A review of methodologies for mitigating incidental catch of protected marine mammals

S.J. Rowe

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ABSTRACT

Marine mammals and seabirds are sometimes caught and killed during fishing operations. The development of methods to mitigate or avoid such incidental mortality is a growing field of research, and information on them is released in a variety of local, national and international media. This report presents the results of the marine mammal component of a global review of mitigation methods aimed at reducing mortalities of protected seabirds, marine mammals and reptiles, and corals due to interactions with fishing gear in New Zealand fisheries (and fisheries elsewhere that operate using similar methodologies). The review assesses the application of these mitigation methods to New Zealand fisheries, makes recommendations for fisheries management, and identifies areas for further research in New Zealand. In set net fisheries, pingers have been shown to reduce harbour porpoise (*Phocoena phocoena*) entanglements. There is, however, concern over the long-term effectiveness of pingers, the possibility that pinger deployment will displace cetaceans and the efficacy of pingers in preventing the incidental catch of species other than the harbour porpoise. Further research is needed to address these questions and to investigate other techniques to mitigate set net entanglement, including modifications to the acoustic properties of net fibres. In trawl fisheries, exclusion devices show potential as a mitigation technique, but further research is necessary to prove the efficacy of current models. Globally, little is known about the level of marine mammal incidental catch in longline fisheries and no known measures have been trialled to mitigate marine mammal incidental mortality. To develop effective mitigation techniques, future studies should aim to replicate results in a range of habitats and for all species that are killed during fishing operations. In all fisheries, the circumstances that lead to marine mammal incidental mortality should be further investigated to aid in the development of successful mitigation measures.

Keywords: marine mammals, fisheries, incidental bycatch, mitigation, pingers, exclusion devices, New Zealand

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1. Introduction

Around the world, marine mammals, birds and other animals are sometimes caught and killed during fishing operations. The development of methods to mitigate this incidental mortality resulting from interactions with fisheries is a growing field of study. Information on these methods has been released in a variety of local, national and international fora (including through conferences, journal articles, government and non-governmental organisation (NGO) literature, fishing industry magazines, and websites). Recent published reviews in the field of non-fish bycatch mitigation have typically focussed on species or fishing method, or a combination of these (Fertl & Leatherwood 1997). However, a comprehensive review across fishing methods and species has not yet been published.

1.1 SCOPE AND OBJECTIVES OF PROJECT

This review collates and synthesises published, unpublished, internet-based, and anecdotal information on methodologies for the avoidance of incidental catch of marine mammals in fisheries that share characteristics with New Zealand fisheries (including longline, set net, lobster pot 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 application of these methods to New Zealand fisheries was assessed and areas for further research in New Zealand identified.

The specific objectives of the project were:

- To conduct a global review of methodologies aimed at mitigating marine mammal incidental catch in fisheries that share characteristics with New Zealand fisheries
- To recommend appropriate avenues of future research into the avoidance and mitigation of marine mammal incidental catch in New Zealand fisheries

1.2 DEFINITIONS

Terms used in this report are defined as follows:

Catch per unit effort (CPUE): the number or weight of fish caught by a unit of fishing effort; e.g. a catch of 100 kg per hour (100 kg/h).

Cetacean: aquatic mammals of the order Cetacea, including whales, porpoises and dolphins.

Codend: the closed end of a trawl net where the target species collects.

Demersal: found on or near the bottom of the sea.

Demersal trawling: the operation of a trawl net designed for use on or near the bottom of the sea.

Depredation: the removal of catch or bait from fishing lines by marine mammals.

Discards: catch that is returned to the water, either dead or alive.

Ensonify: to expose an area of the water column to acoustic (sonar) energy.

Green weight: the weight of fish prior to any processing or removal of any fish part.

Incidental mortality: the non-target marine mammal species that are incidentally caught whenever fishing gear is not perfectly selective (Terry 1994).

Isobath: a contour line connecting points of equal water depths on a map or chart.

Longline: fishing gear in which short lines carrying hooks are attached to a longer main line at regular intervals. Pelagic longlines are suspended horizontally at a predetermined depth with the help of surface floats. Demersal longlines are set at the seabed with weights.

Mitigation measures: the modification to fishing practices and/or equipment that reduces the likelihood of incidental non-fish catch (Brothers et al. 1999).

Nautical mile: a unit of distance that is used on the water, equivalent to approximately 1850 m.

Otariidae: eared seals or fur seals and sea lions.

Pelagic: associated with surface or middle depths of a body of water, rather than the sea floor. This term is usually applied to free-swimming species, such as tuna and sharks.

Phocidae: earless seals or true seals, e.g. elephant seal (*Mirounga leonina*).

Pinniped: a suborder of aquatic carnivorous mammals with all four limbs modified into flippers. It includes seals, sea lions, and walruses.

Set net: a type of passive fishing gear consisting of panels of net held vertically in the water column, either in contact with the seabed or suspended from the sea surface.

Sonar target strength (TS): the amount of sound reflected back towards the sonar.

Squid 6T fishery (SQU6T): the southern squid trawl fishery which operates around the Auckland Islands, from February to April or May, or until the fishing-related mortality limit for sea lions (set by the Minister of Fisheries) is reached (see Ministry of Fisheries 2006).

Target catch: catch that has been selected by species or size. Generally the highest ‘value’ catch available.

Trawling: a variety of fishing operations in which nets are towed behind a boat to sweep the water. The nets may be set to fish at different depths, depending on the target species (see demersal trawling).

1.3 FISHERIES AND THE INCIDENTAL CATCH OF MARINE MAMMALS

Individuals of most marine mammal species are known to have been killed as a result of fishing operations (Northridge & Hoffman 1999). In New Zealand, marine mammals have been incidentally caught predominantly in set nets[1] and trawl nets, but also on longlines and, occasionally, in lobster pot lines (Manly et al. 2002b; Dawson et al. 2001; S. Cranwell, DOC, pers. comm. 2006). Hector's (*Cephalorhynchus hectori hectori*) and Maui's (*C. hectori maui*) dolphin subspecies[2] have been reported entangled in inshore set nets set by both commercial and recreational fishers (Dawson et al. 2001). Incidental mortality of New Zealand sea lions (*Phocarctos hookeri*) and New Zealand fur seals (*Arctocephalus forsteri*) occurs almost entirely during trawl fishery operations (Manly et al. 2002b, c). Fur seals also become caught during longlining, but very few are killed (Manly et al. 2002a). Humpback whales (*Megaptera novaeangliae*) have occasionally become entangled in lobster pot lines, but have been released alive. Six entanglements were recorded in a 4-year period (S. Cranwell, DOC, pers. comm. 2006).

Globally, cetaceans are frequently caught in set nets and, consequently, many of the studies included in this review refer to mitigation methods designed for set net fisheries. Substantially fewer studies have concentrated on marine mammals caught in trawl, longline and lobster pot fisheries.

1.3.1 Set nets

The entanglement and subsequent drowning of cetaceans in fisheries is of worldwide concern (Reeves et al. 2003), with global incidental mortality of small cetaceans estimated to be in the region of 300 000 animals per year (Read et al. 2003). There has been much debate over why cetaceans become entangled in set nets and it is still uncertain whether marine mammals become entangled because they do not detect the nets in time to avoid them, or whether they detect them in time, but do not perceive them as a threat (Kastelein et al. 2000).

The introduction of set net fishing has been implicated in the decline of the harbour porpoise (*Phocoena phocoena*) and populations of Hector's dolphins (Westgate & Read 1998; Dawson et al. 2001; Martien et al. 1999). Based on observer data collected in North Sea set net fisheries between 1994 and 1995, Vinther (1999) estimated the total annual incidental mortality of harbour porpoises in that fishery to be 6785 animals. This level of incidental mortality was well above that set by the Agreement on the Conservation of Small Cetaceans of the Baltic and North Seas (ASCOBANS) which came into force in 1994 (ASCOBANS 1992) and led to the development of an action plan to reduce incidental mortality of the harbour porpoise (Larsen et al. 2002a). Since the 1997/98 New Zealand fishing season, the Department

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[1] In New Zealand, fishers use the term 'set net' rather than gill net; therefore, 'set net' will be used throughout this document.

[2] Hereafter, references in this document to 'Hector's dolphins' include 'Maui's dolphins', unless otherwise stated.

of Conservation (DOC) has documented all reported Hector's dolphin strandings. Between 1997/98 and 2002/03, 64 Hector's dolphin carcasses were necropsied to establish a likely cause of death: 16 deaths were reported as due to net entanglement and a further 22 dolphins were confirmed to have died as a result of net entanglement (Duignan 2003; Duignan et al. 2003a, b, 2004; Duignan & Jones 2005).

1.3.2 Trawling

Some marine mammal species feed opportunistically from trawl nets, and animals may become trapped in the net and drown. Globally, little published information exists on the number of marine mammals caught in trawl nets or the causes of incidental mortality (Fertl & Leatherwood 1997). However, in New Zealand and other countries where observers are used, observer reports provide information on the number of marine mammals caught.

During the 2002/03 fishing season in New Zealand, 66 New Zealand fur seals were caught in trawls targeting at least seven commercial fish species. Of the 66 animals caught, 87% were dead when landed on the vessel (Baird 2005a). Based on government observer data, earlier reports of estimated total catch of New Zealand fur seals in the New Zealand Exclusive Economic Zone (EEZ)[3] ranged from 401 animals in the 1990/91 fishing year to 2110 in 1995/96 (Manly et al. 2002b).

Endemic New Zealand sea lions are predominantly caught incidentally in the SQU6T squid fishery. Low numbers of New Zealand sea lions are incidentally caught outside the SQU6T fishery (Baird 2005b; Baird & Doonan 2005). The Ministry of Fisheries 2006-07 SQU 6T Seal Lion Operational Plan provides recent fishery statistics from the fishery including sea lion bycatch levels recorded since the 1987–88 fishing season (Ministry of Fisheries 2006: 8).

Common dolphins (*Delphinus delphis*) have been observed entering nets to feed in the bass pair trawl fishery in the United Kingdom (SMRU 2004), where approximately 90 dolphins were incidentally caught between 2000 and 2003 (Northridge & Sanderson 2003). Northridge (1998) reported that, compared with demersal trawls, cetaceans are more likely to be captured in mid-water trawls, as they are towed at relatively high speeds, are generally larger than demersal trawls and usually target the same species as cetaceans.

Common dolphins have also been observed to be incidentally caught in the New Zealand jack mackerel (*Trachurus declivis, T. novaezelandiae* and *T. murphyi*) trawl fishery (Norden & Fairfax 2004). Reports of Hector's dolphins being caught in trawls are rare, but observer coverage is low (Blezard 2002; Fairfax 2002). In 1997/98, one dolphin was observed caught in the Canterbury region (Starr & Langley 2000) and a further two were voluntarily reported (Duignan 2003). Another incidental capture was reported in the 1999/2000 fishing year (Duignan et al. 2003a).

[3] New Zealand's Exclusive Economic Zone (EEZ) extends 200 miles out and around the coastline. It covers 2.2 million km^2 and ranges over 30 degrees of latitude from the subtropical Kermadec Islands to the subantarctic Campbell Island/Motu Ihupuku.

1.3.3 Lobster potting

Globally, crayfish and lobster pot lines pose an entanglement risk to several whale species including blue (*Balaenoptera musculus*), fin (Balaenoptera physalus), humpback, minke (*Balaenoptera acuturostrata*), southern right (*Eubalaena australis*) and northern right whales (*Eubalaena glacialis*) (ASMFC 1997; Western Rock Lobster Council Inc. 2003). Off the coasts of North America and Australia, baited pots are set on the ocean floor, either inshore or offshore, and are hauled every few days. Multiple pots are tied together forming a single line, called a trawl, with another line leading to a float or buoy on the surface to mark the location of the pots. Whales become entangled in both the vertical buoy lines and the horizontal ground or float lines that join the pots (ASMFC 1997; Seafood Industry Victoria Inc. 2004).

In comparison, the risk of whale entanglement in New Zealand may be lower because of the type of pots used and the manner in which the gear is deployed. Baited pots are set on the sea floor and marked with a single vertical line attached to a buoy (SeaFIC[4]). Between 2001 and 2005, six humpback whales have been freed alive from pot line entanglement in the spiny rock lobster, or crayfish (*Jasus edwardsii*) fishery at Kaikoura (S. Cranwell, pers. comm. 2006).

In Australia, juvenile Australian sea lions (*Neophoca cinerea*) frequently take lobsters through the neck of pots and have been reported as becoming entrapped and drowning (Campbell 2005). New Zealand fur seals and sea lions do not seem to interact with lobster pots.

1.3.4 Longlining

Marine mammals are known to be incidentally taken during longline fishing, but little published data are currently available detailing the number or frequency of incidental mortality events (Ovetz 2004). The nature and extent of marine mammal interactions with the world's longline fisheries vary by region, target catch species, and gear deployment method (Donoghue et al. 2003). Animals may become hooked or entangled while removing bait or fish from lines, although few fatalities have been recorded (Kock et al. 2004).

Tuna longline fisheries operating in New Zealand waters have recorded incidental catches of fur seals, but animals are usually caught and released alive. In the 2002/03 fishing season, Government observers recorded 56 New Zealand fur seals caught in the southern bluefin tuna (*Thunnus maccoyii*) longline fishery, of which 98% were released alive (Baird 2005a).

1.4 MARINE MAMMALS

An understanding of marine mammal biology and foraging behaviour is necessary in order to design appropriate and effective methodologies aimed at reducing or eliminating incidental mortality.

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[4] www.seafood.co.nz/business/fishaqua/catch/lobpot.asp

1.4.1 Biology

All marine mammals are long-lived, with low reproductive rates, so that recovery from population reduction is slow compared with shorter-lived species with high reproduction rates (Boyd et al. 1999).

Female pinnipeds tend to live longer than males and also reach sexual maturity before males. In polygynous species, males must mature for several further years after reaching sexual maturity before they can compete for access to females (Berta 2002). New Zealand fur seals are estimated to live to approximately 15 years of age (Mattlin 1978b). Females reach sexual maturity at 4 years of age and produce their first pups at 5 years. Males are thought to reach sexual maturity at 8–9 years, but gain their first territory at 10 years. The maximum age for New Zealand sea lions is approximately 23 years for males and 18 years for females. Females become sexually mature at 4 years of age and bear their first pup at 5 years. Males reach sexual maturity at 5 years, but have limited success holding stable harems until 8 years (King 1999).

The reproductive systems of pinnipeds generally include delayed implantation in all species and highly seasonal, synchronised reproductive cycles in most species (Boyd et al. 1999). Female New Zealand fur seals give birth from late November until the end of December, after which females alternate between feeding and suckling their pups until July or August (Mattlin 1981). In pinnipeds, only one offspring is produced from each reproductive attempt (Boyd et al. 1999). Pinniped species may be monogamous (one mate for each gender), polygamous (multiple mates for one gender but not the other), or promiscuous (multiple mates for both genders). Males are not thought to contribute to offspring care and the extent of female care primarily involves nursing offspring (Wells et al. 1999).

Cetaceans are also long lived; sperm whales (*Physeter macrocephalus*) are thought to live up to 60 years of age and some dolphins live until 30 years. Sexual maturity is reached in dolphins and porpoises at 3–4 years of age, and in large whales, such as the sperm whale, at 10 years (Baker 1999). Hector's dolphins are reported to live to approximately 20 years, and females first give birth at 7–9 years of age (Duignan 2003; Duignan et al. 2003a; Duignan & Jones 2005). Males were thought to reach sexual maturity between 6 and 9 years (Slooten & Lad 1991), but necropsy results have reported males as young as 4–5 years with mature gonads (Duignan et al. 2003b; 2004).

Cetacean species are either polygamous or promiscuous, with no cetacean species known to exhibit monogamy. Long-lasting relationships are not formed and, at most, are only maintained for the duration of the breeding season (Wells et al. 1999; Boyd et al. 1999). Mysticetes (baleen whales) migrate to breeding grounds and fast for the duration of the breeding season before migrating back to feeding grounds. While breeding may be seasonal for most odontocetes (toothed whales), mating does not involve migration to breeding grounds or a fasting period (Wells et al. 1999). Cetaceans breed seasonally and usually bear only one offspring after gestation periods ranging from 9 to 16 months (Baker 1999; Boyd et al. 1999). Parental care generally lasts for several months to one year, but may last up to several years (Wells et al. 1999).

1.4.2 Foraging behaviour

Pinnipeds spend most of their time at the surface and dive to obtain food. In otariids, many foraging studies have focussed on females. Lactating otariid females are relatively shallow foragers, typically diving to depths of less than 100 m for a period of 2–3 minutes. Diving is mainly during the night or at dawn and dusk. The length of foraging periods is constrained by the necessity for females to periodically return to the breeding colony to nurse their pups. There is great variation both between and within species in terms of the duration of a foraging trip and the distance travelled (Wells et al. 1999).

New Zealand fur seals are thought to feed in surface waters at night and near the sea floor during the day (King 1999). For lactating females, the mean dive depth, dive duration, and bottom time for dives over 6 m in depth is lower during summer and increases through to winter (Mattlin et al.1998). Mattlin et al. (1998) recorded the maximum dive depth for a lactating female at 274 m, indicating the New Zealand species is the deepest-diving fur seal recorded to date. Of the otariids, New Zealand sea lions undertake the deepest and longest dives. Individuals dive to a mean of 123 m (median = 124 m, maximum > 500 m) and, on average, are under water for 3.9 minutes (median = 4.33 minutes, maximum = 11.3 minutes) (Gales & Mattlin 1997).

In most phocids (true seals), foraging is suspended during the breeding season. At the end of the northern and southern elephant seal breeding season, animals depart from the breeding site with depleted body fat stores and embark on extended foraging trips. Adult male and female elephant seals differ somewhat in diving patterns and foraging locations, even though they take similar prey. Such sexual segregation in foraging locations is also found in some cetacean species (Wells et al. 1999).

Many mysticetes annually migrate from lower latitude breeding grounds to higher latitude regions in order to locate a more abundant and concentrated food supply. Mysticetes use the baleen plates in their mouths to filter large quantities of small organisms from the water column. They feed mainly on krill, copepods, amphipods and, in the Northern hemisphere, on schooling fish. Individual species are adapted to feeding primarily on benthic organisms, in the water column, or at the surface, although some species may feed in multiple areas (Wells et al. 1999).

In contrast, odontocetes use their teeth and jaws to capture single prey items such as fish, squid or, for larger species, other marine mammals. The size and type of prey targeted by odontocetes is dependent on their body size, manoeuvrability, diving capabilities and the number and type of teeth. Odontocetes generally forage daily and throughout the year, making them resident where prey is available. Among smaller odontocetes, feeding patterns vary by region, season, sex, age and reproductive class, presumably due to different energy requirements. Odontocetes generally live in either the open ocean, coastal or riverine areas and feeding patterns will vary depending on the habitat type in which animals live (Wells et al. 1999).

Cetaceans can dive to considerable depths to search for food. Sperm whales regularly dive to depths of around 1000 m and can stay under water for 1.5 hours. Baleen whales dive for shorter periods of 10–15 minutes to depths of 90 m or more. Dolphins generally dive to shallow depths for periods up to 5 minutes (Baker 1999).

Hector's dolphins have been observed predominantly within the 100 m isobath (Bräger et al. 2002), and are rarely seen further than 15 n.m. from shore. During the summer months, dolphins are often seen in the surf zone of beaches (Bejder & Dawson 2001). Hector's dolphins are reported to inhabit shallow, turbid waters (Bräger et al. 2003). Dolphins generally feed opportunistically in small groups, at the bottom and throughout the water column, and take a variety of species (Slooten & Dawson 1988).

Unlike mysticetes and pinnipeds, odontocetes locate prey using echolocation. Animals produce species-typical broadband clicks with peak energy between 10 kHz and 200 kHz and either constant or modulated frequency whistles ranging up from 416 kHz. Odontocetes are thought to use echolocation to image their environment by producing high frequency clicks and then detecting echoes that bounce off distant objects (Tyack 1999; Wartzok & Ketten 1999).

1.5 SUCCESSFUL MITIGATION

The aim of marine mammal mitigation techniques should be to eliminate or substantially reduce incidental capture and mortality of marine mammals without causing increases in the incidental capture of other species or reductions in target catch (Hall et al. 2003). In order to be successful, any mitigation technique designed to reduce incidental mortality must be accepted and adopted by fishing industries (Bache 2003).

Tucker et al. (1997) outlined the following preconditions to consider when designing fishing gear modifications for incidental mortality mitigation:

- That minimal loss of target species occurs or, if loss occurs, that the increased quality of what remains adequately compensates for that loss
- That the use of the incidental mortality reduction device does not increase operating costs
- That the device is safe, simple and practicable to use

In New Zealand, several fisheries have developed voluntary Codes of Practice (COPs) aimed at outlining best practice methods to remedy, mitigate or avoid the incidental capture and mortality of marine mammals and seabirds in commercial fisheries. Codes of Practice may include recommendations for gear modifications, setting and hauling practices and voluntary area closures (see SEFM 2002; HFMC 2004).

1.6 INTERACTIONS BETWEEN MARINE MAMMALS AND FISHING GEAR

Understanding the circumstances that lead to the death of marine mammals in a fishery is essential to determining how future mortalities can be prevented. Describing these circumstances will provide a clearer understanding of how and when a mitigation measure can reduce mortality (Bache 2003).

1.6.1 Set netting

Dolphins and porpoises are especially susceptible to entanglement because of the nature of set net design. Set nets are designed to be see-through and have almost the same density as water, making them difficult to detect in the water column, especially at night (Kastelein et al. 2000). Nets are made from monofilament nylon and are designed to catch fish behind the gills. Cetaceans become caught when their flippers, dorsal fins, tail or head become entangled or catch in the net (Stone et al. 2000).

Although set net design contributes to animals becoming entangled, it is less clear why cetaceans fail to detect, and avoid, nets. Experiments have shown that echolocating dolphins and porpoises can detect headlines, floats, ropes and leadlines at a distance great enough to avoid them. However, the net mesh is not as easily detected by echolocation, with detection estimates ranging from a distance of 9 m for a bottlenose dolphin (Tursiops truncatus) to less than 2 m for a harbour porpoise (Au & Jones 1991; Goodson et al. 1994). Detection is further compromised by angle of approach to the net, noise, level of dolphin attention (concentration) and distraction by prey (Kastelein et al. 2000). Cetaceans may become entangled for several reasons (Au & Jones 1991; Dawson 1994; Bordino et al. 2002; Cox et al. 2003), including:

- Animals not continually echolocating and therefore failing to detect nets
- Animals being aware of the net but not perceiving it as an impenetrable object
- Animals feeding on prey in the vicinity of nets
- The presence of entangled fish masking the presence of set nets

To reduce marine mammal entanglements in set nets, Goodson (1997) recommended the following measures:

- Removing the fishery through time/area closures or total bans
- Deterring the animals from approaching the vicinity of the net
- Ensuring that the entire net structure is detectable and recognised as an obstacle by the animals
- Constructing set nets with safe passing places

Take Reduction Plans and Codes of Practice (COP) are used internationally to outline best practices aimed at reducing the likelihood of marine mammal entanglement in set nets. A Harbour Porpoise Take Reduction Plan was introduced in the Gulf of Maine and Bay of Fundy in 1999 and resulted in a 77% decrease in fishing-related porpoise mortality (Rossman 2000). In New Zealand, the South East Finfish Management Company (SEFM)[5] developed a voluntary COP for commercial set net users in 1999 (SEFM 2002). Challenger Finfisheries Management Company (CFMC) based their COP on the SEFM model in 2002 (see CFMC 2003). To mitigate Hector's dolphin entanglements, the COPs outline best practice for gear deployment including the use of acoustic alarms (hereafter termed 'pingers') and setting and hauling practices. The SEFM COP has been updated each year and specifies areas to be voluntarily closed to fishing to reduce the interaction between commercial set nets and Hector's dolphins in shallow waters and to protect nursery grounds for target fish species.

[5] SEFM is a commercial stakeholder organisation representing 94% of all finfish quota owners in the southeast of the South Island (Quota Management Areas 3 and 5).

Several complete or seasonal area closures are currently in place in New Zealand in order to reduce the level of interaction between Hector's dolphins and inshore set nets. In the South Island, the Banks Peninsula Marine Mammal Sanctuary (1170 km^2) only allows limited recreational set netting between 1 March and 31 October. Recreational set netting is otherwise prohibited, and there is no commercial set netting allowed within the Sanctuary. There are further regulations in place that reduce the chances of dolphins being caught in set nets at those times of the year when set nets are allowed: setting a net overnight is forbidden; using a net longer than 30 m is forbidden; each boat may only set one net at a time and fishers should take steps to ensure the boat is crewed and not more than 50 m from the net while the it remains set.

In addition to the Sanctuary restrictions, the Minister of Fisheries established a 'Canterbury Set Net Area' between the Waiau and the Waitaki Rivers in December 2001. In this area, recreational set netting is prohibited from the shore out to 4 n.m. between 1 October and 31 March each year. The area excludes inland waters such as rivers, estuaries, lagoons and lakes, but does include the Estuary of the Heathcote and Avon Rivers/Ihutai. The prohibition on recreational set netting covers the time when Hector's dolphins come close inshore for breeding and are vulnerable to the impacts of set nets. The Minister of Fisheries has set an annual mortality limit for the area of three dolphins. In establishing the Canterbury Set Net Area, and the Hector's dolphin annual mortality rate, it was agreed that the industry would initiate the measures contained within a voluntary COP to address Hector's dolphin mortalities.

Since 2000, commercial fishers within the SEFM have implemented voluntary closed areas to protect the nursery grounds for rig and elephant fish and to reduce the interaction between commercial nets and Hector's dolphins in shallow waters. The closed area is from the southernmost end of the Banks Peninsula Marine Mammal Sanctuary southward to the northern bank of the Waitaki River (a distance of approximately 180 km). The area is voluntarily closed out to 4 n.m. for the period 1 October to 31 January in every fishing year. In addition, the area is voluntarily closed to commercial finfish set netting for the period 1 February to 30 September out to 1 n.m.

A voluntary recreational set net ban is in place on open beaches on the Kaikoura coast. The ban was put in place by the Kaikoura Boating Club and members of the local Recreational Fishing Association in April 2002 to help prevent the incidental catch of Hector's dolphins.

Local fishers in the Catlins region voluntarily agree not to set nets in the vicinity of Porpoise Bay.

In the North Island, regulatory closures were put in place on the west coast in 2003, when commercial and recreational set netting was banned between Maunganui Bluff (north of Dargaville) and Pariokariwa Point (north of New Plymouth), to a distance of 4 n.m. offshore. Set netting has also been banned in the Manukau Harbour entrance.

1.6.2 Trawling

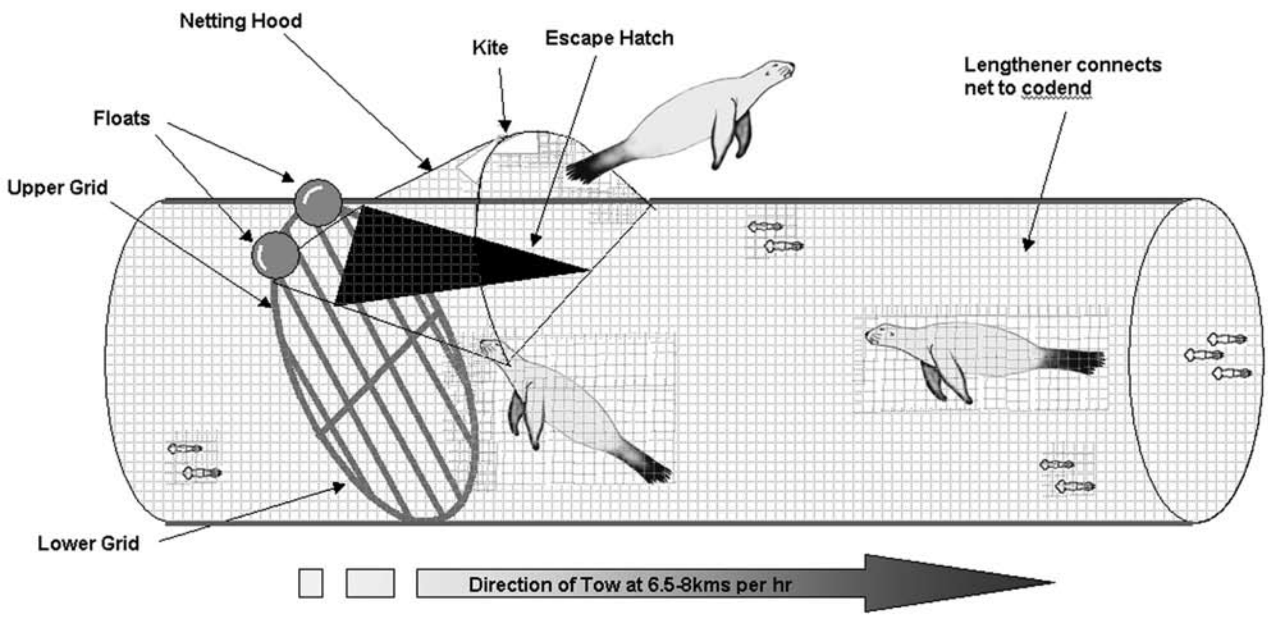
Pinniped species frequently exploit trawl fisheries for food and can become trapped in nets and drown (Fertl & Leatherwood 1997; Morizur et al. 1999). New Zealand fur seals are attracted to the physical presence of fishing vessels and are thought to become caught either when the net is being shot or during hauling (Baird & Bradford 2000). The probability of New Zealand fur seal capture occurring during a tow differs significantly with the Fisheries Management Area (FMA), the target fish species, the fishing year, the season, the nationality of the vessel, the average green weight of fish caught per tow and the duration of fishing (Manly et al. 2002b).

Mitigation techniques for use in trawl fisheries include deploying sounds to frighten marine mammals away, large-mesh nets across the net mouth to discourage entry, and escape devices (Morizur et al. 1999).

In order to reduce New Zealand sea lion incidental mortality near breeding sites, a 12-n.m. fishing exclusion zone was established around the Auckland Islands in 1982, which later became a Marine Mammal Sanctuary in 1993 (Wilkinson et al. 2003) and finally became the Auckland Islands Marine Reserve in 2003 (Suisted & Neale 2004). Since 2001, sea lion exclusion devices (SLEDs) have been used in trawl nets (see Fig. 1) in the SQU6T squid fishery around the Auckland Islands (Mattlin, 2005).

The Hoki Fishery Management Company (HFMC) has a voluntary COP aimed at mitigating the incidental capture of pinnipeds during trawling (HFMC 2004). The COP outlines best practices to be employed during shooting and hauling and what to do when pinnipeds congregate around the vessels or when animals are caught in nets. The COP also outlines methods for processing and storing offal and waste onboard, as pinnipeds are often attracted by the discards from fishing vessels. It also states that discards must not be thrown overboard during shooting or hauling or when the net is on the surface of the water. The Squid Fishery Management Company (SFMC) has a similar voluntary COP to mitigate sea lion mortalities in the SQU6T trawl fishery (Mattlin 2005).

Figure 1. Diagram of a sea lion exclusion device in a trawl net (image supplied by the New Zealand Seafood Industry Council).



During the 1980s, many types of seal scarers and acoustic harassment devices (AHDs) were trialled to determine their efficacy in scaring pinniped species away from coastal fish farms. AHDs, which emit loud, pain-inducing sounds, were moderately successful, but some degree of habituation has almost always been found and some researchers believe they can act as dinner gongs attracting pinnipeds to fishing vessels (Reeves et al. 2001; Jefferson & Curry 1996). In the early 1990s, AHDs were trialled in the west coast hoki (*Macruronus novaezealandiae*) fishery in New Zealand. The results indicated that the device would not effectively deter New Zealand fur seals from fishing vessels (Stewardson & Cawthorn 2004). The use of these devices may affect the animals' sensory capabilities and behaviour, displacing marine mammals from critical habitat (Reeves et al. 2001; Stewardson & Cawthorn 2004). Generally, AHDs are not recommended to mitigate pinniped capture in trawl fisheries (Jefferson & Curry 1996; Reeves et al. 2001; Stewardson & Cawthorn 2004).

1.6.3 Lobster potting

The risk of whale entanglements has been reduced in overseas fisheries through the use of gear modifications, such as break away lines, and changes to fishing practices that restrict the number of pots attached along a line and the time pots can be left unattended in the sea. Where lobster pots pose a threat to endangered species, such as the northern right whale, time/area closures have been introduced during periods that whales are present (ASMFC 1997; Western Rock Lobster Council Inc. 2003; Seafood Industry Victoria Inc. 2004).

In Kaikoura, Department of Conservation (DOC) staff meet annually with lobster fishermen to discuss the entanglement risk and to suggest safe fishing practices, such as ensuring there is no slack in rope lines. The fishing industry and local community are kept informed of whom to contact should they discover an entangled whale. The Department also works cooperatively with Australian response teams in developing and practicing disentanglement procedures (S. Cranwell, DOC, pers. comm. 2006).

1.6.4 Longlining

While some mitigation measures have been attempted to reduce interactions between cetaceans and longline fisheries, there have been no quantitative studies of their effectiveness. These measures include the deployment of 'seal scarers' when hauling, tying magnets to the fishing line, switching off onboard acoustic equipment during line hauling, offal retention during line hauling, delaying hauls when marine mammals are present, interrupting hauls, buoying-off lines, and steaming away from sites when marine mammals appear (Donoghue et al. 2003).

Reports of depredation in the Southern Ocean suggest that some vessels seem to attract more cetaceans than others. One factor which might play a role is the varying noise levels emitted by line haulers or vessel engines. Longline operators may attempt to make fishing operations quieter, but it is unclear at present if these measures are effective and attract fewer cetaceans (Donoghue et al. 2003; Kock et al. 2004).

2. METHODS

Information (post-1990) on mitigation measures to reduce marine mammal incidental mortality was obtained from various forms of media including peer-reviewed journals, unpublished reports, magazine articles, conference papers, websites and literature from government and non-government organisations. Relevant factors were extracted from the material and tabulated for each fishery for which information could be found (spreadsheet available from author on request). Based on this information, the influence of mitigation measures on incidental marine mammal catch and target fish catch rates was summarised and is presented and discussed in sections 3 and 4.

3. Results

For ease of reference, this section is divided into four main sections on mitigation measures suitable for: set net fisheries, trawl fisheries, lobster potting and for longline fisheries. Within each type of fishery, summaries for the relevant mitigation measures include a description of how the mitigation measure operates, reported results from trials/observations, a summary of the costs/problems (if any) and a listing of the benefits of each measure.

3.1 SET NETTING

3.1.1 Acoustic devices

Pingers

Mitigation method: Pingers are small underwater acoustic warning devices (transponders) that emit high-frequency pulsed signals. When they are attached at specific intervals along a net, the sound they emit either deters marine mammals from approaching the net or alerts them to the presence of the net (Reeves et al. 1996).

Pingers were developed in the New England groundfish set net fishery in the early 1990s to mitigate the incidental killing of approximately 2000 harbour porpoises (*Phocoena phocoena*) per year. Preliminary trials were conducted in the early 1990s and the first large-scale double-blind experiment was conducted in 1994 (see Kraus et al. 1997). Since that time, pingers have been used in northeastern United States fisheries as part of a strategy to keep harbour porpoise catches below the level set in 1998 by the by the National Marine Fisheries Service stock assessment group (483 individuals per year) under the United States Marine Mammal Protection Act (Kraus 1999).

The first pinger used in commercial set net fisheries in New Zealand to deter Hector's dolphins was a modified version of the Dukane NetMark 1000 pinger, called the Dukane NetMark 1050, which was tuned to a higher frequency range (Stone et al. 1997). As the Dukane NetMark 1050 was susceptible to damage and could be a hazard when hauling nets, it was replaced with the

Fumunda pinger, which has a 100 m ensonification range, 10 kHz frequency, 300 ms pulse width, 4 s pulse rate, 132 dB (re 1 μPa at 1 m), 250 m operating depth and a battery life of one year (SEFM 2002). The robust design is more resistant to wear and cracking, can be tied to the headrope, does not interfere with setting and hauling of the net, can be left on the net and is easier to use.

Results of trials undertaken in an artificial environment: Kastelein et al. (1995) observed the reactions of two harbour porpoises to two different pingers attached to a set net set in a pool. The two pingers were similar in source level (115 dB and 119 dB (re 1 μPa at 1 m), respectively) and in fundamental frequency (2.5 kHz), but differed in their harmonic. The first pinger emitted great energy in the 7th harmonic (17.5 kHz) together with weak harmonics extending to over 40 kHz, whereas the second alarm produced a clear 2.5-kHz signal without harmonics. Fast swimming and schooling behaviour was observed in response to the 17.5 kHz signal, compared with exploratory behaviour during the 2.5 kHz signal.

Two harbour porpoises in a floating pen displayed evasive behaviour and increased respiration rates (i.e. more frequent surfacings) in reaction to sounds emitted from three different pingers. The standard Dukane alarm (NetMark 1000) had a fundamental frequency of 11.3 kHz, 300 ms pulse duration, a 4.3-s pulse interval and harmonics ranging from 20 kHz to more than 100 kHz. The Random Dukane alarm produced the same sound as the standard Dukane alarm, but pulse intervals were produced at random intervals between 2 s and 30 s. Sound produced by the 'Bird Alarm' sweeps up and down in frequency between 2 and 3.5 kHz, has harmonics with high sound pressure levels above 30 kHz, peak frequency between 55 and 70 kHz and signal duration 800 ms and pulse interval 2 s. Qualitative observations suggested the Dukane NetMark 1000 and the Bird Alarm had stronger effects on porpoise behaviour than the Random Dukane pinger (Kastelein et al. 2000).

Further trials conducted by Kastelein et al. (2001) in a floating pen tested another three pingers: XP-10, 2MP, and HS20-80. The XP-10 alarm produced 0.3-s tonal signals randomly selected from a set of 16, with fundamental frequencies between 9 and 15 kHz, and a constant pulse interval of 4.8 s (duty cycle 6%). The 2MP alarm produced 0.3-s tonal signals randomly selected from a set of 16 with similar fundamental frequencies but with random pulse intervals between 2 and 5 s (duty cycle 8%). The HS20-80 alarm produced a constant, but asymmetrical, frequency-modulated sinewave between 20 and 80 kHz with total pulse duration of 0.3 s, with random pulse intervals of between 2 and 5 s (duty cycle 4.6%). All three pingers affected the porpoises' behaviour, as animals swam further away and respired more often than they did during control periods. The XP-10 pinger had the strongest deterring effect.

In all three trials, no habituation was detected, animals recovered quickly and the results were statistically significant (Kastelein et al. 1995, 2000, 2001).

Results of at-sea observational trials using stationary pingers: Cliff-top observations of Hector's dolphin movements around active or inactive pingers attached to a float were conducted in Akaroa Harbour, Canterbury (Stone et al. 1997). Researchers used an unnamed pinger which emitted a

10 kHz sound (with harmonics up to 110 kHz) for 300 ms every 4 s. Dolphins remained further away from active pingers, with the median approach distance being 372 m from active pingers and 299 m from inactive pingers. During boat trials, active or inactive pingers were placed in the water when dolphins were swimming next to the boat. Dolphins displayed no change in behaviour to inactive pingers but swam rapidly away from active pingers.

Observations of porpoise groups around a pinger attached to a floatline in Clayoquot Sound, Canada, found that 92.4% avoided the pinger and the closest approach observed was 133 m (Koschinski & Culik 1997). The pinger used was unnamed and produced 76–77 beeps per minute with a source level of 115 dB, a peak frequency of c. 2.9 kHz and strong harmonics. To determine whether porpoises were displaced from the area where pingers were deployed, observations of porpoise distribution were made before and after pinger deployment. Prior to the pinger being deployed, porpoises were present 95.5% of the observation time and after the pinger was turned off, porpoises were present 100% of the time indicating no long-term displacement of porpoises.

Laake et al. (1998) observed harbour porpoise behaviour around four set nets alternately set with and without pingers for 2–5-day periods off the coast of Washington State, USA. Researchers used the Lien alarm which produces a broadband signal with peaks at 3 and 20 kHz, with mean source levels between 121.7 and 124.7 dB (re 1 µPa at 1 m). Observations suggested porpoises were displaced 100 to 150 m from net No. 10 (closest net to observation area). The presence of pingers significantly reduced the probability of a harbour porpoise surfacing within 125 m of net No. 10.

Stone et al. (2000) tested the behavioural responses of Hector's dolphins in reaction to three pingers (black Pice, red Dukane and white Dukane) and a control (no pingers) by lowering pingers into the water from a boat. The Black PICE pinger has a random bandwidth between 50 and 80 kHz with varying frequency peaks. The pulse length is nominally 300 ms every 4 to 30 s. The Red Dukane pinger has a pulse length nominally 400 ms every 4 s, fundamental frequency at 10.2 kHz with 10 frequency components above 110 dB and three frequency components below 100 dB. The White Dukane pinger has a pulse length nominally 400 ms every 4 s, fundamental frequency at 9.6 kHz with six frequency components above 110 dB and four frequency components below 100 dB. The white Dukane pinger elicited the strongest response with 62.5% of groups exhibiting avoidance behaviour.

In Clayoquot Sound, Canada, Culik et al. (2001) tracked harbour porpoise movements around a stationary set net set with active or inactive pingers. A PICE pinger was used which generates eight different wide-band swept frequency signals between 20 and 160 kHz at a maximum source level of 145 dB for 300 ms at random intervals of 5 to 30 s. While the pinger was inactive, the median distance from the mid-point of the float line was 150 m. While the pinger was active, the median distance was 503 m (range 130–1140 m) and the mean closest approach was 414 m. Catch rate of herring (*Clupea harengus*) were similar in nets with and without pingers suggesting that herrings were not affected by the pinger sound.

Cox et al. (2001) tracked harbour porpoises off the coast of Grand Manan Island, Canada, around a mooring with either an active or inactive Dukane NetMark 1000 pinger attached. The pinger emits a regular interval pulsed, broad-band signal every 4 s for c. 300 ms with a fundamental frequency of 10 kHz and a minimum source level of 132 dB (re 1 µPa at 1 m). Over the two-week study period, porpoises were initially displaced 208 m from the pinger, but this displacement diminished by approximately 50% within 4 days, suggesting that porpoises habituated to the sound. Porpoises echolocated less frequently when the pinger was active.

Cox et al. (2003) set a 200-m-long commercial set net in 3–6-m-deep water at Atlantic Beach, California, and equipped it with three Dukane NetMark 1000 pingers, one at each end and one in the middle. Pingers were randomly set as active or control (silent). Bottlenose dolphins were displaced by pingers in a 'subtle way', but not to the extent observed for harbour porpoises in other studies. There was no significant difference in the number of dolphin groups observed per hour or the closest approach to the net between active and passive trials.

In another study, a stationary floatline set at Iracema Beach in Brazil was equipped with dummy or functional Dukane NetMark 100 pingers or with no pingers (control) (Monteiro-Neto et al. 2004). Sightings of tucuxi dolphins (*Sotalia fluviatilis*) in areas close to the floatline were significantly lower when active pingers were attached compared with dummy or control trials. There was no significant difference in sightings between dummy and control trials except in areas immediately adjacent to the floatline.

Costs/problems: The distance that pingers displaced harbour porpoises from a stationary pinger diminished by 50% within four days of initial pinger deployment, indicating possible habituation (Cox et al. 2001).

Benefits: Pingers appear to have a localised displacement effect on Hector's dolphins and harbour porpoises and animals return to the immediate area once pingers are removed (Koschinski & Culik 1997; Stone et al. 1997).

Results of at-sea trials under normal fishing conditions: Trials in a New Hampshire commercial set net fishery for Atlantic cod (*Gadus morhua*) and pollock (*Pollachius virens*) resulted in two harbour porpoises caught in nets with pingers and 25 caught in control nets (no pingers) (Kraus et al. 1997). Two harbour seals were entangled in nets with pingers and one in control nets. The alarm used emitted a regular interval pulsed, broad-band signal every 4 s for c. 300 ms with a fundamental frequency of 10 kHz and a minimum source level of 132 dB (re 1 µPa at 1 m).

Trippel et al. (1999) conducted controlled experiments in demersal multi-species set net fisheries in the lower Bay of Fundy in the USA during normal fishing operations. Set nets equipped with Dukane NetMark 1000 pingers significantly reduced harbour porpoise catch rates by 68% in 1996 (July 8–19 and August 1–15) trials and 85% in 1997 (July 8–19 and August 1–15) trials. Combined 1996 and 1997 data gives a mean harbour porpoise catch rate of 0.012 per string with pingers and 0.52 per silent string, indicating an overall 77% reduction in harbour porpoise incidental catch (three mortalities in 249 strings with pingers and 14 mortalities in 267 silent strings ($X^2 = 4.94$, df = 1, $P < 0.005$).

At-sea trials in the Danish bottom-set set net fishery for cod compared incidental catch rates in nets with active pingers, passive pingers and no pingers (control) (Larsen 1999). One porpoise was caught in a net with active pingers, 13 were caught with inactive pingers and 10 were caught with no pingers (frequency of dolphin catch per net set was 0.00, 0.02 and 0.03, respectively). Significantly higher incidental catch was recorded for silent nets (pooled data for silent pingers and no pinger) than active nets (X^2 test; $P < 0.01$). There was no significant difference in incidental catch between nets with silent pingers and no pingers. Pinger specifications were not detailed in the paper.

Pinger trials conducted in the Northern Washington set net fishery for Chinook salmon (*Oncorhynchus tshawytscha*) and sturgeon (*Acipenser* sp.) showed a reduction in harbour porpoise entanglements in nets equipped with Lien pingers compared to nets without them (Gearin et al. 2000). In 1995, for harbour porpoises interacting with nets with pingers and control nets, the catch per unit effort (CPUE) values were 0.019 and 0.365 per net day, respectively; and in 1996, values were 0.016 and 0.467. In 1997, the majority of nets in the fishery were equipped with pingers, resulting in an estimated 85% reduction in incidental catch.

Following the introduction of the 1999 Harbour Porpoise Take Reduction Plan (NMFS 1999) to Gulf of Maine and Bay of Fundy sink set net fisheries for groundfish species, observer data indicated that harbour porpoise incidental catch was reduced by 77%. Much of the reduction can be attributed to complete area closures. In areas where pingers were used, the incidental catch rate was 0.03 (animals/haul), which is lower than average non-pinger incidental catch rate of 0.05 over 6 years (Rossman 2000).

Experiments undertaken in the Cabo San Antonio multi-species set net fishery off the Argentinean coast indicated that the Dukane NetMark 1000 pinger is effective in reducing Franciscana dolphin (*Pontoporia blainvillei*) catch. Between October 1999 and February 2000, 45 dolphins were caught in silent nets and seven were caught in nets with pingers (Bordino et al. 2002). The mean CPUE for dolphins was 0.002 in nets with pingers and 0.14 in silent nets. Females constituted 61% of entanglements, of which 56% were immature and, among males, 90% were immature.

Carlström et al. (2002) reported no incidental catch in either control or active strings during at-sea trials in the Swedish set net fishery for cod and pollock. Compared with previous years, this significant reduction in incidental catch may have been due to the Dukane NetMark 1000 pingers ensonifying the general area and, consequently, displacing porpoises. In addition, herring (*Clupea harengus*) appeared to be more abundant in other parts of the porpoises' habitat range.

From August 2000, Danish bottom-set set net fisheries targeting cod in the North Sea were required to use pingers between August and October when net lengths up to 300 m in length were used. The pingers used (prototype LU-1) emit eight different signals between 40 and 120 kHz for 300 ms at random intervals between 5 and 30 s. Source level 145 dB (re 1 μPa at 1 m). Comparison of observer data before and after this requirement revealed a 100% reduction in incidental catch (873 sets without pingers, 129 sets with pingers, $P = 0.05$). A separate controlled experiment reliant on voluntary reporting by fishermen reported two porpoises caught from 12 sets without pingers and no porpoises caught from 87 sets with pingers (Larsen et al. 2002a).

A controlled experiment conducted between 1996 and 1997 in the Californian drift set net fishery targeting broadbilled swordfish (*Xiphias gladius*) and sharks (*Alopius vulpinas* and *Isurus oxyrinchus*) caught 74 marine mammals (43 cetaceans and 31 pinnipeds) (Barlow & Cameron, 2003). The marine mammal catch rate in nets with pingers (Dukane NetMark 1000) was significantly lower than in nets without pingers for all cetacean species combined (chi-square goodness of fit test, $P < 0.01$) and for all pinniped species combined (chi-square goodness of fit test, $P = 0.003$).

Costs/problems: Widespread use of pingers might displace cetaceans, particularly from coastal areas, forcing animals into sub-optimal foraging areas (Culik et al. 2001; Carlström et al. 2002).

Bordino et al. (2002) reported that sea lion (*Otaria flavescens*) attempts to remove fish from nets were more frequent in nets equipped with pingers. Such events increased throughout the experiment, indicating that sea lions learned to associate pinger sound with food. However, Kraus et al. (1997) and Gearin et al. (2000) found that pinnipeds damaged fish with similar frequency in strings with pingers and strings without pingers.

A disadvantage of pingers is that they are expensive, require periodic maintenance to check batteries, and can interfere with net setting and hauling (Dawson et al. 1998).

Benefits: Pingers have significantly reduced cetacean catch rates in a number of fisheries and locations. At-sea trials during normal fishing operations found that pingers reduced cetacean incidental catch (Kraus et al. 1997; Larsen 1999; Trippel et al, 1999; Gearin et al. 2000; Bordino et al. 2002, Barlow & Cameron 2003) and, in one case, it was completely eliminated (Larsen et al. 2002a).

Porpoises did not habituate to pingers during a two-year trial in the Danish bottom-set set net fishery (Larsen et al. 2002a). Koschinski & Culiks (1997) reported that continuous pinger deployment for 154 hours did not decrease the number of porpoises in the observation area.

Similar quantities of target fish species were caught in nets with and without pingers, including Atlantic cod, Atlantic herring, broadbill swordfish, Chinook salmon, common thresher, pollock, parona leatherjack (*Parona signata*), patagonian smooth-hound (*Mustelus* sp.), sea trout (*Cynoscion striatus*), shortfin mako, sturgeon and whitemouth croaker (*Micropogonias furniei*), (Kraus et al. 1997; Trippel et al. 1999; Culik et al. 2001; Bordino et al. 2002; Carlström et al. 2002; Cox et al. 2003; Barlow & Cameron 2003). Culik et al. (2001) also reported that Lien pingers appear to attract Atlantic herring.

Passive reflectors

Mitigation method: The acoustic properties of set nets can be modified to increase their detectability to cetaceans so that animals perceive the net as an impenetrable barrier. Modifications include chemically enhancing net fibres, increasing the density of net fibres with air-filled plastic tubing, braided wire or plastic coating or the addition of extra floats or bead chains spaced along the net (Au & Jones 1991; Koschinski & Culik 1997; Cox & Read 2004).

Results of passive reflector trials: Au & Jones (1991) used an echo measurement system to test the sonar target strength (TS) of five commercially used net types and three associated gears (poly rope, surgical rubber tubing and household light switch chain). The standard monofilament set net had the smallest TS, from –62.4 dB to –52.6 dB, indicating it would be the most difficult for echolocating dolphins to detect. All associated gear had similar TS values, which were at least 20 dB greater than the standard monofilament net, indicating modified nets should be more easily detected by echolocating odontocetes.

Set net trials conducted on the Moray Firth in Scotland found that a net comprising a 2 m × 2 m grid of acoustic reflectors was detectable by echolocating bottlenose dolphins. Dolphins approaching the modified net changed course and avoided it from distances ranging from 50 m to 170 m away. Entanglement only occurred in cases where non-echolocating stragglers failed to detect the net. Sonar images indicated that the acoustic reflectors produced detectable echoes and filled in the area between the headline (along top of net) and the leadline (along bottom). In comparison, the unmodified set nets appeared completely transparent, even at short range, with no detectable echoes returning from the 18-m-deep net (Goodson et al. 1994).

Koschinski & Culik (1997) tested two reflectors (set net floats and spherical plastic bobbers) suspended vertically every 2–3 m and spaced horizontally every 2 m. A 75-m floatline was set as a control. Reactions to passive reflectors did not differ from those to the floatline only, with approximately half the harbour porpoise groups observed avoiding passive reflectors and the floatline.

Trials of high-density nets in the Danish set net fishery were conducted during normal fishing operations. High-density nets consisted of monofilament fibres modified through the incorporation of a metal compound in the polymer. Following manufacture, the modified nets were unexpectedly stiffer than control nets, which caused the early cessation of trials due to considerably lower target fish catch rates. No porpoises were taken in the high-density nets but it could not be determined whether this resulted from increased density or increased stiffness. Subsequent seawater tank trials revealed that acoustic target strength did not differ between the two net types indicating the increased stiffness was responsible for differences in catch rates for both fish and porpoises (Larsen et al. 2002b).

Trippel et al. (2003) compared two types of nylon monofilament net in the Grand Manan Island demersal set net fishery for Atlantic cod, pollock, haddock and spiny dogfish (*Squalus acanthias*). The strands of one net type contained fine barium sulphate particles, while the other net type was made from 100% nylon. No harbour porpoise were captured in reflective nets, but 12 were captured in control nets (four porpoises in 1998 and eight in 2000). This reduction in harbour porpoise catch was significant (Fishers Exact Test; $P = 0.02$). Testing of the acoustic reflective properties of each net-type revealed that the barium sulphate net was approximately three times more reflective than standard nylon.

Northridge & Sanderson (2003) compared a set of polyamide (nylon) nets 'filled' with barium sulphate and standard monofilament skate nets. Incidental catch rates of both porpoises and seals were higher in the barium sulphate nets (mean of 0.05 porpoises/haul and 0.06 seals/haul) than in the standard nets (0.02 porpoises/haul and 0.03 seals/haul). This difference is only significant for porpoises at the 10% level and only at the 20% level for seals. The finding that incidental catch rates were higher in barium sulphate nets for both seals and porpoises suggests that there may be a common reason aside from the acoustic properties of the chemically enhanced nets.

Further trials of barium sulphate nets were undertaken by Cox & Read (2004) in the Bay of Fundy/Grand Manan demersal set net fishery for Atlantic cod, pollock and white hake (*Urophycis tenuis*). Porpoise Echolocation Detectors (referred to as PODs) were attached to 9 experimental and 14 control nets to record echolocation activity near nets. No harbour porpoises were caught in nets equipped with PODs and neither echolocation rate nor echolocation occurrence differed between the two types of net. Authors concluded that the mechanism by which the experimental nets reduced incidental catch in previous studies is unrelated to the acoustic properties of the nets.

Mooney et al. (2004) simulated dolphin-like echolocation signals to test the target strength (TS) of acoustically enhanced, barium sulphate filled nets compared with standard nylon nets. Results indicated that barium sulphate nets should be detected at a greater range by bottlenose dolphins and harbour porpoises when the net is approached from angles between 0° and 40° (the angle of the net was varied from normal incidence to angles of 10°, 20°, 30° and 40°).

Costs and problems: The ability of cetaceans to detect net modifications is variable (Cox & Read 2004; Tripple et al. 2003; Koschinski & Culik 1997; Goodson et al. 1994).

Acoustic reflectors attached to set nets may create handling problems for fishermen because of differences in volume, buoyancy and increased stiffness (Goodson et al. 1994; Larsen et al. 2002b).

Chemically enhanced nets are very expensive because the procedure of filling monofilament twine with metal is costly (Cox & Read 2004).

Benefits: The acoustic detectability of nets can be increased through the addition of objects or the modification of net fibres (Au & Jones 1991).

Echolocating dolphins avoid set nets with acoustic reflectors attached in a 2 m × 2 m grid (Goodson et al. 1994).

There was no difference in catches of commercial fish species between control nets and reflective nets (Cox & Read 2004; Tripple et al. 2003).

3.1.2 Net modifications

Mitigation method: Modifications can be made to nets to make them more detectable to cetaceans through changes to net length, twine type or twine size.

Results: The Take Reduction Plan for Harbour Porpoise (NMFS 1999) in the Gulf of Maine and Mid-Atlantic waters included complete time/area closures as well as time/area closures where fishing was allowed if specified gear was used. Such gear included specific twine sizes, limitations on the maximum string length and the use of tie downs (lengths of twine spaced along the net connecting the floatline and the leadline) (Palka 2000). In 1999, harbour porpoise catch was 53 animals, a decrease from 446 in 1998. Results indicate the Plan was at least partially responsible for the lower incidental catch during 1999, although to what degree is difficult to quantify. It is also difficult to separate the influence of time/area closures when determining the effectiveness of the gear specifications in lowering incidental catch (Palka 2000).

At-sea trials in demersal set net fisheries in Yorkshire, England compared two sets of skate netting, one of which was a monofilament nylon net and the other a three strand multi-filament net. Results indicated no significant difference in the catch rate of harbour porpoises between the two net types. Five porpoises were caught in 90 hauls using multi-filament net and five porpoises were caught in 87 hauls using monofilament net (Northridge & Sanderson 2003).

A second set of trials compared monofilament nets with different twine diameters; 0.4 mm ('thin') and 0.6 mm ('thick'). The thin twined net also had a smaller mesh size (90 mm stretched mesh). There was a significant difference in the incidental catch of both seals (grey seals, *Halichoerus grypus* and common seals, *Phoca vitulina)* and harbour porpoises between the two net types ($P < 0.01$). In 142 hauls with thin twine, one porpoise and one seal were caught (0.007 porpoises/haul and 0.007 seals/haul) and in 142 with thick twine, 8 porpoises and 10 seals were caught (0.06 porpoises/haul and 0.07 seals/haul). After all nets had soaked for roughly 1000 hours, there were 39 large holes in the thick twined nets and 58 in the thin twined nets. Some, if not all, of the holes in the thin twined nets may have been caused by animals becoming entangled and breaking free or falling out of the net (Northridge & Sanderson 2003).

Benefits: Grey seal, common seal and harbour porpoise incidental catch was significantly reduced through the use of thinner twine, possibly because animals could break free more easily (Northridge & Sanderson 2003).

3.1.3 Incidental catch avoidance

Time/area closures

Mitigation method: Areas are closed to fishing effort for a specific season or period when levels of marine mammal incidental catch are considered by fisheries managers to be too high. Closures may also be implemented in areas where fishing operations overlap with the range of an endangered species.

In order for area closures to be effective, several criteria need to be met: the area where incidental mortality occurs should form a small subset of the area where fishing effort occurs; patterns of incidental mortality should be predictable in time and space; displacement of fishing effort should not result in incidental mortality rates as high or higher than in the closure area; fishers should support and co-operate with the regulations; and an adequate information base should exist on which to design closures (Bache 2003; Murray et al. 2000). When planning an area closure, the economic impact on fishers should be assessed in order to clarify whether the proposed closure can effectively reduce incidental mortality while maintaining a viable fishery (Murray et al. 2000).

Results: Murray et al. (2000) analysed incidental catch levels before, during and after a closure in the New England multi-species sink set net fishery. Results indicated that the closed area was too small, as incidental catch occurred in waters adjacent to the closed area. Closure was not an effective technique for this area and fishery because of spatial and temporal variation in the incidental catch of marine mammals.

The Take Reduction Plan for Harbour Porpoise (NMFS 1999) implemented in the Gulf of Maine, Bay of Fundy region comprised both time/area closures and acoustic deterrents. The time/area closures were in place from May 1998 and throughout 1999. Observer data collected during the closure period indicated the average estimated catch was 77% lower compared to the average estimated incidental catch that from 1994–1998. Analysis of observer data attributed this reduction to the lack of commercial fishing effort during the winter season in areas that historically had high incidental catch rates. During winter, these areas were either completely closed or only open to vessels equipped with pingers resulting in very little fishing effort overall (Rossman 2000).

Costs/problems: Temporal and spatial movements of harbour porpoises are extremely variable from year to year making it difficult to determine the appropriate time and area suitable for closure (Murray et al. 2000).

Fishermen whose traditional fishing grounds are within a closed area will be impacted more than those whose fishing grounds lay outside the closed area (Murray et al. 2000).

Benefits: Time/area closures can reduce the incidental mortality of marine mammals where incidental catch events are predictable in time and space (Rossman 2000).

3.1.4 Comparative studies

Koschinski & Culik (1997) compared the effectiveness of two different passive reflectors and a pinger attached to a floatline by observing the behavioural reactions of harbour porpoises. The pingers produced 76–77 beeps/min with a source level of 115 dB, a peak frequency of c. 2.9 kHz and strong harmonics. 335 groups of porpoises were observed around the floatline. Reactions of these groups to the refectors and pinger varied significantly, with 92.4% avoiding the pinger but only around half (48.6% and 58.9%) avoiding the reflectors and only 51.8% avoiding the floatline. Closest observed approach distances were 133 m for the pinger, 33 m and 30 m for passive reflectors and 34 m for the floatline only. The difference between pingers and all other stimuli was significant. Schooling was observed only in reaction to pingers.

3.2 TRAWLING

3.2.1 Exclusion devices

Mitigation method: Exclusion devices are designed to allow the escape of marine mammals safely from trawl nets while allowing the target species to pass through the bars of the exclusion device into the codend. The exclusion device consists of a metal or high-impact plastic grid that directs large, non-target species to the top of the net where there is an escape hatch (Wilkinson et al. 2003; R. Mattlin, Ministry of Fisheries, pers. comm. 2006).

Sea lion exclusion device

The current Sea lion exclusion device (SLED) design (Mk 3/13) consists of two- or three-panel grids constructed of 20-mm vertical stainless steel bars designed to conform to the shape of the net (Mattlin 2005). The maximum spacing allowed between bars for the 2005/06 fishing season was 23 cm between bar centres. The grid is sewn into the lengthener section of the net, anterior to the codend, at an angle of 45° ± 5° from vertical. The angled grid directs sea lions towards the top of the net where an escape hatch is located. The triangular escape hatch measures 1–1.25 m at its base and the apex of the opening is at least 1 m from its base. A backward-facing hood (80–100-cm high) with an opening facing into the water flow covers the escape hatch and is kept open by a strip of semi-rigid material sewn into its opening.

Originally SLEDs were called marine mammal exclusion devices (MMED) until, in 1997, the fishing industry took over the development of the MMED and renamed the device as a SLED (Wilkinson et al. 2003).

The design of the original marine mammal exclusion device (MMED) commissioned by DOC was trialled in a flume tank with dummy seals. Three different escape hatches were compared and all were 100% successful in ejecting dummy seals from the net (Gibson & Isakssen 1998).

SLEDs were incorporated into trawling operations during the 2000/2001 fishing season in the SQU6T squid fishery around the Auckland Islands. Closed cover nets were placed over escape hatches of 276 tows to retain ejected New Zealand sea lions so that post-ejection behaviour could be videoed. SLEDs ejected 91% of sea lions (30 of 36 animals) which entered the net. Clear video footage was available for three sea lions following ejection into closed nets, and analysis indicated the three sea lions survived ejection (Wilkinson et al. 2003). Subsequent necropsies of five ejected sea lions indicated long-term survival was expected to be poor as two animals had suffered severe trauma, three animals had traumatic lesions and one had mild lesions (Gibbs et al. 2003). However, the cause of injuries and the location in the net or SLED at which they occurred is unknown.

New Zealand Fisheries observer data for the 2004/05 SQU6T fishing season documented eight sea lions caught and killed on trawls using SLEDs. Of those eight mortalities, five sea lions passed through the bars of the SLED into the codend and two were found in the pounds (the section where squid are emptied from the net) (DOC, unpubl. data, 2005). In order to address this issue, the Squid Fishery Management Company reduced bar spacing from 28 cm ± 10% between bar centres to 23 cm ± 10% in 2005 (Mattlin 2005).

At the time of writing, SLED research was continuing, with a joint industry, DOC and Ministry of Fisheries scientific group planning video and tagging studies to examine sea lions passing through a SLED.

Costs/problems: SLEDs may cause injuries to sea lions (Ministry of Fisheries 2001; Gibbs et al. 2003).

Some female sea lions passed through the bars of the Mark 3/13 SLED in 2005 and were caught in the codend or pounds (DOC, unpublished data, 2005). However, the distance between the bars of the grid was to be reduced in 2006 (Mattlin 2005) which should mitigate this problem.

Benefits: SLEDs can be manufactured at an affordable price, and are easily fitted and removed from a trawl by a competent deckhand in less than 30 minutes.

They can be easily stored on deck and are robust and easy to use (Gibson & Isakssen 1998).

Seal exclusion device and physical barriers

In a pilot study conducted in the Australian South East Fishery for blue grenadiers (*Macruronus novaezelandiae*), Tilzey (2000) found that the use of seal excluder devices (SEDs) resulted in an increase in the number of Australian fur seals (*Arctocephalus pusillus doriferus*) escaping the net once inside. There was a 78% mortality of seals caught in nets without SEDs, whereas only 34% of caught animals died in nets using SEDs. However, fish loss via the SED escape hatch was sizeable.

Hooper et al. (2005) observed various mitigation methods aimed at reducing or eliminating Antarctic fur seal (*Arctocephalus gazella*) incidental catch in the krill (*Euphausia superba*) fishery around South Georgia. The range of mitigation measures included: physical barriers (panels of netting) excluding seals from entering the net; physical barriers (panels of netting) positioned within the net accompanied by escape channels or openings; manufactured seal exclusion devices in front of the codend (consisting of a separator grill that deflects seals to an escape opening); fishing gear configured with panels of a mesh size adequate to allow seals to escape. In all cases the incidence of seal entanglements during the 2004 season were either eliminated or greatly reduced.

Costs/problems: Fish loss through the escape hatch may be sizeable, as indicated by a pilot study in the Australian fisheries (Tlizey 2000).

Benefits: The use of SEDs in the Australian blue grenadier fishery resulted in a significant increase in the ability of Australian fur seals to escape the net once caught (Tilzey 2000).

The use of SEDs, physical barriers or mesh panels in the krill fishery around South Georgia either eliminated or greatly reduced Antarctic fur seal incidental catch (Hooper et al. 2005).

Dolphin exclusion device

The following trials were all conducted by the British Sea Mammal Research Unit (SMRU) in the pelagic offshore bass (*Dicentrarchus labrax*) pair trawl fishery off the coast of Southwest England (SMRU 2004).

During the 2002/03 fishing season, SMRU (2004) trialled a steel grid exclusion device designed to exclude animals from entering the rear end of the net. Video footage revealed that no common dolphins (*Delphinus delphis*) entered the net as far as the grid. Researchers suggested that animals may have either been deterred from entering the net or, if they did, they exited back through the trawl mouth.

During the 2003/04 fishing season, SMRU conducted further trials with the steel grid exclusion device as well as a tubular steel device and a flexi-panel grid device. The tubular steel grid, used in conjunction with a 2.4-m-long escape hole and relatively small meshed and stiff netting, resulted in a lower incidental catch rate (by 60%) compared with steel and flexi-panel designs (SMRU 2004).

Benefits: Dolphin incidental catch was reduced by 60% when the tubular steel grid exclusion device was used (SMRU 2004).

3.2.2 Acoustic devices

Pingers

Mitigation method: Pingers are small underwater acoustic warning devices (transponders) that emit high-frequency pulsed signals. When attached to fishing equipment the sound emitted either deters marine mammals from approaching the net or alerts them to the presence of the net (Reeves et al. 1996).

Results of pinger trials on trawlers: In 2001, SMRU (2004) placed up to 12 pingers around the headline and footrope of the trawl. Pingers used in 2001 were Dukane NetMark 1000s. In 2002, up to six pingers were placed further back in the net around the 'sharks teeth' section of the trawl. In 2002 trials, the Aquatech 200 was used. This has wideband frequency modulated waveforms, each 200–300-ms long, with harmonic energy in the 5 kHz to 160 kHz band and 145 dB (re 1 μPa at 1 m). The acoustic devices tested in both instances were not effective at reducing dolphin incidental catch, possibly because background noise levels inside the trawl were too loud, or because the pingers are not loud enough, or because the animals were highly motivated to get inside the trawl and were not put off by the noise (SMRU 2004).

3.3 LOBSTER POTTING

3.3.1 Exclusion devices

Sea lion exclusion device for lobster pots

Mitigation method: In Australian trials, lobster pot necks were modified with sea lion exclusion devices (LP SLED) for potential use in the Australian lobster fishery. The exclusion devices aimed to prevent Australian sea lions from entering pots, thus preventing them from becoming trapped (Campbell 2005). The issue of pinnipeds entering lobster pots has never occurred in New Zealand and is unlikely because of the design of New Zealand lobster pots.

Results: Three different LP SLED designs (steel bar, double neck and T-bar) were trialled in Western Australia to determine their effectiveness in preventing Australian sea lions from entering pots (Campbell 2005). The steel bar design, consisting of a metal bar secured across the neck of the pot, stopped sea lions from entering the pot. The T-bar design, comprising an upright bar welded to the base and a cross piece attached at the top, reduced the number of sea lions entering the pot but a number of successful attempts were observed, and predation rate of lobsters was reduced but not eliminated. The double neck design extended the pre-existing neck to create a deeper entry. As the neck was flexible, sea lions were still able to remove lobsters from the pot, indicating that this design is not suitable as an exclusion device. Commercial trials are continuing with both the steel bar and T-bar SLEDs.

The steel bar design reduced lobster catch by 18% and the T-bar design lowered catch rate by only 2%.

Costs/problems: Industry members raised concerns that pot ropes could potentially become caught around the T-bar device resulting in a pot being flung around the deck and endangering workers.

Benefits: The steel bar design stopped sea lions entering the pot.

3.3.2 Concepts not trialled

American lobster (*Homarus americanus*) fisheries operating in the northwest Atlantic Ocean must abide by a fishery management plan to reduce the incidence of whale entanglement in buoy and ground lines. Fisheries operating in low-risk areas must include at least one specified gear mitigation device during fishing, and gear set in high-risk areas must include at least two devices. Gear mitigation characteristics include a size limit on buoy line diameter, incorporation of a weak link attaching buoys to the buoy line, a specified breaking strength for weak links, and buoy lines and ground lines are to be made of sinking line. In addition, all gear must be rigged so that the buoy line does not float on the surface at any time and gear must be hauled every 30 days. Areas considered 'critical habitat' for the endangered northern right whale are seasonally closed to all fishing. The Interstate Fishery Management Plan for Lobster (ASMFC 1997) came into effect in 1997 but, to date, no information has been published on the success of the plan in mitigating whale entanglement (ASMFC 1997).

Australian rock lobster fisheries in Victoria and Western Australia have developed voluntary Codes of Practice to reduce whale entanglements. The Codes include changes to fishing practices as well as the expectation that fishermen adopt a co-operative approach to avoiding and reacting to entanglements. Pre-entanglement practices include avoiding excessive slack in pot ropes, not setting pots in clusters and removing pots from the water when not actively fishing. Fishermen must also check pots regularly and report any entanglements immediately so that trained disentanglement teams have a greater chance of success (Western Rock Lobster Council Inc. 2003;

Seafood Industry Australia Inc. 2004). The Victorian Code of Practice has not been in place long enough to measure any improvement (J. Newman, SeaNet, pers. comm. 2005).

3.4 LONGLINING

No studies examining techniques to mitigate marine mammal incidental catch in longline fisheries were found for analysis in this report.

Observer data collected in New Zealand longline fisheries during the 1990/91 to 1995/96 seasons suggested that New Zealand fur seal incidental catch was generally higher during January–March and April–June and lower during other months. Fur seal incidental catch was higher when a bait thrower was not used (see Manly et al. 2002a).

In November 2002, the Workshop on Interactions between Cetaceans and Longline Fisheries set priorities for mitigation and current information on best practice for South Pacific longline fisheries (Donoghue et al. 2003). The Workshop suggested that fishers should consider the following practices:

- Minimise vessel and gear noise during fishing and while travelling to fishing grounds in order to avoid attracting cetaceans to the vessel
- Avoid fishing in areas known to be frequented by cetaceans
- Avoid setting or hauling when cetaceans are present around the vessel
- Retain offal and bait discards during fishing
- Allow scientists or observers to travel aboard longline vessels to provide expert advice on species identification and behaviour

4. Discussion

4.1 MITIGATION STUDIES

Many mitigation trials discussed in this report were conducted in one area, for one season and to test methodologies for mitigating the incidental mortality of one species. Dawson et al. (1998) suggested that future studies should aim to replicate results in time and space, in a range of habitats and for all species that are incidentally killed during fishing operations. However, if the problem is localised and consists of the incidental take of a specific species in a specific fishery, such as New Zealand sea lions in the Auckland Islands SQU6T squid trawl fishery, then local solutions need to be developed (R. Mattlin, Ministry of Fisheries, pers. comm. 2006).

In many regions where mitigation techniques have been trialled during fishing operations, rigorous experimental protocols were not in place and results often relied on observer data (Kraus 1999). Furthermore, many fisheries are now required to use certain gear modifications, such as pingers or exclusion devices, making further controlled experiments problematic. In such cases, the effectiveness of a mitigation technique can only be determined through historical analysis of observer data (Read 2000). While observer data can provide valuable information, the data are limited due to their method of collection (i.e. time restraints are placed on the observer to do other tasks, the observer is not trained in species identification). Controlled studies do require comparatively more resources compared to the use of observer programme data, however they are necessary in order to make meaningful use of the data collected and comparisons between studies (Bull 1997).

Despite the limitations of some studies in this review, there was sufficient information to provide recommendations for mitigation measures to reduce marine mammal captures in the New Zealand fisheries.

4.2 SET NETTING

The methodology to mitigate marine mammal incidental mortality in set net fisheries that has been most thoroughly trialled was the attachment of pingers to nets. Pingers were shown to reduce cetacean entanglements during normal fishing operations in a variety of fisheries and locations (Kraus et al. 1997; Trippel et al. 1999; Larsen 1999; Gearin et al. 2000; Bordino et al. 2002; Larsen et al. 2002a; Barlow & Cameron 2003), displace porpoises and dolphins from the immediate area surrounding stationary pingers (Stone et al. 1997; Stone et al. 2000; Culik et al. 2001; Cox et al. 2001; Monteiro-Neto et al. 2004; Koschinski & Culik 1997) and cause harbour porpoises in pools or floating pens to swim rapidly away from activated pingers (Kastelein et al. 1995, 2000, 2001). While the reviewed literature indicates that pingers reduce entanglements, there is still uncertainty about the long-term efficacy of pingers and their efficacy in fisheries that cause the incidental mortality of species other than harbour porpoises (Reeves et al. 1996).

Various opinions have been expressed regarding the likelihood of marine mammals habituating to pingers, as well as the possible impact of habituation. Koschinski & Culik (1997) stated that if habituation does occur, then incidental mortality rates may return to levels present before the use of pingers, or to increased rates if animals investigate the noise and become entangled. In contrast, the report of the Scientific Committee of the International Whaling Commission (IWC 1999) states that marine mammals may habituate to pingers over time, but this does not necessarily translate into a loss of pinger effectiveness in reducing incidental catch. They suggest that the aversive affect of pingers may only be reduced, not nullified. In addition, if pingers alert animals to the presence of a barrier that they perceive as dangerous, resulting in learned avoidance, then incidental mortality may not increase following any level of habituation (Cox et al. 2001). Larsen et al. (2002a) reported that harbour porpoise incidental mortality did not increase over a 2-year period during at-sea fishing trials, indicating that animals did not habituate to pingers, or at least learnt to avoid nets with active pingers attached. In areas where nets are moved frequently or fishing seasons are short, habituation may be less likely than in areas where nets remain set in the same location for long periods (Gearin et al. 2000).

In the majority of pinger studies to date, the harbour porpoise was the main marine mammal studied. In many fisheries and for most cetacean species, pingers have not been tested. Generally, porpoises tend to avoid novel stimuli, whereas dolphins may display investigative behaviour (Dawson et al. 1998). This suggests that the results of harbour porpoise studies should not be used to justify the introduction of pingers to mitigate the incidental capture of other cetacean species. Kraus (1999) proposed that rigorous experiments should be undertaken to determine pinger effectiveness in a particular fishery and on a particular species before pingers are implemented.

Widespread use of pingers might displace coastal cetacean populations into sub-optimal areas (Culik et al. 2001; Carlström et al. 2002). Trials using a single, stationary set of pingers indicated that harbour porpoises and Hector's dolphins were only displaced from the immediate area, and returned soon after pingers were inactivated (Koschinski & Culik 1997; Stone et al. 1997). However, the extensive deployment of pingers throughout large areas of coastline would ensonify a greater proportion of cetacean habitat, and nets without pingers in such areas might pose further risks.

Experiments in which the acoustic properties of nets were modified to increase their detectability by echolocating odontocetes have reported mixed results. Goodson et al. (1994) demonstrated that acoustic reflectors attached to nets enabled dolphins to change course in time to avoid entanglement, whereas Koschinski & Culik (1997) reported that harbour porpoise reactions to passive reflectors did not differ from those to the floatline only. Several studies have compared entanglement rates between standard nylon nets and nets containing fine barium sulphate particles. While Trippel et al. (2003) reported a significant reduction in the incidental mortality of harbour porpoises, Northridge & Sanderson (2003) reported higher levels of incidental mortality for both seals and harbour porpoises in barium sulphate nets. Modified nets may reduce incidental catch because of their stiffness or increased weight, rather than their acoustic properties, which would provide fishers with an effective and inexpensive alternative to reduce cetacean incidental catch (Cox & Read 2004). However, stiffer nets are likely to be unpopular with fishers if the increased stiffness or weight reduces target fish catch.

Other modifications to nets such as changes to twine size or type also reported mixed results. However, Northridge & Sanderson (2003) reported significantly lower incidental catch rates of common seals, grey seals and harbour porpoise in nets made with 0.4 mm twine compared with 0.6 mm twine. The authors suggested that the thinner twine may enable entangled animals to break free or fall out of the net (Northridge & Sanderson 2003).

Avoiding incidental catch of marine mammals through closing areas either completely or seasonally to fishing will be effective in areas where incidental catch events are predictable in time and space (Rossman 2000). To determine whether an area closure is appropriate, several criteria should be met: the closure should reduce incidental mortality, ideally while maintaining a viable fishery; fishing effort and incidental mortality should not simply be displaced to other areas outside the closure; and fishers must support and cooperate with the regulations (Bache 2003; Murray et al. 2000).

4.2.1 Recommended methods

The IWC (1999) recommends that if a fishery is to implement the use of pingers to mitigate incidental mortality of marine mammals, the following criteria should be met:

- Controlled scientific experiments should be conducted to demonstrate whether the devices significantly reduce incidental mortality.
- Field trials should be conducted to address operational issues and the acoustic properties of the pingers with respect to ambient noise and spacing of pingers.
- A scientific monitoring programme should be implemented—preferably using independent observers at sea. Reports of incidental mortality should detail whether pingers were functioning.
- Fishers should be involved directly in the process of developing mitigation measures.

Fisheries using pingers need to be monitored, either by observers or electronic monitoring systems, to ensure compliance and to determine the long-term efficacy of pingers. Such monitoring will help to address questions regarding habituation and displacement of cetacean populations.

Some scientists have suggested that in fisheries where endangered marine mammals are incidentally caught, pingers may not reduce incidental mortality to a level low enough to prevent population decline (Dawson 1994; Reeves et al. 1996). To date, only one trial has indicated that pingers can reduce entanglements by 100% (see Larsen et al. 2002a). The reduced incidental mortality rates reported in all other studies may still be too high in areas where populations are struggling to recover from the impacts of fishing-related mortality events (Dawson 1994). Culik et al. (2001) suggested that for endangered species directly threatened by set net fishing, the use of pingers should complement, and not be a substitute for, other measures such as reduced fishing effort or area closures. For some fisheries, incidental mortality may be mitigated through reduced fishing effort via restricting the number of vessels, net length, soak time and time of day nets are set (Dawson 1991).

4.2.2 Future research

At-sea trials should be undertaken around the world to test the efficacy of pingers in mitigating the incidental mortality of all marine mammals that become entangled in set nets. Each fishery should trial pingers throughout the distribution of the fishery and for the duration of the fishing season, before pingers are employed as a mitigation technique (Gearin et al. 2000).

The potential for habituation needs to be addressed. The likelihood of habituation may be reduced by designing pingers that change frequency at random intervals (Larsen 1999; Koschinski & Culik 1997). The use of high-amplitude, short-duration sounds which are triggered by odontocete vocalisations at close range may also prevent habituation and cause a useful startle effect (Kastelein et al. 1995). Observer data could be used to examine long terms trends in incidental catch and pinger deployment.

The distance from which marine mammals can detect pingers is not known, so the distance to which large-scale fisheries deploying pingers may displace animals cannot be determined. Further research using hydro-acoustic devices and time-depth recorders should be undertaken to examine the movements of cetaceans in relation to set nets with pingers (Tripple et al. 1999). It is essential to determine whether large-scale pinger use might force animals into sub-optimal foraging areas.

Pingers emit a sound within the hearing range of some commercially important species. Each fishery should determine whether pingers will affect the catch rate of target species, prior to recommending the introduction of pingers (Cox et al. 2003; Koschinski & Culik 1997).

Research should be conducted to determine whether pingers attract pinnipeds and dolphins to nets to feed, the so-called 'dinner bell effect' (Gearin et al. 2000). Bordino et al. (2002) found that sea lions fed more frequently from nets with pingers, and feeding increased over time.

Pingers are currently being deployed in commercial inshore set net fisheries in New Zealand to mitigate the incidental mortality of Hector's dolphins. Experiments conducted by Stone et al. (1997; 2000) suggested that stationary pingers set in Akaroa Harbour displaced Hector's dolphins from the immediate area surrounding the pinger. No at-sea trials have been undertaken to determine whether a similar displacement effect occurs during normal fishing operations and such trials are unlikely to be undertaken due to the risk of dolphins dying in control nets without pingers. To determine whether pingers will mitigate Hector's dolphin incidental mortality in the short and long term, observer data should be utilised to monitor pinger deployment and to report whether pingers were in use if an entanglement occurs. Observer data could also be used to determine whether any displacement effect reduces over time and, if so, whether there is a subsequent increase in entanglement rates. Such data would elucidate whether dolphins are habituating to pingers.

A major issue remains in New Zealand relating to the use of set nets by recreational fishermen who are not monitored or effectively regulated. Recreational fishermen do not have Codes of Practice and do not use pingers. They pose a large challenge for the Government in protecting Hector's dolphins from the adverse effects of incidental non-fish bycatch.

Variable results were reported in experiments trialling chemically enhanced set nets and further investigation is warranted. Cox & Read (2004) suggested that the reduction in cetacean entanglements in chemically enhanced nets may be a result of their increased stiffness rather than increased acoustic reflectivity. Northridge & Sanderson (2003) reported a significant reduction in incidental catch of several species through the use of thinner twine, possibly because animals could break free more easily. Controlled experiments could be undertaken to determine whether stiffer nets or nets with thinner twine are effective, cost-efficient practical mitigation methods.

4.3 TRAWLING

The use of exclusion devices in a variety of international trawl fisheries has resulted in the increased ability of marine mammals to escape from trawl nets once caught. Tilzey (2000) reported a significant increase in the ability of Australian fur seals to escape nets in the blue grenadier fishery in Australia. The use of SEDs, physical barriers or mesh panels in the krill fishery around South Georgia either eliminated or greatly reduced Antarctic fur seal incidental mortality (Hooper et al. 2005). SMRU (2004) trialled a variety of exclusion devices in the offshore bass pair trawl fishery in the United Kingdom and found that common dolphin capture was reduced by 60% when a tubular steel grid exclusion device was used. The use of SLEDs in the SQU6T squid fishery around the Auckland Islands allowed 91% of New Zealand sea lions that entered the net to escape (Wilkinson et al. 2003). Exclusion devices did not significantly reduce target fish catch in three studies (Wilkinson et al. 2003; SMRU 2004; Hooper et al. 2005).

Despite the promising results in the SQU6T squid fishery, there is debate over whether sea lions that escape through SLEDs survive in the short and long term. In 2004, the Minister of Fisheries requested that the Squid Fishery Management Company, government agencies and stakeholders work together to develop a plan of action to determine the efficacy of SLEDs. The fishing company has since organised a working group with the aim of determining the efficacy of SLEDs and, in particular, whether sea lions survive following escape through the SLED (Mattlin 2005).

4.3.1 Recommended methods

Various exclusion devices are recommended for use in the krill fishery around South Georgia, which have all eliminated or greatly reduced the incidental mortality of Antarctic fur seals (Hooper et al. 2005).

Stewardson & Cawthorn (2004) stated that SEDs are recommended for use in the South East Trawl Fishery in Australia, but only in mid-water nets, in areas with high seal density and on vessels with large fishing decks that enable storage of the device between shots.

Dolphin exclusion devices or net panel barriers are not currently used in the offshore bass pair trawl fishery in the United Kingdom, as further research and modifications are planned (SMRU 2004).

Discussions and research are currently underway to determine the efficacy of SLEDs being used in the New Zealand SQU6T trawl fishery (Mattlin 2005) and, as such, SLEDs were not recommended for use outside this fishery until the Sea Lion Exclusion Device Working Group (comprising Government Officials, fishing industry representatives and NGOs) had completed its research in 2006.

4.3.2 Future research

The Sea Lion Exclusion Device Working Group is currently developing an action plan to determine the efficacy of SLEDs and, in doing so, will outline the type of research required to determine the survivability of sea lions after passing through SLEDs (Mattlin 2005). Trials conducted in the 2000/01 fishing season in the New Zealand SQU6T fishery reported that 91% of sea lions entering the trawl escaped through the SLED. Research will be conducted to determine the survival of sea lions that escape the trawl net.

The British Sea Mammal Research Unit is continuing trials in the offshore bass pair trawl fishery in England to further develop and test dolphin exclusion devices. At present, exclusion devices are not being used in this fishery (SMRU 2004).

Once questions regarding current exclusion devices and net panels have been addressed, approved designs could be tested in other trawl fisheries where marine mammals are incidentally caught.

Determining why marine mammals are attracted to vessels and how they become caught in trawls will also aid in the development of mitigation techniques. The influence of offal discards, vessel noise, fishing practices and the spatial and temporal distribution of marine mammals and fishing activities could all be investigated.

4.4 LOBSTER POTS

No trials have been conducted in New Zealand to determine which gear modifications or fishing practices are effective in reducing whale entanglements in lobster pot lines. Current methods used in Australia and the United States have not been in place long enough to allow assessment of long-term trends in entanglement rates.

In New Zealand, whale entanglements are relatively infrequent (six recorded in a 4-year period) compared with other incidental mortality events of marine mammals generally. To date, humpback whales entangled in lobster pot lines have been localised to the Kaikoura area and all entangled whales have been released alive, although their post entanglement survival is unknown. No whale mortalities have been reported (S. Cranwell, DOC, pers. comm, 2006).

4.4.1 Recommended methods

Once the efficacy of mitigation practices used in the United States and Australia have been determined, these practices could be used elsewhere.

4.4.2 Future research

The humpback whale is a threatened migrant in New Zealand waters (Hitchmough 2002). The present population migrating through New Zealand waters is thought to be recovering following population decline to very low levels during New Zealand's whaling era (Suisted & Neale 2004). Gear modifications similar to those introduced in the United States could be trialled in New Zealand should it be considered appropriate. One of the considerations in assessing the appropriateness of gear modifications must be cost.

4.5 LONGLINING

4.5.1 Recommended methods

There are currently no recommended methods.

4.5.2 Future research

Further research is needed to determine the extent of marine mammal interactions with longline fisheries, to address the problem of marine mammal depredation and to assess and implement mitigation strategies under controlled experimental conditions (Kock et al. 2004).

In order to determine why some vessels attract more marine mammals than others, it is essential to know and compare the characteristics of vessels that have and have not incidentally caught marine mammals or experienced depredation. Determining the spatial and temporal patterns of interactions will be critical for solving or reducing this problem (Kock et al. 2004; Donoghue et al. 2003).

In New Zealand, observer data indicated that New Zealand fur seal incidental catch was lower when a bait thrower was used (Manly et al. 2002a). Research could be conducted to determine whether bait throwers, or other setting techniques, can aid in mitigating incidental capture.

4.6 OTHER FISHERIES

Other types of fishery operating in New Zealand waters include purse seine, jig, and troll; however, no material was found with respect to mitigation measures for these fishery operations. Purse seine fishing began in the 1970s in New Zealand. Preliminary reports from Ministry of Fisheries' observer data on four recent purse seine operations have recorded no marine mammal incidental mortality. No observer data are available for jig fisheries.

5. Conclusions

To develop effective mitigation techniques, future studies should aim to replicate results in time and space, in a range of habitats and for all species that are killed during fishing operations. In all fisheries, the circumstances that lead to marine mammal incidental mortality should be further investigated to aid in the development of successful mitigation measures.

At-sea trials during normal set net fishing operations have shown that pingers designed to deter harbour porpoises reduce entanglements. Concerns over the use of pingers include: long-term effectiveness; habitat exclusion; efficacy to prevent entanglement of species other than the harbour porpoise and their suitability for endangered species. Further research is needed to address these questions.

Modifying the acoustic properties of set nets through the addition of acoustic reflectors has not given consistent results, but further investigation should be undertaken.

Exclusion devices show potential as a mitigation technique in trawl fisheries, but further research is necessary to investigate the efficacy of current models.

The risk of whale entanglements in lobster pot lines can be reduced through gear modifications, such as break-away lines, and seasonal area closures.

Globally, no known measures have been trialled in longline fisheries to mitigate marine mammal incidental mortality.

6. Recommended contacts in the field of marine mammal bycatch mitigation

This review of marine mammal bycatch mitigation techniques has emphasised the importance of well-designed controlled studies in order to obtain meaningful results about 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 marine mammal bycatch in the trawl, longlining and gill net fisheries can be obtained from the author.

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