zealand fisheries bycatch (Robertson et al. 2004a), specific research needs to be undertaken to assess the effectiveness of night-setting for birds and for fish.

Despite encouraging results (both in terms of reducing seabird bycatch and the potential to increase fishing efficiency), side-setting has been reported from a limited number of longline fisheries (Gilman et al. 2003a; Sullivan 2004). The uptake of this method may be limited by the vessel size and the initial costs of the vessel alterations. Pilot observations were made in a New Zealand ling fishery, and the results suggest that side-setting should not be ruled out as a possible mitigation measure for future trial in New Zealand longline fisheries (especially those employing larger-sized vessels).

Initial studies of fish oil have shown this to be an effective measure at reducing seabird interactions with fishing gear, particularly in the New Zealand snapper longline fishery (Pierre & Norden 2006). However, this is a recently reported concept and requires further investigation, particularly with regards to the mechanism behind its effectiveness (i.e. why does it reduce the dives made by seabirds?) and the impacts on the birds and marine ecosystem of introducing potentially large quantities of fish oil into environment (Melvin et al. 2004; Pierre & Norden 2006).

While certain fisheries currently set conditions around offal discharge (i.e. when, where and in what form), further research is required in order to eliminate the uncertainty regarding the influence of offal discharge on seabird bycatch, particularly in New Zealand fisheries. In the Patagonian toothfish demersal longline fishery around the Kerguelen EEZ, Weimerskirch et al. (2000) reported that the release of offal increased the number of birds attending the vessel, especially on the number of large species and white-chinned petrels.

Miscellaneous mitigation measures

Bait-casting machines can reduce bait loss to birds in pelagic fisheries by half when used with a BSL (Brothers 1993). However, the neglect of some bait-throwing machines to incorporate the initial designs to mitigate against seabird bycatch (cycle time, direction reversal, immediate distance dial, and low arc of throw) in favour of the labour saving functions, has greatly reduced the value and potential of this device to reduce incidental captures (Brothers et al. 1999a).

While Løkkeborg & Robertson (2002) recorded a reduction (though not significant) in seabird bycatch during line shooter trials in the Norwegian demersal longline fisheries, an increase in seabird bycatch was found when this device was tested in the Alaskan demersal longline fisheries (Melvin et al. 2001b). Throughout the course of this review, this was the only instance in which a mitigation measure was found to increase seabird bycatch, and as such is not recommended for use in New Zealand longline fisheries.

Limited tests were conducted on magnetic deterrents, water cannons, electric deterrents, acoustic deterrents, the Brickle curtain, and blue-dyed bait; however these methods seem unlikely to be effective as long-term mitigation measures due to logistical or possible habituation issues.

Thawing and dying of bait blue was initially employed to improve swordfish catch in the United States East Coast longline fishery (Boggs 2001). Fishermen considered the dyed bait to be more visible to target fish, however it was also observed to reduce seabird scavenging on longline bait. While blue-dyed bait was shown to be initially effective at reducing seabird bycatch, is unlikely to be a feasible long-term mitigation measure. One of the New Zealand studies recorded a change in the bird's behaviour towards the blue-dyed bait at the end of the trials, actively attacking both the dyed and the un-dyed baits on the final set; behaviour indicative of habituation (Lydon & Starr 2005).

TRAWLING

Few published studies report on methods to reduce seabird bycatch in trawl fisheries around the world, and none of these have been undertaken in the New Zealand trawl fisheries. As such, the recommendations and discussion below are based on relatively recent observations (some anecdotal), pilot tests and trials undertaken in the Falkland Islands, Bering Sea, South Georgia and Australian trawl fisheries.

The use of net sonde cables is banned in New Zealand trawl fisheries, therefore the two areas of potential danger to seabirds are entanglements in the net (during setting and hauling when it is at the surface and the birds are trying to obtain food) and collisions with trawl warps.

Based on the numbers of seabirds killed and returned for autopsy from the New Zealand trawl fisheries (1996–2002), the species of most concern in terms of reported bycatch are the white-chinned petrel, white-capped albatross, Buller's albatross, Salvin's albatross and sooty shearwaters (Robertson et al. 2004a). However, it is important to note that reported captures are strongly affected by spatial and temporal patterns in observer coverage. Observations of seabird behaviour and interactions with trawl fishing gear outside of New Zealand have recorded high contacts and mortalities of white-chinned petrels and black-browed albatross (similar in size and behaviour to white-capped, Buller's and Salvin's albatrosses) with fishing gear: contacts usually occurs when individuals of both species are sitting on the water, the albatrosses usually touch the warps while the white-chinned petrels are more likely to interact with the net (Weimerskirch et al. 2000; Wienecke & Robertson 2002; Robertson & Blezard 2005; Sullivan et al. in press).

Recommended methods

Based on the reviewed material and limited studies undertaken for trawl bycatch mitigation, a combination of paired-BSLs, retention of offal during fishing operations (especially during setting and hauling), and reducing the time the net is on (or near) the surface, are likely to be the most effective regime at this point in time to mitigate seabird bycatch in New Zealand trawl fisheries.

The deployment of two BSLs provides protection over both warp cables on a trawler. Paired-BSLs have been found to reduce seabird bycatch relative to no BSL, and are more effective than single-BSLs (Melvin et al. 2004; Sullivan et al. 2004a).

Given that the white-chinned petrel is a bycatch species of particular concern due to the relatively high numbers that are caught (Wienecke & Robertson 2002; Robertson et al. 2004a), reducing the time the net is on the surface would reduce the time during which they could interact with the net. In the South Georgia icefish fishery, Hooper et al. (2003) recorded a peak in seabird (including white-chinned petrels) catches after the net had been on the surface for between 9–10 minutes.

Future research

Much of the limited work that has investigated mitigation methods for trawl fisheries, have concentrated on methods to reduce interactions with the warp cable (Melvin et al. 2004; Sullivan et al. 2004b). While this is an important area of focus, there is an urgent need for research into methods for reducing seabird interaction with the net.

As stated previously for longlining, further research is required in order to determine the relationship between particular seabird species and characteristics of offal discharge within targeted studies. In the trawl fisheries around the Kerguelen EEZ, Weimerskirch et al. (2000) reported that the presence of offal affected the presence of some seabird species, but had no significant influence on the number of birds attending trawlers. On the contrary, results from a study using specifically tasked seabird observers on demersal trawl fisheries around the Falkland Islands (and the associated high seas), reported increasing contact rates with increasing levels of offal discharge (Sullivan et al. in press). Furthermore, all mortalities occurred at times of factory discharge (Sullivan et al. in press). The possible link between offal discharge and seabird bycatch are implicated in the autopsy data from seabirds killed (and returned) in New Zealand fisheries 1996 to 2002: a significant proportion of the birds returned from the combined trawl and domestic bottom longliner fleets had fisheries offal or discards forming a significant part of their stomach contents (Robertson et al. 2004a). Recent analysis of New Zealand Fisheries observer data for squid trawling (2002/03, 2003/04, 2004/05) showed that the discharge of offal had a significant influence on seabird bycatch: lower bycatch was recorded when offal was not discharged during the fishing operation (Conservation Service Programme unpubl. data). Preliminary results from a Ministry of Fisheries warp strike project has also shown that in the New Zealand squid trawl fishery, the warp injury and death rate is higher when offal is discharged (0.25 birds per tow) compared to when it is not discharged (0.007 birds per tow) (unpubl. AEWG report). As such, further research is required into the effect of offal discharge in seabird bycatch rates in New Zealand and overseas fisheries.

To date, several methods have been trialled (to a limited extent) in the South Georgia icefish trawl fishery to reduce the time the net is on or near the surface: net binding and adding weights to the net (Hooper et al. 2003; Sullivan et al. 2004c). Initial trials of net binding have shown potential as a mitigation method; despite some problems, the net appeared to sink faster than under normal operational conditions, and the bound section of the net appeared to prevent the meshes from opening and lofting (Sullivan et al. 2004c). Four different weighting regimes were trialled by Hooper et al. (2003). While the findings were inconclusive regarding the most appropriate weighting design, the codend immediately submerged on shooting when the footrope weighting was used (Hooper et al. 2003). Both the net binding and weighting methods warrant further investigation to determine their relative effectiveness at reducing seabird bycatch.

Just as the trials using fish oil in the New Zealand snapper longline fishery reduced seabird numbers (Pierre & Norden 2006), the same effect was observed when this method was used in the Bering Sea pollock trawl fishery (Melvin et al. 2004). However, as stated in the longline section, using fish oil as a deterrent is a new concept and requires further investigation, particularly with regards to the mechanism behind its effectiveness (i.e. why does it reduce the dives made by seabirds?) and the impacts on the birds and marine ecosystem of introducing potentially large quantities of fish oil into environment (Melvin et al. 2004; Pierre & Norden 2006).

Miscellaneous mitigation

The BSL and Warp Scarer both performed substantially better than the baffler at reducing contacts, however the BSL represented a small but significant improvement on the Warp Scarer (Sullivan et al. in press). Analysis of three years of New Zealand Fisheries observer data for squid trawling found that the use of bird bafflers as a mitigation measure did not significantly reduced seabird bycatch (Conservation Services Programme unpubl. data). Abraham (2005) recorded a reduction in heavy seabird contacts with the warp when a bird baffler was used, however noted that this may be an artefact of the vessel effect. Thus, the relatively poor performance of the baffler, due perhaps in part to varying effectiveness in deployments, does not make it an attractive mitigation measure compared to other methods such as BSLs, Warp Scarers and offal retention. To date, there are no published studies from New Zealand trawl fisheries proving that bird bafflers significantly reduce seabird bycatch and interactions with fishing gear. Furthermore, there is great variability in the design and deployment of bird bafflers in the New Zealand trawl fisheries (W. Norden pers. comm.).

Hooper et al. (2003) advocated responsible operation and maintenance of fishing gear as a means of reducing seabird bycatch: keep nets clean, reduce the time the nets are sitting on or close to the surface during setting and hauling, and conduct net maintenance when the net is fully onboard.

Anecdotal observations of the following mitigation methods were made by Melvin et al. (2004) in the Bering Sea trawl fishery, in an attempt to assess the relative merit of the methods for possible future testing: a snatch block (third wire), third wire scarers, buoy array and boom line (warp).

GILLNET

The majority of studies investigating mitigation methods for gillnetting have focused on the impact of this fishery on marine mammals, with little work on seabirds (Dawson 1991; Jefferson & Curry 1996; Slooten et al. 2000; Bordino et al. 2002; Barlow & Cameron 2003; Cox et al. 2003).

Melvin et al (1999) tested the impacts of visual and acoustic alerts on seabird and target fish species catch rates in the coastal salmon drift gillnet fishery in Puget Sound (Washington). Modified fishing gear which incorporated visual alerts in the upper 20 meshes of the net was found to be the most effective at reducing seabird bycatch while not compromising fishing efficiency. The influence of the time of day (as opposed to day versus night) on target fish species and seabird catch rates was also investigated (Melvin et al. 2001a). Having trialled a number of mitigation methods, Melvin, Parrish et al. (2001) advocated the use of three complimentary tools to reduce seabird bycatch in the coastal salmon drift gillnet fishery: gear modifications, abundance-based fishery openings, and time of day restrictions.

Penguins and other seabirds such as shags have been incidentally caught in coastal set nets (Darby & Dawson 2000; Norman 2000; Taylor et al. 2002), however the full extent of this bycatch around New Zealand is unknown.

OTHER FISHERIES

Other fisheries operating in New Zealand waters include purse seine, jig, set net and troll; however no material was found with regards to mitigation measures. A combination of very limited (in most cases no) observer coverage and vessel size means that the extent of seabird bycatch in these fisheries is yet to be quantified.

New Zealand Ministry of Fisheries observers have only recently (2005) been placed on purse seine fishing vessels; preliminary reports from observer data on four purse seine operations have recorded no seabird bycatch (Conservation Services Programme unpubl. data). This fishery produces little (if any) offal discharge.

5. Conclusions

- Mitigation research needs to be done through controlled studies. Studies in longlining mitigation are increasingly incorporating the criteria required to make studies more robust, and it is important that the same should occur in the emerging field of trawling research.
- The retention of offal and discards during setting and hauling (at the very least) has been shown to reduce seabird bycatch in both longline and trawling fisheries.
- For New Zealand demersal and pelagic longline fisheries, retaining offal and discards, using BSLs and line weighting are current measures that are recommended as ways of reducing seabird bycatch.
- For New Zealand trawl fisheries, retaining offal and discards during fishing operations, at least during and hauling, and using paired BSLs are current measures that are recommended as ways of reducing seabird bycatch.
- Much of the limited work that has investigated mitigation methods for trawl fisheries have concentrated on methods to reduce interactions with the warp cable, there is also an urgent need for research into methods for reducing seabird interaction with the net.
- The effectiveness of underwater setting devices (such as the capsule, chute and funnel) at reducing Southern Hemisphere seabird bycatch is questionable. In terms of future advances in effective underwater systems, they should be considered in the vessel design (i.e. hull integrated underwater setting system) rather than an afterthought (E. Melvin pers. comm.).
- Methods such as acoustic deterrents are expected to be limited in their long-term use as seabird deterrents due to the likelihood of habituation. Further work is required to determine if seabirds will habituate to blue-dyed bait and fish oil.
- The mechanism responsible for the effectiveness of fish oil at deterring seabirds, and the potential impacts on the environment and seabirds, require further research.
- Ministry of Fisheries observer data is relatively comprehensive for only four New Zealand fisheries (charter tuna, ling autoline, hoki trawl and squid trawl). The level of seabird bycatch in other New Zealand fisheries requires quantification in order to better direct resources for mitigation research and techniques that may be required in those fisheries.

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8. Appendix 1. Recommended contacts in the field of seabird bycatch mitigation

Comment: Numbering of the Appendix may change depending on how Tables (WGNHO-230230) are published.

The review of seabird bycatch mitigation techniques emphasised the importance of well designed controlled studies in order to obtain meaningful results regarding the effectiveness of the mitigation methods. Listed below are the contact details for researchers that are, or have recently been, involved with undertaking appropriately designed projects investigating the potential reduction of seabird bycatch in the trawl, longlining and gill net fisheries. The Seabird Bycatch Project E-mail List Directory (http://straylight.primelogic.com/mailman/listinfo/birdbycatch) should be consulted for further global contacts general in the general field of seabird bycatch.

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