A review of methodologies for mitigating incidental catch of seabirds in New Zealand fisheries

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CONTENTS

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ABSTRACT

This report presents the results of the seabird component of a global review of mitigation methods aimed at reducing mortalities of seabirds, marine mammals and reptiles, and corals from 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 is assessed, recommendations made for the fisheries management, 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). Realistically a combination of measures is required to reduce or eliminate seabird bycatch, and even within a fishery individual vessel refinement of mitigation techniques is often required in order to maximise their effectiveness. Retention or strategic management of offal and discards are recommended as the most effective 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). Offal and discard management, combined with paired bird-scaring lines, and reducing the time the net is on or near the surface, are likely to be the most effective regimes to mitigate seabird interactions with the warp cables and nets in trawl fisheries. Urgent investigation is needed into more effective measures at reducing seabird interactions with the trawl nets.

Keywords: seabirds, longline, trawl, gillnet fisheries, bycatch, mitigation, New Zealand

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1. Introduction

In New Zealand, seabirds have been recorded caught in longlines, trawl, set nets, and pots (NPOA 2004; Robertson, Bell et al. 2004). Worldwide, a total of 61 seabird species have been recorded as killed by longlining operations on at least one occasion (Brothers, Cooper et al. 1999). 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 through interactions with fisheries operations has been linked with 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.

When designing a mitigation method, it is essential to understand those factors and circumstances which lead to interactions between seabirds and fishing gear; the two most important factors being the type of fishery and seabird species present. The relevant aspects of each of these factors are outlined below, followed by a summary of how seabirds interact with the different fisheries.

1.1 FISHERIES

The two main types of fisheries for which seabird interactions have been recorded are longlining and trawling (Robertson, Bell et al. 2004). Each type of fishery uses different gear, and as such differ in the ways that they interact with seabirds. A brief description of the fisheries follows.

1.1.1 Longlining

Longlining involves setting a line with a series of baited hooks into the water. 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, Cooper et al. 1999). 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 increase the chances of seabird takes during hauling.

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, Cooper et al. 1999; 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, Cooper et al. 1999). 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 as acute then, because gear was heavier in the past (Brothers, Cooper et al. 1999). The mechanisation of fishing operations has also greatly expanded the scope of these operations (Brothers, Cooper et al. 1999).

From 1993, the use of tori lines (a mitigation method discussed in section 3.2.2—Bird-scaring lines) became mandatory for all tuna longline fishing vessels (foreign and domestic) in the New Zealand Exclusive Economic Zone (EEZ) under Regulation 36a of the Fisheries (Commercial Fisheries) Regulations 1993 (Duckworth 1995).

1.1.2 Trawling

Trawling operations involve towing a net through the water. This method of fishing has been associated with a lower, though still substantial, reported seabird mortality than longliners (Bartle 1991a; Weimerskirch et al. 2000). However, it is important to note that not all interactions with trawling gear results in birds being landed on deck (see section 1.3.2), and therefore incidental mortality may be substantially higher than that recorded from such a measure.

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, Brickle, Reid, Bone et al. 2004). 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, Brickle, Reid, Bone et al. 2004).

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 might 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.

1.1.3 Gillnet, driftnet, and purse seine fisheries

Gillnets, driftnets, and purse seine nets are fishing devices used to obtain high catch rates in relatively short periods of time. Each of these methods involves using a net to catch target species, however they differ in the type and operation of the net. A driftnet is a wall of netting (sometimes as long as 48 km) that is left to drift with the prevailing currents. Fish swim through the virtually invisible netting and are entangled by their gills. Because of their indiscriminate and destructive nature, driftnets were globally banned on the high seas in the early 1990s (Montevecchi 2002; Brooke 2004). Much of the fishing effort that had used drift nets subsequently shifted to longlining (Brothers, Cooper et al. 1999). Gillnets work in a similar manner to driftnets, but are smaller, equipped with weights at the bottom and floats at the top, usually anchored at each end, and used in coastal waters. Purse seine fishing involves encircling a school of fish with a large net.

1.1.4 Other fisheries

Jigging involves attaching a grapnel to a line, which is manually or mechanically jerked in the water to snag the fish in its body. Jig fishing usually happens at night with the aid of light attraction. Trolling involves towing baited hooks or lures through the water.

1.2 SEABIRDS

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. Smaller birds (e.g. terns, storm petrels and auklets) are unable to swallow such large food items as longline baits, and so are rarely found captured in this way (Brothers, Cooper et al. 1999). However, scavenging seabirds often have large gapes and are thus able to swallow large food items whole; this increases their likelihood of getting caught on longline hooks (Brothers, Cooper et al. 1999).

1.2.1 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. If one parent dies during a breeding season, this means that the widowed parent is unable to feed the chick sufficiently. Also, 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.

1.2.2 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. Diving seabirds are capable of diving considerable distances to retrieve baited hooks, which exposes them to the risk of 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 shearwaters (*Puffinus* spp.) have found that the maximum dive depths of these species ranges between 35.4 m and 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, have 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, therefore, able to catch sinking baits underwater (Prince et al. 1994). Robertson, Bell et al. (2004) reported that 94.8% of the seabirds autopsied in their study of longline and trawl fisheries bycatch specimens, were in fact these proficient diving species (*Puffinus, Procellaria,* and the small albatrosses).

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 they can be sources of food through scavenging offal and bait. Removing the source of food either directly (i.e. management of discards material) or indirectly (i.e. using a bird-scaring line) should in the long-term discourage seabirds from following vessels (Weimerskirch et al. 2000).

1.3 SEABIRD INTERACTIONS WITH FISHING GEAR

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, Cooper et al. 1999; Bache 2003). This section provides a brief summary of current knowledge according to fishery type.

1.3.1 Longlining

Seabirds may become entangled on the line or caught during line setting and hauling (primarily with pelagic gear) (Brothers, Cooper et al. 1999). Brothers & Foster (1997) observed three situations in which baited hooks on longlines pose a threat to seabirds following astern of the vessel: as the hooks were cast into the water and before sinking; if the hooks float on or near the surface as a result of current or tide action during their soak time; or, when hooks with unused bait were hauled back aboard the vessel. Therefore, reduction in seabird bycatch through modifications to fishing practices and/or equipment could 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, Cooper et al. 1999).

1.3.2 Trawling

Seabird interactions with trawl gear include collisions with the net monitoring (net sonde or net sonar third wire; to attach electronic monitoring equipment) cable and trawl warps (cable by which the trawl net is attached), 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, Brickle, Reid, Bone et al. 2004). Hooper et al. (2003) identified four types of seabird entanglement that may occur with trawl nets: plunge diving through the large meshes; pecking at enmeshed fish during which procedure the neck is squeezed as the meshes close; feet becoming jammed as meshes close while birds 'ride' the net; and wings becoming caught at the 'wrist' as meshes close.

1.3.3 Gillnetting

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).

1.3.4 Other fisheries

No information was available at the time of writing regarding the mechanisms of incidental seabird capture associated with the purse seine, jig, and troll fisheries.

1.4 SUCCESSFUL MITIGATION

Gilman, Boggs et al. (2003) listed the following criteria as important for seabird mitigation methods: reducing seabird mortality to insignificant levels; avoiding increases in bycatch of other sensitive species; requiring minimum alteration of traditional fishing practices and providing operational benefits; being simple for crew to employ and not increasing safety hazards to crew; increasing fishing efficiency; and feasibility of enforcement 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, Cooper et al. 1999). 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, Cooper et al. 1999; Melvin et al. 1999; Kock 2001; Gilman, Boggs et al. 2003).

1.5 SCOPE AND OBJECTIVES OF THIS REVIEW

The development of techniques to avoid and mitigate incidental mortality of seabirds and marine mammals resulting from fisheries interactions is a growing field. 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, Cooper et al. 1999; 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 would focus, however, on interactions between fishing gear and these species in New Zealand fisheries and fisheries that operate using similar methodologies to New Zealand fisheries. It would aim to collate and synthesise 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 review aimed to access the applications of these methods to New Zealand fisheries and identify areas for further research in New Zealand.

2. Methods

National and international 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, and the literature of government and non-government organisations. Relevant factors were extracted from the material and recorded in detailed tables (available on request from Conservations Services Programme, Marine Conservation Unit, New Zealand Department of Conservation (DOC)) for each fishery for which information could be found.

From the information provided in the original source material (see above), this review summarises the methodologies, effects, costs, benefits, and problems for each of a wide range of mitigation measures for bycatch and target fish catch rates for different fisheries. For ease of reference, the Results section of this report is divided into four main sections on mitigation measures suitable for: multiple fisheries, for longlining, for trawling, and for gillnetting (no information was found regarding bycatch mitigation measures for purse seine, jig, or troll fisheries); this is followed by a fifth section which reviews studies of comparative mitigation techniques in the longline, trawl and gillnet fisheries. Wherever the term significant is mentioned in the text, this refers to the significance of a statistical test, the details of which can be found in the original source that is cited.

For the context of this paper, a few key definitions should be clarified:

Bycatch is defined as the 'non-target species that are obtained whenever fishing gear is not perfectly selective' (Terry 1995).

Mitigation measures are defined as the 'modification to fishing practices and/or equipment that reduces the likelihood of seabird incidental catch' (Brothers, Cooper et al. 1999).

A contact is defined as 'an event during which a seabird comes into contact with gear' (Gilman, Brothers et al. 2003).

Total contacts are the combined **heavy contacts** (those that pushed birds, or parts of birds, under the water) and **light contacts** (Sullivan et al. 2006).

A capture is 'based on a count of the number of seabirds hauled aboard, and not the number of seabirds observed as caught during setting' (Gilman, Brothers et al. 2003).

3. Results

3.1 MITIGATION METHODS RELEVANT TO MULTIPLE FISHERIES

3.1.1 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—Cherel et al. (1996) found that dumping homogenized offal during line settings in the Patagonian toothfish (*Dissostichus eleginoides*) demersal longline fishery in the Kerguelen Exclusive Economic Zone (EEZ) greatly reduced the incidental capture of seabirds.

Weimerskirch et al. (2000) analysed fisheries observer data from demersal trawlers and longliners around the Kerguelen 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. 2006) Furthermore, all seabird mortalities occurred at times of factory discharge (Sullivan et al. 2006).

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 was 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 (ANOVA, $P = 0.012$) influence on seabird bycatch: lower bycatch was recorded when offal was not discharged during the fishing operation (W. Norden, DOC, pers. comm. 2005).

Costs/problems—Possible logistical implications of offal retention, because of the vessel's storage capacity.

Benefits—The general consensus is that retention of offal reduces seabird bycatch rates (Abraham 2005; Robertson & Blezard 2005; Sullivan et al. 2006).

3.1.2 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, USA), Melvin et al. (1999) recorded temporal variation in seabird bycatch and abundance over different temporal scales (interannually, within fishing seasons, and over the day). Because of a reduction in effort (i.e. total sets) to meet the quota, it was estimated that a 43% reduction in seabird bycatch could be achieved by limiting fishery openings to periods of high salmon abundance.

Costs/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, Cooper et al. 1999).
- 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).

3.2 MITIGATION METHODS RELEVANT TO 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.

TABLE 1. APPROPRIATE (✓) MIGATION METHODS FOR DEMERSAL AND PELAGIC LONGLINE FISHING.

MITIGATION METHOD	PELAGIC	DEMERSAL
Offal retention	✓	✓
Funnel		✓
Chute	✓	
Capsule	✓	
Bait-casting machine	✓	
Blue-dyed bait	✓	
Night-setting	✓	✓
Bird-scaring line	✓	✓
Brickle curtain	✓	✓
Line weighting	✓	✓
Line shooter		✓
Bait condition	✓	

3.2.1 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, Cooper et al. 1999). The three types of devices (funnel, chute and capsule) are discussed individually below.

Funnels (lining tubes)

Method—The Mustad Company developed a commercially available underwater setting funnel (Brothers, Cooper et al. 1999). In contrast to other underwater setting devices, both the mainline and branchlines are fed through the funnel. This device delivers the groundline 1 m below the surface in the propeller wash, which is at a much shallower depth than the pelagic chutes (E. Melvin, Washington Sea Grant Program, Alaska, pers. comm. 2005).

Results—The funnel has been trialled in demersal longline fisheries in South Africa, Alaska, and Norway under normal fishing operations. All noted a reduction, sometimes significant, in seabird bycatch when the funnel was used (Løkkeborg 1998, 2001; Melvin, Parrish, Dietrich et al. 2001; 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). Results from studies to date have found the funnel's performance to be inconsistent at reducing seabird capture.

Costs/problems—

- Suitable for demersal longline fisheries only (Brothers, Cooper et al. 1999).
- Can increase bait loss (Løkkeborg 1998), which can result in reduced catch rates (Ryan & Watkins 2002).
- Underwater setting tubes are expensive (approximately GB£40 000) (Brooke 2004).
- Occasions on which technical difficulties have arisen have rendered the tube useless as a seabird deterrent (Melvin, Parrish, Dietrich et al. 2001).
- During high seas and when the vessel is front heavy, the bottom of the funnel may lift out of the water during setting, decreasing the depth of the setting funnel and making baited hooks available to seabirds (Løkkeborg 1998).
- The funnel may lack 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, Cooper et al. 1999).

Benefits—

- Løkkeborg (2001) recorded higher catch rates for target fish species when the funnel was used.
- Reduction in seabird bycatch compared to when no deterrent was used (Løkkeborg 1998, 2001; Melvin, Parrish, Dietrich et al. 2001; Ryan & Watkins 2002).

Chutes

Method—Early 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, Cooper et al. 1999). 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, DOC, pers. comm. 2005).

Results—The concept and early developmental trials of the chute occurred 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 Hawaiian 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, Brothers et al. 2003). Both chutes were found to be effective at reducing seabird captures: for the 6.5 m chute there were 0.01 captures/1000 hooks/bird for tuna gear; for the 9 m chute there were 0.05 and 0.03 captures/1000 hooks/bird for tuna and swordfish gear respectively. The 9 m chute was 95% effective at reducing albatross contacts with fishing gear compared to the control (no mitigation method), when expressed as contact rate/1000 hooks/albatross (normalised for albatross abundance). 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, Boggs et al. 2003).

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 (1.08 birds/1000 hooks) were reported while using the chute (B. Baker, Australian Antartic Division, Tasmania, pers. comm. 2005). The majority (97%) of the birds caught were flesh-footed shearwaters (*Puffinus carneipes*).

Costs/problems—

- The chutes trialled in Hawaii performed inconsistently and were inconvenient to use due to manufacturing flaws and design problems (Gilman, Brothers et al. 2003).
- There was a slower hook setting rate with the chute compared to normal setting (Gilman, Boggs et al. 2003).

- Chutes were relatively expensive, costing c. US $5000 for the hardware, plus additional costs of installation (Gilman, Brothers et al. 2003).
- Chute use in large swells caused fouled hooks and tangled gear (Gilman, Brothers et al. 2003).
- Chutes required a lot of deck space to stow (Gilman, Brothers et al. 2003).
- High bycatch (1.08 birds/1000 hooks) was recorded while using the chute in Australian trials (B. Baker, Australian Antartic Division, Tasmania, pers. comm. 2005).

Benefits—

- Reduced seabird contacts and captures in Hawaiian trials (Gilman, Brothers et al. 2003).
- May increase fishing efficiency due to increased bait retention (Gilman, Brothers et al. 2003).

Capsules

Method—Since its 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, DOC, New Zealand, pers. comm. 2005).

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 occassions when tangles occurred). Brothers 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.

Costs/problems—

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

Benefits—

- Offers versatility in the depths at which baits can be delivered (Brothers, Cooper et al. 1999).
- Compact and easily fitted to any size vessel, irrespective of associated gear configuration (Brothers, Cooper et al. 1999).
- Causes birds to generally remain further astern and to roam more widely (Brothers et al. 2000).

Bait casting/throwing machines

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, Cooper et al. 1999).

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 significantly lower seabird bycatch rates when using a BCM compared to not using one (Duckworth 1995; Klaer & Polacheck 1998).

Costs/problems—

- The original bait-casting machines developed by (Gyrocast Pty Ltd) were designed with functions to mitigate seabird bycatch as well as labour saving device. When such machines proved expensive to produce (c. A$20 000 each), cheaper models were produced with only the labour saving functions (Brothers, Cooper et al. 1999).
- Applicable to pelagic longlining only (Brothers, Cooper et al. 1999).

Benefits—

- Possible increase in fishing effort or maintaining present fishing effort but reduced actual work due to reduced cycle time between setting hooks (Brothers 1993).
- No loss of baits from hooks during machine throwing (Brothers 1993).

Blue-dyed bait

Method—Thawing and dyeing bait blue is thought to reduce the seabirds' ability to see the bait through camouflage (Gilman, Brothers et al. 2003), 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 Hawaiian 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 reducing bird interactions than side-setting and the underwater chute (Gilman, Brothers et al. 2003). 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. It would produce a gain in efficiency of 45.2% over fishing with the 6.5 m chute (Gilman, Brothers et al. 2003).

In a comparative study of Japanese Southern bluefin tuna pelagic longline vessels fishing off Capetown, South Africa, 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 fish species when using blue-dyed bait.

Blue-dyed bait pilot trials undertaken on a New Zealand pelagic longliner recorded seabird captures on undyed bait sets, but none when using dyed bait (Lydon & Starr 2005); however these differences were not significant. Lydon & Starr (2005) also 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 seabirds were apparently indifferent to the blue-dyed bait in the first six sets, seabirds actively attacked both bait types on the final set.

The lack of blue-dyed bait trials in demersal fisheries may be due to the fact that they deploy many more hooks and use considerably more bait, making this approach less practical for the demersal fishery compared to the pelagic fisher (E. Melvin, Washington Sea Grant Program, Alaska, pers. comm. 2005).

Costs/problems—

- Pre-dyed bait is not sold commercially, making the thawing and dying of bait impractical and inconvenient for the crew (Gilman, Brothers et al. 2003).
- It does not sufficiently minimise bird mortality (Gilman, Brothers et al. 2003).
- May not be employed consistently by different crew (Gilman, Brothers et al. 2003).
- Has achieved variable results with regards to fishing efficiency (Minami & Kiyota 2004).
- May be ineffective as a long-term mitigation solution if birds habituate to the blue-dyed bait (Lydon & Starr 2005).
- A reduction in target species catch rate has been recorded when using blue-dyed bait (Minami & Kiyota 2004).
- Only trialled on pelagic longline vessels to date.

Benefits—

- Relatively inexpensive, costing approximately US $14.00 per set or US $1.00 per 100 squid (Gilman, Brothers et al. 2003).
- Safe to use.
- Catch rates of fish increased in the Hawaiian tuna longline fishery when blue-dyed bait was used (Gilman, Boggs et al. 2003).

Side-setting

Method—Setting fishing gear from the side of the vessel, it is thought to allow the bait to sink sufficiently deep by the time it reaches the stern to be out of seabirds' reach (Gilman, Brothers et al. 2003; Sullivan 2004).

Results—A comparative at-sea trial in the Hawaiian 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, Brothers et al. 2003). 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 FV *Daniel Solander* while fishing for ling; a total of six voyages were undertaken, each of 6–7 weeks duration, during which setting was from the side (P. Ballantyne, Seafood Industry Council, New Zealand, pers. comm. 2005). 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 the *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 (equating to 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, Washington Sea Grant Program, Alaska, pers. comm. 2005).

Costs/problems—

- There are some costs associated with initial alterations to vessel's deck design for side-setting (Gilman, Boggs et al. 2003).
- It is recommended that a bird curtain (estimated cost US $50.00) is used concurrently (Gilman, Boggs et al. 2003).
- Potential increased risk to the safety of the crew member undertaking the task of clipping the branchlines (Gilman, Boggs et al. 2003).
- In heavy weather, the swell may come on to the side of the boat causing discomfort to crew, particularly on smaller boats (Gilman, Boggs et al. 2003).
- In the New Zealand trials, the line became tangled around the propeller. However, this was overcome by extending the line away from the vessel 1.5 m in a tube and lowering the line closer to the water (P. Ballantyne, Seafood Industry Council, New Zealand, pers. comm. 2005).
- The 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 only 10 m) (E. Melvin, Washington Sea Grant Program, Alaska, pers. comm. 2005).

Benefits—

- Shown to be effective at reducing seabird interactions and mortality in some fisheries (Gilman, Boggs et al. 2003).
- Practicable for crew to use (Gilman, Boggs et al. 2003).
- Crew in the Hawaiian trials perceived this method as causing fewer gear tangles compared to conventional stern setting (Gilman, Boggs et al. 2003).
- Requires a nominal amount of initial expense to employ (Gilman, Boggs et al. 2003).
- No additional effort required to implement the method once the initial conversion is made (Gilman, Boggs et al. 2003).
- Has potential to increase fishing efficiency through the effects of bait retention and hook setting rates (Gilman, Boggs et al. 2003).
- Has potential to reduce seabird interactions on a wide range of longline vessel deck designs (Gilman, Brothers et al. 2003).
- No incidences of gear being fouled in the propeller recorded while side-setting from any of the three positions in the Hawaiian trials (Gilman, Boggs 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 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, Cooper et al. 1999).

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 before sunset (pelagic fishery) (Belda & Sánchez 2001).

In the Patagonian toothfish longline fishery in the Kerguelen EEZ, Weimerskirch et al. (2000) reported that night-setting resulted in a significant reduction in bycatch of white-chinned petrels (from a mean of 0.91 ± 1.72 birds/1000 hooks during the day to 0.17 ± 0.82 birds/1000 hooks at night), 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 (mean of 0.25 birds/1000 hooks) compared to night sets (mean of 0.022 birds/1000 hooks).

Seabird abundance and bycatch rates during night-setting can also be influenced by the phase of the moon: there is a greater chance of catching seabirds during the full half-phase of the moon 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 fish species catch rates in the Japanese Southern bluefin tuna longline fishery. Fluctuations (both increases and decreases) in target catch rate were recorded in relation to night setting ratios.

Costs/problems—

- Crew safety may be compromised due to the need to work under reduced lighting levels (Brothers, Cooper et al. 1999).
- There are 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).
- There may be lowering of the bycatch rate of one suite of seabird species (diurnal feeders) at the expense of another (crepuscular/nocturnal feeders) (Brothers, Cooper et al. 1999).
- Limited potential as a comprehensive approach, particularly in high-latitude fisheries, where there is close to 24 hours of light in a day for part of the year. Furthermore, higher light levels experienced during a full moon are another limitation on the effectivness of night-setting in reducing seabird bycatch (Brothers, Cooper et al. 1999).

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).
- Demonstrated 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).

3.2.2 Deterrents

Bird-scaring lines

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, Cooper et al. 1999). 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, 2001, 2003; Løkkeborg & Robertson 2002), Hawaiian pelagic swordfish longline fishery (Boggs 2001), Chilean demersal Patagonian toothfish Spanish-style longline fishery (Ashford & Croxall 1998), Alaskan demersal longline fishery (Melvin, Parrish, Dietrich et al. 2001), Japanese Southern bluefin tuna pelagic longline fisheries (Minami & 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/1000 hooks set) caught during the trial: 10 grey petrels (*Procellaria cinerea*), 1 Chatham albatross (*Thalassarche eremita*), and 1 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, Cooper et al. 1999). 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, Cooper et al. 1999).

Costs/problems—

- Commercially-produced BSLs range in cost from A$200.00 to A$300.00. A mounting ('tori') pole may be a further associated cost (Brothers, Cooper et al. 1999).

- 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, 2001; Boggs 2001; Melvin, Parrish, Dietrich et al. 2001; Smith 2001; Løkkeborg & Robertson 2002; Minami & 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, 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, Washington Sea Grant Program, Alaska, pers. comm. 2005).

Brickle curtains

Method—A protective curtain is positioned around the hauling bay, deterring birds from approaching too close to it and reducing the incidence of hooking/entanglement (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, Cooper et al. 1999). Sullivan (2004) noted that some species (particularly black-browed albatross and cape petrels) become habituated to the curtain when used over long periods in the Falkland Islands longline fisheries. Therefore, it is 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.

Costs/problem—Possible habituation to the curtain (Sullivan 2004).

Benefits—

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

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—Trials have been undertaken at sea (preliminary and under normal fishing operations) using school shark (*Galeorhinus galeus*) liver oil in the snapper pelagic longline fishery in the Hauraki Gulf of New Zealand. These resulted in a significant reduction in the numbers of seabirds attending the vessel and the numbers of dives on baits, compared to trials using canola oil, and a control of seawater (Pierre & Norden 2006). This method was effective in a mixed species inshore seabird community numerically dominated by flesh-footed shearwaters.

Costs/problems—

- Unknown effects of introducing large amounts of fish oil into the marine environment (Pierre & Norden 2006).
- Unknown effects 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 cannons

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, emission angles and mixing ice particles to maximize the range of the water jet (Kiyota et al. 2001). Observations indicated that seabirds avoided the water jet and did not try to fly under the water curtain, but the water jet's effect was reduced by cross winds. As the use of this device during cold windy conditions adversely affected the crew, it was switched off under these conditions (Brothers, Cooper et al. 1999).

Costs/problems—

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

Benefits—Can be used by pelagic and demersal longline fisheries (Brothers, Cooper et al. 1999).

Acoustic deterrents

Method—An acoustic deterrent is any noise used to deter birds away from the vessel. Methods commonly used include firing shotguns, canons, hitting the steel hull, or commercial devices that emit loud, high-frequency noises or distress calls (Brothers, Cooper et al. 1999).

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 loud, high-frequency noise as well as distress calls (Brothers, Cooper et al. 1999).

Costs/problems—

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

Benefits—Temporarily scares birds (Brothers, Cooper et al. 1999).

Magnetic deterrents

Method—Commercially available magnetic devices claim to interfere with receptors that birds have for detecting magnetic fields (Brothers, Cooper et al. 1999).

Results—A 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, Gales et al. 1999). The device did not significantly affect the catch of seabirds during the at-sea trials, and there were no apparent effects in the behaviour of birds at the breeding colony (Brothers, Gales et al. 1999).

Costs/problems—Unlikely to offer protection extending to 100 m (or more) astern, as required with present line-setting methods (Brothers, Cooper et al. 1999).

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

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

3.2.3 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 m/s 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 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 of New Zealand, Anderson & McArdle (2002) recorded the depth of a baited hook 30 s after deployment for: 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). From their observations of sink rates, they concluded that the addition of a 60 g weight removes the baited hooks from the recorded diving range of white-chinned petrels, shy albatrosses, black-browed albatrosses, grey-headed albatrosses and light mantled sooty albatrosses (*Phoebetria palpebrata*), but not sooty shearwaters (*Puffinus griseus*).

Boggs (2001) tested the effectiveness of attaching 60 g swivel weights 3.7 m above the bait in the Hawaiian-based pelagic longline swordfish fishery. Contact rates (expressed as contact rate/bird/100 branchlines) were significantly lower for weighted lines compared to unweighted lines: the weights were 93% effective for black-footed albatrosses and 91% for 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 (without a control) under normal fishing operations in the Australian East Coast tuna and billfish pelagic longline fishery (B. Baker, Australian Antarctic Division, Tasmania, pers. comm. 2005). Bycatch rates 0.167 birds/1000 hooks for the 38 g and 1.04 birds/1000 hooks for the 60 g trials were recorded. 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 m 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/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, Dietrich et al. (2001) reported variable effects of weighted gear on seabird bycatch 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, Parrish, Dietrich et al. 2001).

The effectiveness of integrated weight (IW) (50 g lead/m) in reducing white-chinned petrel and sooty shearwater mortality was tested in the New Zealand ling demersal autoline longline fishery off Solander Island, New Zealand during October/November 2002 and 2003 (Robertson, McNeill et al. 2004). When using IW compared to unweighted (UW) line, a 98.7% (in 2002) and 93.5% (in 2003) reduction in mortality of white-chinned petrels was recorded. 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, McNeill et al. 2004).

Using two different vessels, Robertson, McNeill 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 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 0.11 ± 0.02 m/s, for IW silver 0.24 ± 0.02 m/s, and for IW polyester 0.27 ± 0.02 m/s. However, adding external weights to unweighted lines resulted in a sink profile similar to IW lines.

Costs/problems—

- Concern for crew safety when using added external weights (Brothers et al. 2001; Melvin, Parrish, Dietrich et al. 2001; Anderson & McArdle 2002).
- Increased risk of a potentially harmful compound (lead weighting, either external or integrated) accumulating in the marine environment.
- Increased cost due to the extra swivels/weights (Brothers et al. 2001).

- Extra cost due to increased loss of weights when external weights attached close to the hook are cut by bycatch (especially sharks) (Brothers, Cooper et al. 1999).
- Variable results regarding the effectiveness recorded in the Alaskan demersal longline fishery (Melvin, Parrish, Dietrich et al. 2001).

Benefits—

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

Line shooters

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, increases the sink rate (Melvin, Parrish, Dietrich et al. 2001; 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 Company line shooter trials in the Norwegian and Alaskan demersal longline fisheries have shown remarkably varying results with regards to reducing seabird bycatch (Melvin, Parrish, Dietrich et al. 2001; 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 (mean ± SD) compared to 26.6 ± 7.3 s without the shooter (i.e. 15% faster). However, sinking rates were similar beyond 3 m depth (Løkkeborg & Robertson 2002). In contrast, Melvin, Parrish, Dietrich et al. (2001) reported total seabird catch per unit effort (including short-tailed shearwaters *Puffinus tenuirostris*) significantly increased, by 54%, when a line shooter was used compared to sets made with out the shooter.

Observations were made on the FV *Avro Chieftain* while using a line setter in the Ross Sea in conjunction with IW line, with the aim of trying to sink the IWL at the CCAMLR requirement of 0.3 m/s, without adding weights. Sink rates were monitored as per CCAMLR requirements. Using bottle test sink rates, the sink rates were found to exceed 0.7 m/s (over twice the required CCAMLR sink rate at that time) and approached 2 m/s. More accurate sink trials were planned to assess the profile of the sink rate using time depth recorders, however these were never performed as CCAMLR altered the sink rate to one that was achievable without using the line setter when using IW line (M. McNeill, Sealord Group, New Zealand, pers. comm. 2005).

Costs/problems—

- Line shooters increased seabird bycatch in the Alaskan cod demersal longline fisheries (Melvin, Parrish, Dietrich et al. 2001).
- Require additional crew to set gear (Melvin, Parrish, Dietrich et al. 2001).
- Variable results achieved in trials (Melvin, Parrish, Dietrich et al. 2001; 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 v. thawed, swim-bladder inflated v. deflated) can influence its buoyancy and, therefore, availability to birds (Brothers, Cooper et al. 1999).

Results—Results from an experiment assessing the sink rates in a tank of stationary salt water found that bait size (large v. small); bait condition (frozen v. thawed); and bait species—mackerel scad (*Decapterus macarellus*) v. chub mackerel (*Scomber japonicus*) v. Japanese pilchard (*Sardinops melanostichus*) v. 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. Sinking bait with inflated swim bladders may be achieved 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, Gales et al. 1999).

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

Costs/problems—

- Thawed baits detach from the hooks more easily than frozen ones when they are thrown from the ship (Brothers, Cooper et al. 1999).
- Inadequate thawing facilities on many vessels lead to inconsistency in the thaw state of bait (Brothers, Cooper et al. 1999).
- Possible costs of installing thaw racks incorporating a sprinkler system (Brothers, Cooper et al. 1999).
- Applicable only to pelagic longlining.

Benefits—

- Thawed baits are easier than frozen to apply to hooks (Brothers, Cooper et al. 1999).

- Handling thawed rather than frozen bait reduces discomfort for crew (Brothers, Cooper et al. 1999).
- Reduction in bycatch recorded when using thawed bait compared to frozen or partially thawed bait (Duckworth 1995; Klaer & Polacheck 1998; Brothers, Gales et al. 1999).
- Bait size (large v. small), bait condition (frozen v. thawed), and bait species had significant effects on sink rates (Brothers et al. 1995).

Other devices

None of these alternative devices have been trialled to date. Methods designed to conceal bait include the bait spider (Patent filed No. 332935), smart lures, and hull-integrated underwater setting (Anon. 1998; Brothers, Cooper et al. 1999; Anon. 2000). Other untested deterrent methods include the Hose, the 'Brigette Bardot' laser gun, the Ultrasonix electronic protection bird scarer, and emitting smoke from refuse disposal incinerators (Brothers, Cooper et al. 1999; Crysell 2002). Frozen block bait or glazed bait has also been suggested for improving sink rates (Anon. 2000).

3.3 MITIGATION METHODS RELEVANT TO TRAWLING

3.3.1 Warp cable and third wire protection

Falkland Islands warp scarer

Method—A device is attached to the warps to create a protective area around the warp. It consists of 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, Brickle, Reid, Bone et al. 2004). From each ring a rope with reflective tape hangs to the sea, to scare birds from the warp (Sullivan, Brickle, Reid, Bone et al. 2004). The warp scarer is deployed after shooting the net and retrieved prior to hauling (Sullivan, Brickle, Reid, Bone et al. 2004).

Results—During a trial in the Falkland Islands pelagic finfish trawl fishery, lower mortality rates (bird deaths/h) were recorded for the warp scarer (0.06 deaths/h) compared to the control with no mitigation device (0.76 deaths/h) (Sullivan, Brickle, Reid, Bone et al. 2004). In comparison to the control, the warp scarer significantly reduced total contacts (6.14 contacts/h compared to 58.34 contacts/h) and heavy contacts (0.93 contacts/h compared to 17.46 contacts/h). The one mortality recorded during the warp scarer trial occurred during shooting (i.e. before the device was deployed).

Costs/problems—
- Seabird mortalities may occur as the device is deployed after shooting and retrieved before hauling (Sullivan, Brickle, Reid, Bone et al. 2004).
- Costs approximately US $800.00 (Sullivan, Brickle, Reid, Bone et al. 2004).

- Crew safety concerns, as a crew member must reach outboard of the stern of the vessel during deployment (Sullivan, Brickle, Reid, Bone et al. 2004).

Benefits—

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

Bird-scaring lines

Method—In order to provide protection over both warp cables on a trawler, Sullivan, Brickle, Reid, Bone 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, Brickle, Reid, Bone et al. 2004).

Results—No mortalities were recorded during BSL trials in Falkland Islands pelagic finfish trawl fishery, compared to 0.76 mortalities/h with no mitigation device. Mortalities were recorded for black-browed albatross, southern giant petrels (*Macronectes giganteus*) and cape petrel (Sullivan, Brickle, Reid, Bone et al. 2004). Total contact rates were significantly reduced when using the BSL (1.00 contacts/h) compared to no BSL (58.34 contacts/h), as were heavy contacts (BSL—0.29 contacts/h; no BSL—17.46 contacts/h) (Sullivan, Brickle, Reid, Bone et al. 2004).

Anecdotal observations were collected 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/h were recorded with no deterrent, compared to 0.8 contacts/h with the paired-BSLs and 4.72 contacts/h 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 $40.00 (Sullivan, Brickle, Reid, Bone et al. 2004).
- Mortalities may still occur when the device is deployed after shooting and retrieved before hauling (Sullivan, Brickle, Reid, Bone et al. 2004).
- More work is needed to ensure BSLs track predictably and to minimize the potential for fouling on gear during haulbacks (Melvin et al. 2004).

Benefits—

- Require little storage space (Sullivan, Brickle, Reid, Bone et al. 2004).

- No costs associated with fitting (Sullivan, Brickle, Reid, Bone et al. 2004).
- Easy to maintain and replace (Sullivan, Brickle, Reid, Bone et al. 2004).
- Simple to deploy, only requires buoys to be thrown in to the water (Sullivan, Brickle, Reid, Bone et al. 2004).
- The use of two BSLs appears to provide protection for both warp cables (Sullivan, Brickle, Reid, Bone et al. 2004).
- Shown to reduce seabird mortalities (Melvin et al. 2004; Sullivan, Brickle, Reid, Bone et al. 2004).
- Relatively inexpensive compared to other mitigation methods.

Boom array and buoy line

Method—A boom is deployed on which mooring lines run from the boom to the water into the discharge plume (Melvin et al 2004). A buoy can also be tied on a line from the rail forward of the stern so that it also floats in the discharge plume (Melvin et al. 2004).

Results—During a pilot test of a boom array and buoy line 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 an area of the discharge plume (Melvin et al. 2004).
- Boom array could be maintained in the area outboard of the wire (Melvin et al. 2004).
- Boom array 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 can be run through a snatch block directly below the third wire block (see fig. 1 in Melvin 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/h) was used compared to no deterrent (16.04 contacts/h).

Costs/problems—
- Retrofitting of vessels would be required (Melvin et al. 2004).
- Adds wear to the third wire which is expensive to replace (Melvin et al. 2004).

Benefits—The snatch block resulted in less of the third wire being exposed, and consequently interactions with seabirds were reduced (Melvin et al. 2004).

Third wire scarers

Method—Scarer devices (four options) were attached directly to the third wire (see figs 2 and 4 in Melvin et al. 2004) to reduce the likelihood of birds approaching the danger area around the third wire.

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 third wire scarer were effective at reducing seabird strikes.

Costs/problems—

- All the third wire scarers tested were difficult to deploy and manage (Melvin et al. 2004).
- The devices created potentially unsafe conditions for the deck crew (Melvin et al. 2004).
- During retrieval, 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 (Melvin et al. 2004).

Bird baffler

Method—The bird baffler consists of a tower fitted to each of the two quarters of the stern gantry. To deploy it, 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, Brickle, Reid, Bone et al. 2004).

Results—During a trial in the Falkland Islands pelagic finfish trawl fishery, lower mortality rates were recorded for the Brady Baffler (Patent pending 508603) (0.07 deaths/h) compared to the control (no mitigation device; 0.76 deaths/h) (Sullivan, Brickle, Reid, Bone et al. 2004). Mortalities were recorded for black-browed albatross, southern giant petrels and cape petrels. While the baffler reduced heavy contacts compared to the control (9.71 contacts/h and 17.46 contacts/h respectively), the rates of total contacts did not differ significantly between the two (44.78 contacts/h and 58.34 contacts/h respectively) (Sullivan, Brickle, Reid, Bone et al. 2004).

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 their use by particular vessels, it may have been 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 (ANOVA, P = 0.767) (Conservation Services Programme unpubl. data). There is also a great variation in the design and deployment of bird bafflers in this fishery (W. Norden, DOC, pers. comm. 2005).

Costs/problems—

- Each baffler costs approximately US $4800 plus fitting costs (Sullivan, Brickle, Reid, Bone et al. 2004).
- Do not provide as much protection to the warp cables as BSLs or warp scarers (Sullivan, Brickle, Reid, Bone et al. 2004).
- Use over 3 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 may influence their effectiveness.

Benefits—

- Reduction in heavy seabird contacts and mortalities recorded during trials at the Falkland Islands compared to using no mitigation device (Sullivan, Brickle, Reid, Bone et al. 2004).
- Can be set at the beginning of a fishing trip and retrieved at the end of the trip or in extreme weather (Sullivan, Brickle, Reid, Bone et al. 2004).

Fish oil

Method—Oil is extracted from bycatch fish species is dispensed over the stern, creating a slick in the water behind the vessel (see also section 3.2.2—Fish oil).

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 min post-application. Before the oil was applied, 13 birds/min were observed feeding at the periphery of the plume and 1.5/min from within the plume; after application, 1.2 birds/min fed from the periphery and zero birds fed within the plume (Melvin et al. 2004).

Costs/problems—

- Unknown effects of introducing large amounts of fish oil into the marine environment (Melvin et al. 2004; Pierre & Norden 2006).
- Unknown effects 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), and requires an application for a waiver to do further research to investigate the use of fish oil as a mitigation method.
- 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 min post-application (Melvin et al. 2004).

3.3.2 Net protection/modification

Net binding

Method—Net binding aims to reduce the time during which seabirds may interact with the net. It does so by preventing the mesh of the net opening once the tension created by the vessel is lost due to waves and swell action; and by increasing the sink rate of the net (Sullivan, Liddle et al. 2004). While the net is sinking, the net bindings are broken and the net is then spread as a result of the force of the water moving through the doors (Sullivan, Liddle et al. 2004).

Results—Sullivan, Liddle et al. (2004) trialled net binding in the South Georgia icefish (*Champsocephalus gunnari*) trawl fishery. Despite low seabird numbers 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, some bindings did in fact break earlier than intended (Sullivan, Liddle et al. 2004). 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, Liddle et al. 2004).

Costs/problems—In trials, the bindings broke, perhaps indicating the need for a stronger binding (Sullivan, Liddle et al. 2004).

Benefits—

- Based on limited observations, fewer birds were caught during when the net was bound (Sullivan, Liddle et al. 2004).
- Based on anecdotal observations, binding may increase the rate at which nets sink to fishing depths (Sullivan, Liddle et al. 2004).

Net weighting

Method—Weights can be added to the net to increase the sink rate or reduce the time at the surface, 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 did not clarify which weighting regime was most appropriate, and the different net designs possibly confounded results (Hooper et al. 2003). However, the use of footrope weighting resulted in the codend (the posterior section of the net where the catch is collected during the tow) submerging immediately on shooting, and was suggested as a likely avenue for future experimental work.

Costs/problems—Findings were inconclusive (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 number of 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 (setting the net) (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 (bringing the net in) (Hooper et al. 2003). 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). A higher proportion of birds caught during the day time were albatrosses. Hooper et al. (2003) suggested further work was required in order to obtain a better understanding of the patterns of day and night catches they observed.

Costs/problems—No conclusive data on the effectiveness of night-setting currently available.

Other devices

These methods have not been formally 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 albatrosses. To prevent birds from approaching the mesh part of the net (to which they are vulnerable to interactions with), Hooper et al. (2003) suggested placing a small mesh top chafer over the area. Another factor that Hooper et al. (2003) believed influenced the likelihood of catching birds was net cleanliness, however their data did not statistically support the concept.

3.4 GILLNETTING

3.4.1 Visual alerts

Method—Fishing nets are modified to incorporate visible panels, acting as visual alerts to seabirds, in order to decrease their chances of entanglement.

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

Costs/problems—Visible panels in the upper 50 meshes significantly reduced the rate of sockeye salmon (*Oncorhynchus nerka*) catch rates by more than 50% (Melvin et al. 1999).

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

3.4.2 Pingers

Method—Fishing nets are modified to incorporate acoustic alerts 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, USA) 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 notable effect on rhinoceros auklet bycatch.

Costs/problems—Did not reduce rhinoceros auklet bycatch (Melvin et al. 1999).

Benefits—
- Did not compromise fishing efficiency (Melvin et al. 1999).
- Significantly reduced common murre bycatch at rates by 50% (Melvin et al. 1999).

3.4.3 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 altered) to minimise chances of bycatch events without reducing target species catch rates (Melvin, Parrish & Conquest 2001).

Results—Melvin, Parrish & Conquest (2001) found that in the coastal salmon drift gillnet fishery in Puget Sound (Washington, USA), 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 $P < 0.001$). Common murre entanglements were higher at both dawn and dusk (compared to during the day), while both sockeye salmon catch and auklet entanglements were highest at dawn (Melvin, Parrish & Conquest 2001).

Costs/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, Parrish & Conquest 2001).

3.4.4 Sub-surface drift gillnet

Method—The depth at which nets are set is increased to reduce bycatch and interactions between seabirds and fishing nets.

Results—Hayase & Yatsu (1993) found that in the Japanese high-seas drift gillnet fishery for flying squid (*Ommastrephes bartrami*), seabird entanglements (including sooty and short-tailed shearwaters) 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 sub-surface nets were used, however fishing efficiency was reduced by up to 95% (Hayase & Yatsu 1993).

Costs/problems—Fishing efficiency reduced by up to 95% (Hayase & Yatsu 1993).

Benefits—Seabird entanglements were significantly reduced (Hayase & Yatsu 1993).

3.5 COMPARATIVE STUDIES

A growing number of studies are now taking a comparative approach when testing for the most efficient method to mitigate against bycatch. To date, comparative studies have been undertaken for a number of mitigation methods relevant to longline, trawl and gillnet fisheries. These comparative studies are discussed (by fishery type) below.

3.5.1 Longlining

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 percentage reduction in contact rates (expressed as contact rate/bird/100 branch lines) in comparison with controls (no deterrents). The BSL was 75% and 77% effective black-footed albatross and Laysan albatross respectively; the blue-dyed bait was 95% and 94% effective; and weights were 93% and 91%.

A comparative assessment between four experimental mitigation devices (6.5-m and 9-m underwater setting chutes, side-setting, blue-dyed bait) was undertaken in the Hawaiian tuna and swordfish pelagic longline fishery (Gilman, Boggs et al. 2003). Based on mean contact and capture rates, side-setting was the most effective (significantly) treatment tested 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 either side-setting or the underwater chutes (Gilman, Boggs et al. 2003).

Trials at sea 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 underwater setting funnel developed by the Mustad Company; lines set without any devices caught 99 birds (1.75 birds/1000 hooks), lines set through the funnel caught 28 birds (0.49 birds/1000 hooks), and lines set with the BSL caught two birds (0.04 birds/1000 hooks) (Løkkeborg 1998).

Løkkeborg (2001) trialled a simple BSL, an advanced BSL and the 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/1000 hooks) when no mitigation measure was used, compared to six birds (0.08 birds/1000 hooks) when using the underwater setting funnel, two birds (0.03 birds/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, and BSL plus line shooter) during trials at sea 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 plus line shooter and the line shooter alone. Løkkeborg & Robertson (2002) concluded from their results that BSLs were the most feasible and effective mitigation measure for the North Atlantic demersal longline fishery.

Melvin, Parrish, Dietrich et al. (2001) tested BSLs (single, paired, and paired plus weight), external line weighting and the Mustad Company line shooter as methods to reduce seabird bycatch in two Alaskan demersal longline fisheries (sablefish and cod). Of all the methods 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, Parrish, Dietrich et al. 2001).

In a comparative study of Japanese Southern bluefin tuna longline vessels fishing off Capetown, Souht Africa, 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 (Minami & Kiyota 2004).

3.5.2 Trawling

Sullivan, Brickle, Reid, Bone 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, Brickle, Reid, Bone et al. 2004). 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 on the relative merit of various mitigation methods as seabird deterrents for future testing in the Bering Sea pollock fishery were made. 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 pilot 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. Some merit in the boom array-warp deterrent was also noted.

3.5.3 Gillnetting

Trials undertaken in the coastal salmon drift gillnet fishery in Puget Sound (Washington, USA) involved modifying traditional monofilament nets to include visual and acoustic alerts (Melvin et al. 1999). Nets with visible panels in their upper 50 meshes successfully reduced the bycatch of major seabird species, but reduced sockeye salmon catch rate by over 50%. Visual panels in the upper 20 meshes were equally successful in reducing bycatch of the major seabird species, while maintaining fishing efficiency. Acoustic pingers also reduced murre bycatch without compromising fishing efficiency (Melvin et al. 1999).

4. Discussion

4.1 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 (these criteria will benefit trawl fisheries mitigation research):

- Setting 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 similar.
- Collaborating with fishers and conduct research on active fishing vessels.

- Using consistent measures of bird interactions (such as abundance and attacks) and bird catch per unit effort and exploring 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 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, Parrish, Dietrich et al. 2001; Gilman, Boggs et al. 2003; Løkkeborg 2003; Robertson, McNeill et al. 2004; Sullivan, Brickle, Reid, Bone et al. 2004).

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. The results of the review for mitigation methods for multiple fisheries, longline, trawl and gillnet fisheries are discussed separately, with recommendations and suggestions for future research provided for each of these fisheries.

4.2 MITIGATION METHODS FOR MULTIPLE FISHERIES

4.2.1 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 abroad (Weimerskirch et al. 2000; Robertson & Blezard 2005; Sullivan et al. 2006). The most important observation made in several studies was that all mortalities occurred at times of offal discharge (Robertson & Blezard 2005; Sullivan et al. 2006). 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, and that offal management is likely to be an effective way to mitigate incidental capture in both trawl and longline fisheries.

4.2.2 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, Bell et al. 2004). 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.

4.3 LONGLINING

4.3.1 Recommended mitigation 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 for mitigating seabird bycatch in New Zealand demersal and pelagic longline fisheries.

Based on observations made in the Kerguelen Patagonian toothfish fishery, Cherel et al. (1996) advocated the dumping of homogenised offal away from where the line is being set as a means of distracting the seabirds away from the baited hooks, and therefore reducing the incidental capture of seabirds. While perhaps an effective method in fisheries where setting can be completed within short periods (eg. 11 minutes in the Patagonian toothfish fishery), this method is not appropriate in New Zealand longline fisheries where setting for tuna can take 5-6 hours. Consequently, the retention of offal during fishing operations is recommended for New Zealand fisheries.

Various studies have reported BSLs effectively reducing (often significantly) 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, 2001, 2003; Boggs 2001; Melvin, Parrish, Dietrich et al. 2001; Smith 2001; Løkkeborg & Robertson 2002; Minami & 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 controlled 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, Cooper et al. 1999). Correct mounting height is critical for achieving maximum effectiveness as it increases the distance of bait protection and prevents interference with the longline (Keith 1998; Brothers, Cooper et al. 1999). Therefore, individual vessel refinement of BSLs is likely to be necessary in order to achieve maximum effectiveness.

BSLs fulfil many of the criteria described by Gilman, Bloggs et al. (2001) as being necessary for a successful mitigation measure (see section 1.4). These criteria include: reduced seabird bycatch rate, reduced bait loss which may lead to a possible increase in target fish catch rates (Løkkeborg 2001), being easy and relatively quick to deploy and retrieve, being reasonably priced, and the ability to be used in both demersal and pelagic longline fisheries.

External and integrated (IW) line weighting have been shown to increase line sink rates and hence reduce the chance of incidental seabird mortality in both pelagic and demersal longline fisheries in New Zealand and international waters (Agnew et al. 2000; Robertson 2000; Boggs 2001; Brothers et al. 2001; Melvin, Parrish, Dietrich et al. 2001; Robertson, McNeill et al. 2004). 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) ones. Identifying which variables have most influence on sink rates will be necessary for the design of a line-weighting regime that will achieve faster line sink rates (Smith 2001).

Trials of external weighting on pelagic longlines, indicate that the line sinks faster the closer the weight is to the hook (Brothers et al. 2001; Anderson & McArdle 2002). 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 (50 g 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, McNeill et al. 2004). These result were encouraging given that both these species are capable of diving to great depths and are regular bycatch species in New Zealand longline fisheries (Robertson, Bell et al. 2004). Catch rates of ling and non-target fish species were not affected by use of IW lines (Robertson, McNeill et al. 2004).

Bait condition (best if thawed and with deflated swim bladders) is a further mitigation measure that could be used in pelagic longline fisheries, but in combination with other measures in order to achieve acceptable levels of reduced bycatch (Brothers et al. 1995; Brothers, Cooper et al. 1999).

4.3.2 Future research

Underwater setting devices have been shown to be more effective at reducing bycatch in Northern Hemisphere seabird assemblages than Southern Hemisphere ones (Gilman, Boggs et al. 2003). The composition of Southern Hemisphere seabird assemblage includes proficient divers, so a device is required that consistently achieves setting depths to 10 m (out of the reach of most seabirds). Ryan & Watkins (2000) noted that structural limitations on tube-type setting devices such as funnels (particularly those that are stern-mounted), 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, chutes, funnels, and capsules all exhibited inconsistencies in line setting performance and bycatch reduction.

Further development and trials at sea under normal fishing operations are required before these devices reach their full potential (which may still be insufficient to reduce Southern Hemisphere seabird bycatch) and before they are ready for commercial use. Future advances in effective underwater systems should be considered at the vessel design stage (i.e. installing hull-integrated underwater setting systems) rather than an afterthought (E. Melvin, Washington Sea Grant Program, Alaska, pers. comm. 2005).

While Melvin, Parrish, Dietrich 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. 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, knowledge of the seabird species implicated in attacking lines and their foraging habits (i.e. time of day, dive depths, etc.) is required. 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, Bell et al. 2004), 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 only a limited number of longline fisheries (Gilman, Boggs et al. 2003; Sullivan 2004). The uptake of this method may be limited by the vessel size and the initial costs of the vessel alterations. The results of pilot observations were made in a New Zealand ling fishery, 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 possible impacts of introducing large quantities of fish oil into the marine ecosystem (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.

4.3.3 Miscellaneous mitigation measures

Bait-casting machines can reduce bait loss to birds in pelagic fisheries by 50% when used with a BSL (Brothers 1993). However, the failure of some bait-throwing machines to incorporate initial designs to mitigate against seabird bycatch (i.e. alterations to 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 these devices to reduce incidental captures (Brothers, Cooper et al. 1999).

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, Parrish, Dietrich et al. 2001). 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 have been 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 New Zealand study 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. This behaviour is indicative of habituation (Lydon & Starr 2005).

4.4 TRAWLING

There are few published studies on methods to reduce seabird bycatch in trawl fisheries around the world, and none for the New Zealand trawl fisheries. The recommendations and discussion below are, therefore, based on relatively recent observations (some anecdotal), pilot tests and trials undertaken in the Falkland Islands, Bering Sea, South Georgia and Australian trawl fisheries.

As net sonde cables are banned in New Zealand trawl fisheries, 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, Bell et al. 2004). 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. In these studies, contacts usually occured when individuals were sitting on the water: the albatrosses usually touched the warps while the white-chinned petrels were more likely to interact with the net (Weimerskirch et al. 2000; Wienecke & Robertson 2002; Robertson & Blezard 2005; Sullivan et al. 2006).

4.4.1 Recommended methods

These recommendations are 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, is likely to be the most effective regime for mitigating seabird bycatch in the New Zealand trawl fisheries.

The deployment of paired-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, Brickle, Reid & Bone 2004).

Given that the white-chinned petrel is a bycatch species of particular concern due to the relatively high numbers that are caught, particulary in Southern Hemisphere fisheries (Wienecke & Robertson 2002; Robertson, Bell et al. 2004), 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 min.

4.4.2 Future research

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

As with longlining (see section 3.1.1), 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. 2006). Furthermore, all mortalities occurred at times of factory discharge (Sullivan et al. 2006).

A possible link between offal discharge and seabird bycatch are implicated in the autopsy data from seabirds killed (and returned) in New Zealand fisheries from 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, Bell et al. 2004). Recent analysis of New Zealand Fisheries observer data for squid trawling (2002/03, 2003/04 and 2004/05 fishing years) 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 (W. Norden, DOC, pers. comm. 2005). 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. Aquatic Environment Working Group report, New Zealand Ministry of Fisheries). Further research is required into the effect(s) of offal discharge in seabird bycatch rates in New Zealand and overseas fisheries.

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 including net binding and adding weights to the net (Hooper et al. 2003; Sullivan, Liddle et al. 2004). 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, Liddle et al. 2004). 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.

Trials using fish oil in the New Zealand snapper longline fishery reduced seabird numbers (Pierre & Norden 2006), and the same effect was observed when this method was used in the Bering Sea pollock trawl fishery (Melvin et al. 2004). However, as discussed (section 3.3.1—Fish oil), using fish oil as a deterrent requires further investigation, particularly with regards to the mechanism behind its effectiveness and potential impacts on the marine ecosystem.

4.4.3 Miscellaneous mitigation measures

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, Brickle, Reid, Bone et al. 2004). 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 (W. Norden, DOC, pers. comm. 2005). Abraham (2005) recorded a reduction in heavy seabird contacts with the warp when a bird baffler was used. However, he noted that this might be an artefact of the vessel effect. The relatively poor performance of the baffler, due perhaps in part to varying effectiveness in deployment, does not make it an attractive mitigation measure compared to other methods such as BSLs, warp scarers and offal retention. There are no published studies from New Zealand trawl fisheries proving that bird bafflers significantly reduce seabird bycatch and interactions with fishing gear. There is also great variability in the design and deployment of bird bafflers in the New Zealand trawl fisheries (W. Norden, DOC, pers. comm. 2005).

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

4.5 GILLNETTING

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, USA). 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, Parrish & Conquest 2001). Having trialled a number of mitigation methods, Melvin, Parrish & Conquest (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.

4.6 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, zero) 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 (2004/05) been placed on purse seine fishing vessels; preliminary reports from observer data on four purse seine operations have recorded no seabird bycatch (W. Nordern, DOC, pers. comm. 2005). This fishery produces little (if any) offal discharge.

5. Conclusions

Based on the material presented in this review, the author has reached the following conclusions regarding mitigation of seabird bycatch in New Zealand fisheries:

- 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 longline and trawling fisheries both in New Zealand and overseas.
- 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. Future advances in effective underwater systems should be considered in the vessel design (i.e. incorporating hull-integrated underwater-setting systems) rather than as an afterthought.
- Methods such as acoustic deterrents are expected to be limited in their long-term use 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 its 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.

6. Recommended contacts in the field of seabird bycatch mitigation

This review of seabird bycatch mitigation techniques has emphasised the importance of well-designed controlled studies in order to obtain meaningful results regarding the effectiveness of the mitigation methods. 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 can be obtained from Conservation Services Program, Department of Conservation, New Zealand. 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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