Mitigating operational interactions between odontocetes and the longline fishing industry: a preliminary global review of the problem and of potential solutions.

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1. ABSTRACT

Context and need: Operational interactions between odontocetes and the longline industry is a global problem. The odontocete populations involved are at risk of population decline due to the incidence of by-catch mortality. The longline fisheries involved are at risk of becoming economically unviable due to the incidence of catch depredation. Identifying and developing mitigation strategies is a priority for ensuring the future sustainability of odontocete populations and longline fisheries.

Approach and methods: This review begins by defining depredation and by-catch, then outlines the history of longlining and describes the fishing gear and practices used. The available published literature is then summarised with a view to describing the trends in and focus of the literature. This information was used to identify the odontocete species that depredate from and become by-catch on longlines, and where these events occur. The review concludes by detailing the mitigation methods that have been or may be trialled in the future.

Results: By-catch of odontocetes was found to occur globally and in many longline fisheries. There are only a few reports of the level of loss, although the level of this phenomenon remains unclear. Of the few cases reported, by-catch ranged between 0.002 and 0.231 individual caught per set. At least 13 odontocete species are involved, although the lack of information about population size and life history characteristics make it impossible to determine if this is sustainable. Depredation by odontocetes occurs in most longline fisheries and may lead to significant economic losses, with one fishery reporting fleet-wide daily losses of between US$928 and US$5,480 in the mid-2000s. Since then, considerable effort has been committed to solving this problem and potential solutions have included acoustic and physical tools. Acoustic mitigation tools have proven difficult to develop to assess. In contrast, recent innovations in physical depredation mitigation devices (PDMDs) have yielded promising results, although they have received less attention to date.

Synthesis and applications: The issue of (i) catch depredation by odontocetes from longline hooks and (ii) by-catch of depredating odontocetes on longlines is a global problem that requires immediate attention. Mitigation strategies should include the development and implementation of PDMDs, but should also be inclusive of a suite of other tools. The experience of fishers and their enthusiasm to be involved in developing mitigation tools should not be underestimated. Governments, research institutions, fisheries and funding bodies that are associated with this problem are encouraged to participate and invest in international collaborations that are focused on finding globally applicable solutions

Key words: Operational interactions, odontocete, whale, longline, depredation, by-catch mortality, PDMD.

2. INTRODUCTION TO OPERATIONAL INTERACTIONS BETWEEN ODONTOCETES AND LONGLINES

The occurrence of operational interactions between cetaceans and commercial fishing operations is a well known phenomenon that occurs worldwide (Northridge, 1984, 1991; Reeves and Leatherwood, 1994; Donoghue et al., 2003; Gilman et al., 2006). This phenomenon has attracted considerable attention in the literature and has been categorised as either trophic (i.e. biological) or operational (i.e. direct) in nature (Beddington et al., 1985; Northridge and Hofman, 1999; Shaughnessy et al., 2003; Kaschner, 2004; Hamer et al., 2008). Trophic interactions involve competition between cetaceans and fisheries for the same fish stock, resulting in either direct reduction (through removal of fish), or indirect reduction (through trophic cascades) of fish stocks (Northridge and Hofman, 1999; Kaschner, 2004). From the perspective of the cetacean this may result in a reduction in the availability of natural prey (Kaschner, 2004; Bakun, et al., 2009) and from the perspective of the fishery this may result in the reduction of a commercially targeted resource (Ashford et al., 1996; Earle, 1996). Operational interactions involve the simultaneous physical convergence of cetaceans and commercial fisheries toward the same spatially retracted area, typically because both are in pursuit of the same fish (Northridge and Hofman, 1999; Shaughnessy et al., 2003; Hamer et al., 2008; Moreno et al., 2008). Operational interactions may result in positive and negative outcomes for cetaceans and commercial fisheries (Northridge and Hofman, 1999; Shaughnessy et al., 2003; Hamer et al., 2008). Positive outcomes of operational interactions include (i) fisheries using marine mammals to indicate the presence of target fish (NMFS, 1992; Gosliner, 1999) and (ii) marine mammals using fisheries to access an otherwise inaccessible or difficult to obtain food resource (Gilman et al., 2006; Moreno et al., 2008). Negative outcomes include (i) fisheries suffering financial losses when cetaceans depredate the catch (Hucke-Gaete et al., 2004; Ramos-Cartelle and Mejuto, 2008) and (ii) cetacean populations suffering losses when depredating individuals are injured by or drown in fishing gear (Gosliner, 1999; Hamer et al., 2008).

There have been significant changes in longline fishing over the last 60 years, since Japan began modernising its fleet in the 1950s (Yamaguchi, 1989; Ward and Hindmarsh, 2007). During this period, cetacean ecologists and resource managers have shown varying degrees of interest in the nature and extent of operational interactions between odontocetes (i.e. toothed whales, dolphins and porpoises) and longline gear. Specifically, interest has focused on the depredation of longline catch by odontocetes and on the by-catch of depredating odontocetes. For the purposes of this review, depredation is defined as a form of operational interaction where an odontocete partially or completely consumes fish caught on longline hooks, or the consumption or deterrence of free swimming fish that may otherwise become caught on a longline hook (Yano and Dahlheim, 1995; Northridge and Hofman, 1999; Gilman et al., 2006; Lauriano et al., 2009). Although depredation of bait has been flagged as an issue, it will not be considered in this review due to uncertainties surrounding its occurrence in some fisheries, as explained later. Depredation is distinguishable from predation, which involves the consumption of free-swimming fish (AFMA, 2005). Again for the purposes of this review, by-catch is defined as the incidental capture of odontocetes on longline hooks subsequent to their attempts to depredate the catch (Beddington et al., 1985; Shaughnessy et al., 2003; Secchi et al., 2005; IOTC, 2007).

These two problems have attracted more interest form researchers and managers over the last decade compared with the previous four decades, principally for three broad reasons. Firstly, fishers may have become increasingly motivated to find ways of mitigating catch depredation to improve catch returns at a time when increased operational costs (i.e. fuel and freight) and depleted fish stocks (i.e overfishing) are eroding profits (Northridge and Hofman, 1999; Ebert et al., 2009; FAO, 2009). Secondly, fishing effort is increasing geographically on a global scale to meet the demands of the burgeoning human population (United Nations, 2009), thus increasing the probability of them having interactions with the cetacean populations that occur in the areas where they fish (Jefferson et al., 1994). Thirdly, as a consequence of these two factors, cetacean researchers may have become motivated to find ways of mitigating by-catch to prevent mortalities and injuries, and of mitigating depredation to prevent dependency on fishing operations for food (Gilman et al., 2006).

This review will summarise the (i) history and methodology of longline fishing, (ii) trends in reporting of catch depredation by and by-catch of odontocetes since the 1960s, (ii) negative outcomes of depredation for cetaceans and for commercial fisheries and (v) varied ways of potentially mitigating the problem.

3. HISTORY AND DESCRIPTION OF LONGLINING

Longlining evolved from hook and line fishing in Norway during the latter half of the nineteenth century (Bjordal and Lokkeborg, 1996). Technological advancements during World War Two (WW2) facilitated Japan's development of pelagic longlining into its modern form during the early 1950s, which resulted in the subsequent expansion of longlining activities throughout the Pacific, Indian and Atlantic oceans, mainly in search of tunas (Scombridae) (Yamaguchi, 1989; Ward and Hindmarsh, 2007). The ban on high seas driftnets by the United Nations Environment Program in 1993 (Northridge and Hofman, 1999) and the proclamation of Exclusive Economic Zones under the United Nations *Convention on the Law of the Sea* (UNCLoS) in 1994 (Rothwell, 1996; SPREP, 2002) resulted in pelagic longlining becoming the predominant fishing activity globally (Bjordal and Lokkeborg, 1996). Consequently, many countries (especially in the South Pacific) developed their own fleets, resulting in an overall increase in the number of longline vessels globally and an increase in their presence on fishing grounds (SPREP, 2002).

Pelagic longlines tend to dominate lower latitudes and typically target tunas and billfishes (Istiophoridae and Xiphiidae), while demersal longlines dominate higher latitudes and typically target Patagonian toothfish (*Dissostichus eleginoides*) in the Southern Hemisphere and several benthic species (e.g. sablefish *Anoplopoma fimbria*, Atlantic cod *Gadus morhua* and Pacific halibut *Hippoglossus stenolepis*) in the Northern Hemisphere (Bjordal and Lokkeborg, 1996; SPREP, 2002). Pelagic longlines drift with localised currents well off the benthos and are typically comprised of a mainline of up to 55 nautical miles (~100 km) in length and up to 3,600 baited hooks that are suspended from snoods and suspended at depths of between 30m and 300m (Gilman et al., 2006; Figure 1). Demersal longlines are made fast on the benthos with weights or anchors and are comprised of a mainline and up to 40,000 baited hooks that are attached to branch lines and sit on the benthos (Gilman et al., 2006; Moreno et al., 2008; Figure 2). Pelagic longline vessels tend to vary considerably in configuration, from small and open (11 m in length) to large and modern (24 m in length), because they operate in a range of environments from protected coastlines to more remote oceanic environments (Chapman, 1999; Hamer, 2009; Figure 3). Demersal longline vessels are typically larger vessels with freezer capacity, because they operate in remote locations at high latitudes and for long periods of time (Moreno et al., 2008; Figure 4).

4. SUMMARY OF DEPREDATION AND BY-CATCH REPORTS IN THE LITERATURE

Reports of odontocetes depredating catch from longlines emerged soon after the expansion of the Japanese longline fleet in the early 1950s (Iwashita et al., 1963; Sivasubramaniam, 1964; Mitchell, 1975). For the purposes of this review, literature relating to operational interactions between odontocetes and longline fisheries was obtained using electronic search engines and databases (i.e. Google Scholar and Web of Science) and from individuals known to have experience and knowledge of the topic. Only literature that was believed to have undergone a peer review process (i.e. journal articles and government reports) was used.

Interest in this topic has persisted in the literature since the 1960s, although their rate or production and the nature of their approach have changed. Only a few reports of operational interactions between longlines and odontocetes emerged during the 1960s and 1970s and they did little more than acknowledge the occurrence of catch depredation. The first report of odontocete by-catch on longline hooks appeared in 1983. Nonetheless, the focus has remained fishery-centric since that time (26 years, between 1984 and 2010), with 18 reports of depredation compared three reports of by-catch and four reports of both (Table 1). There have been two spikes of interest, with the earliest occurring during the 1980s and the latest occurring during the 2000s (Figure 5). The latest surge of interest has been sustained and exceeds the previous four decades combined, in terms of the number of reports.

The literature indicates that 11 odontocete species are involved in operational interactions with longline gear (Table 1). Other unverified and anecdotal sources indicate that at least two other species (the rough toothed dolphin *Steno bredanensis* and the spinner dolphin *Stenella longirostris*) become by-catch on longlines (Northridge, 1984; SPREP, 2002; Culic, 2004; Secchi et al., 2005; Watson and Kersletter, 2006). Killer whales (*Orcinus orca*) appear to be the main species involved with demersal longline fisheries at higher latitudes and close to land masses, while false killer whales (*Pseudorca crassidens*) appear to be the main species involved with pelagic longline fisheries at lower latitudes and offshore (AFMA, 2005; Hernandez-Milian et al., 2008). The literature also indicates the problem is geographically widespread, occurring in 26 locations in all of the world's major oceans from high latitudes in both hemispheres to the equator (Figure 6).

Interestingly, the few published reviews that explore the topic of operational interactions between cetaceans and fisheries in any detail indicate that most of the problems are associated with drift nets and gill-nets and they make few, if any, references to longlines (Northridge, 1984, 1991; Ridgway and Harrison, 1999; Culic, 2004). Despite this, catch depredation has been reported as an economic issue for pelagic longline fishers in the South Pacific since the late 1990s (SPREP, 2002) and in the Australian region since the early 2000s (Australian Fisheries Management Authority, 2005; McPherson et al., 2008; Hamer, 2009). There is also evidence that all of the 11 nations that use longlines in the Indian Ocean have problems with catch depredation (IOTC, 2007).

There may be a number of explanations for the general increase in the number of reports of operational interactions between odontocetes and longline fisheries. Most noteworthy is that reports of the phenomenon have become more widespread and more frequent in their occurrence as longlining effort has increased (Northridge, 1984, 1991; Reeves and Leatherwood, 1994; SPREP, 2002; Donoghue et al., 2003; Gilman et al., 2006). Despite the downturn in fisheries yield since the late 1990s (ref. see intro), humans have continued to increase exponentially worldwide (United Nations, 2009), have generally moved toward the coast (Martinez et al., 2007; McGranahan et al., 2007) and have changed their diet to contain a greater proportion of fish products (Duarte et al., 2009). Given that odontocetes are ubiquitous (Ridgway and Harrison, 1989; Ridgway and Harrison, 1999; Culic, 2004; Carwardine, 2006) and that longline fishing is the predominant fishing method globally (ref. see intro), the resulting increase in geographic overlap between the two has likely led to a greater number of reports of depredation. The adverse impact these events are reported to have on the economic viability of affected fisheries has encouraged them to prioritise the need to find solutions. As a result, researchers have been given unprecedented and increasing access to fishing vessels to observe and quantify the problem (Figure 5; Table 1).

5. IMPACTS OF BY-CATCH ON ODONTOCETES

Longline gear poses a significant entanglement and drowning risk to depredating odontocetes (Ashford et al., 1996; Northridge and Hofman, 1999; Visser, 2000; SPREP, 2002; Secchi et al., 2005; Gilman et al., 2006; Forney and Kobayashi, 2007; Hamer 2009; Lauriano et al., 2009; Reeves et al., 2009). Some individuals may accidentally ingest a hook when they depredate catch from longline hooks, which may become lodged in their mouth, throat or stomach (Secchi et al., 2005; Figure 7). These events may lead to internal injuries, infections and starvation, which may result in delayed death (Hamer, 2009; ref.). Hooked animals may be unable to reach the surface to breathe, which results in a more immediate death by drowning (Hamer, 2009; ref.).

Many of the 72 odontocete species overlap geographically with longline fishing activities (Northridge, 1984; Bjordal and Lokkeborg, 1996; Culik, 2004; Carwardine, 2006). This review has revealed that at least 13 of those species have operational interactions with longline fisheries (11 quantified and 2 surmised) and that at least nine of them experience some degree of loss as by-catch mortality. Given that reports predominantly involve killer whales and false killer, those two species may suffer the greatest losses. Two baleen whale (Mysticete) species were recorded as by-catch (i.e. the Bryde's whale *Balaenoptera edeni* and the humpback whale *Megaptera novaengliae*), although it is unlikely they were depredating catch from longlines, because they tend to lunge feed on aggregations of small fish, krill and plankton (Murase et al., 2007; ref.). Instead, they may have become incidentally entangled in the gear during their natural foraging activities after failing to detect the longline fishing gear (Northridge and Hofman, 1999; Gilman et al., 2006).

Some of these odontocete species are known to be geographically widespread and are comprised of more than one genetically distinct sub-population (e.g. killer whale: Pilot et al., 2010; false killer whale: Chivers et al., 2007; common dolphin: Bilgmann et al., 2008; bottlenose dolphin: Krutzen et al, 2004). However, contemporary population estimates for many of them are either absent from the literature, or are only available for one or two sub-populations. Recent findings suggest a trend of population decline in some species in areas where longlining effort is high, with by-catch mortality on longlines being flagged as a possible cause (e.g pilot whale *Globicephala* spp.: Waring et al., 2006, Garrison, 2007; false killer whale: Forney and Kobayashi, 2007; Reeves et al., 2008). Even small losses may have been sufficient to cause these declines, given that cetaceans are slow to reach sexually maturity and have low fecundity (Reeves and Leatherwood, 1983; Miller, 2007). Under natural circumstances, pristine populations are in equilibrium with their environment, with births and deaths being equal (Krebs, 1985). However, anthropogenic sources of loss (i.e. by-catch mortality) are in addition to natural deaths, which may result in the overall death rate exceeding the overall birth rate. This situation is unsustainable in the long term. Nonetheless, it is not possible to determine how sensitive each of these species is to such losses without a more comprehensive understanding of the carrying capacity and life history of the species involved, thus highlighting the need to exercise caution until sustainable levels of loss can be determined with some degree of confidence.

Depredating odontocetes may also become habituated to feeding on fish hooked on longlines, especially if the presence of vessels in an area is predictable (i.e. there are a sufficiently large number of vessels that conduct a sufficiently high level of fishing effort within an area). This situation may provide depredating odontocetes with easy access to fish species that would otherwise be difficult or impossible to obtain, because the fish are too large or too fast, or because they occur in waters that are beyond the dive limit of the depredating odontocete (Gilman et al., 2006; Tixier et al., 2009). odontocetes depredate catch from fishing gear because it offers a net energetic gain compared with foraging naturally, which often involves pursuits that can be energetically expensive (Guinet et al., 2007). Although it is unlikely that entire odontocete populations become dependent on fish caught by fishing gear, some individuals may become specialists at doing so. While any individual that depredates from longlines is at risk of becoming caught, it is possible that young and naïve animals may be particularly at risk.

6. IMPACTS OF DEPREDATION ON LONGLINE FISHEIRES

Despite the relatively recent concerns surrounding the conservation impacts of longline fishery induced by-catch on cetacean populations, interest in the economic impact of catch depredation on longline enterprises has persisted for much longer (Dahlheim, 1988; Yano and Dahlheim, 1995; SPREP, 2002; AFMA, 2005; IOTC, 2007). Depredation by odontocetes can impact on and even threaten the economic viability of some longline fisheries, because it results in the loss or damage of hooked fish (Yano and Dahlheim, 1995; Northridge and Hofman, 1999; Gilman et al., 2006; Hamer 2009; Lauriano et al., 2009). There are suggestions that depredating odontocetes may also consume or deter free swimming fish that would otherwise have become caught on longline hooks, although this would be difficult to confirm or quantify.

When depredating odontocetes attack tunas or billfishes caught on pelagic longline hooks, they often remove the entire torso from behind the gill plates, or sometimes leave tooth lacerations on the torso (Figure 7). The nature of the damage to fish caught on demersal longlines appears to be similar (Dahlheim, 1988; Yano and Dahlheim, 1995). Toothed whale teeth are canine-like and tend to rip the flesh of the fish they attack. In contrast, depredating sharks tend to remove clean, bite-shaped portions of flesh from the torso of caught fish with their blade-like teeth, making the damage caused by them distinguishable from damage caused by toothed whales (Figure 8). Making the distinction between shark and odontocete depredation is important; odontocetes are often blamed for any damage that occurs, regardless of its nature, because their presence is easier for fishers to detect (Hamer, 2009).

Depredating odontocetes may also damage hooks or break snoods when they remove fish, or may damage larger portions of the longline gear if they become caught themselves (Northridge and Hofman, 1999; Gilman et al., 2006). They have also been implicated in the removal of bait (Secchi et al., 2005; McPherson et al., 2008). While this may be the case on some occasions (especially where small dolphins are depredating), the nature of the damage to much of the bait (Hamer, 2009) and the occasional observation of small pelagic fish in the vicinity of the longline gear (Figure 9) suggest toothed whales are rarely responsible for this activity.

Depredation by toothed whales comes at a significant cost to the longline industry globally, although estimating the monetary value of the fish that are deterred, damaged or taken is difficult. Two studies conducted in the Bering Sea (northeast Pacific) between 1977 and 1989 estimated the daily monetary loss across the fleet of sablefish, Greenland terbot (halibut *Reinhardtius hippoglossoides*) and arrowtooth flounder (*Atheresthes stomias*) caused by killer whale depredation was US$928–3,374 (Dahlheim, 1988; Yano and Dahlheim, 1995). Two studies conducted around the Crozet and Kerguelen Islands (Southern Ocean) between 2003 and 2008 estimated the daily monetary loss across the fleet of Patagonian toothfish caused by killer whale depredation was US$4,349–5,480 (adjusted from a yearly to a daily estimate and from € to US$) for each day of fishing (Roche et al., 2007; Tixier et al., 2007). However, these are likely to be marked underestimates of the real monetary cost of depredation, because they do not include the cost of the (i) unquantifiable number of fish that are removed completely from hooks, (ii) fish that are deterred from taking a baited hook, (iii) gear that is damaged and (iv) avoidance strategies, such as moving away from problem areas (Yano and Dahlheim, 1995; Hamer, 2009).

Depredation by odontocetes can hamper the effectiveness of fishery management practices aimed at sustaining target fish stocks. Overfishing may occur if the depredated fish are not included when calculating how many have been removed from the system, particularly when the fishery is managed using total allowable commercial catch (TACC) limits based on biomass estimates (Gilman et al., 2006; Hamer, 2009). On the other hand, underfishing may occur if depredation of fish results in a reduction of catch per unit of fishing effort (CPUE) to the vessel or the fishery, because the managers may decide to reduce or cease fishing effort to stem stock depletion caused by the impression that fewer fish exist in the population (Gilman et al., 2006; Roche et al., 2007). Therefore, the problem of catch depredation should be taken into account when determining methods of sustainable management for target species in longline fisheries.

7. BY-CATCH AND DEPREDATION MITIGATION STRATEGIES

Since the mid 1980s, a number of reports concerning the mitigation of catch depredation by and by-catch of odontocetes from longlines have appeared in the literature. Some have merely flagged promising ideas (Northridge and Hofman, 1999; Visser, 2000), while others have attempted to compile more detailed accounts of mitigation measures trialled informally by longline fisheries (Dahlheim, 1988; Secchi et al., 2005), or have conducted experimental trials that have produced quantitative results (Moreno et al., 2008; Mooney et al., 2009). In essence, research on this issue appears to have evolved from acknowledgement, to description and quantification, then to mitigation. While there are now a number of reports available that detail the successful development of cetacean depredation and by-catch mitigation strategies into other fisheries (purse-seine: Gosliner, 1999; Hamer et al., 2008; gill-net: Trippel et al., 1999; Barlow and Cameron, 2003), the development of similar tools for longline fisheries has only gained momentum relatively recently.

A summary of mitigation measures that have been considered or used as tools for solving this issue in longline fisheries has been compiled for this review (Table 2). Approaches that have received the most attention are (i) management controls, (ii) acoustic deterrents and (iii) physical deterrents. Historically, management through input controls such as marine protected areas (PMAs; i.e. when and where fisheries can operate) have been resisted by fishers, because they typically result in reductions in efficiency and opportunity, both of which affect their economic bottom line (Klein et al., 2008). In contrast, the use of acoustic and physical mitigation strategies may be mutually beneficial (i.e. reduce catch depredation by odontocetes and reduce by-catch of depredating toothed whales). This situation means their development and implementation is likely to receive widespread support from among stakeholders. For this reason, the development of acoustic and physical tools for mitigating operational interactions between odontocetes and longline gear will be explored further below.

Acoustic depredation mitigation technologies

Acoustic technology used to mitigate depredation by toothed whales can be placed in four categories: (i) harassment, (ii) deterrence and echolocation disruption (iii) warning that elicit avoidance by cetaceans and (iv) detection that elicits avoidance by fishing operations. Firstly, acoustic harassment devices (AHDs) have received the most attention and they are designed to emit high noise levels that frighten depredating individuals. Their development has been encouraged by fisheries that stand to gain economically if depredating marine mammals are excluded from an area. Typically, the level of noise AHDs transmit is greater than >180dB at 1 m and they are deployed on moveable or transient gear (Nowacek et al., 2007). Secondly, acoustic deterrence devices (ADDs) function by deterring depredating whales under the assumption that lower levels of noise merely annoy individuals and encourage them to leave an area, without long-term adverse effects (Nowacek et al., 2007; Figure 10). They are distinguishable from AHDs in that they typically transmit at noise levels below 180 dB at 1 m and they are typically deployed on permanent structures such as fish pens and dams (Dawson et al., 1998; Nowacek et al., 2007). Echolocation disruption also fits into this category (Mooney et al., 2009), simply because it is as yet not possible to determine the mechanism that causes depredating individuals to move away from a noise source (i.e. if depredating individuals are deterred due to discomfort, or due to an inability to navigate). Thirdly, the comparatively low level noises or signals emitted from 'pingers' are designed to warn cetaceans of the presence of fishing gear, so they can avoid it (Barlow and Cameron, 2003). A number of studies have shown that pingers significantly reduce harbour porpoise by-catch in demersal gill-nets (Lien et al., 1995; Kraus et al., 1997; Trippel et al., 1999; Gearin et al., 2000; Barlow and Cameron, 2003). These results are promising for longliners, whose gear is also set over long distances.

Despite the large degree of attention that AHDs, ADDs and pingers have received, all have had problems in their application. The use of AHDs has largely been abandoned due to growing concerns about the wider adverse effects of high level noise on the exclusion and stranding of cetacean populations (Johnston and Woodley, 1998; Morton and Symonds, 2002). One study suggested that ADDs designed to deter dolphins may have deterred the target fish from becoming caught in a demersal gill-net fishery (Krause et al., 1997). They also cited that the concurrent reduction in dolphin by-catch may have been related to the deterrence of the target fish by the ADD (i.e. dolphins followed the deterred fish away from the gill-net), rather than direct deterrence of the dolphins (Kraus et al., 1997). There is also reasonable evidence to suggest that while ADDs may successfully deter cetaceans in the first instance, they typically lose their effect over time as depredating individuals become habituated to the noise (Jefferson and Curry, 1996). In much the same way, odontocetes may be attracted to fishing gear by pingers, which literally act as a 'dinner bell' (Jefferson and Curry, 1996; Mooney et al., 2009). These problems highlight the fact that very little is known about the mechanisms under which acoustic depredation mitigation tools, harass or deter or warn odontocetes that are close to fishing gear. In addition, measuring their success has generally been hampered by the expense and size of each unit (McPherson et al., 2008; Mooney et al., 2009), lack of replication (Nowacek et al., 2007), differences between the response of cetacean species involved and the specificity of ADD models (Jefferson and Curry, 1996; Kastelein et al., 2006). The predominantly ambiguous outcomes of most of the research conducted to date indicate that future development should involve much a much more stringent experimental approach on a case-by-case basis.

The fourth acoustic depredation mitigation tool is designed to assist fishers in detecting and avoiding depredating odontocetes (i.e. by relocating the fishing operation to another area). This tool has received much less attention, mainly because of logistical problems associated with how listening stations or arrays must be deployed (Nielsen and Mohl, 2006), damage caused by predators such as sharks and whales (Johnson et al., 1982) and sound interference originating from the vessel and the marine environment masking the vocalisations of depredating whales (Thode et al., 2007; McPherson et al., 2008). A recent study in the Coral Sea detailed the practical and logistic aspects of such an approach (McPherson et al., 2008). Although considerable work was committed to improving the functionality of these systems, equipment failure (McPherson et al., 2008) and lack of association between the presence of toothed whales and depredation events (Personal communications: Trent Timmiss, Australian Fisheries Management Authority; Mark Coker, Debrett Seafoods; ref.) continue to hamper their uptake and implementation in longline fisheries.

Physical depredation mitigation technologies

Innovations in physical depredation mitigation device (PDMD) technology have received attention relatively recently. Given that the baited hook must remain unimpeded prior to catching a target fish, solutions may need to include moving parts and trigger systems (Hamer, 2009). This challenging situation was overcome recently in the Chilean Patagonian toothfish demersal longline fishery, where a PDMD known as a 'net sleeve' reduced catch depredation by sperm whales from 5% to 0.36% (i.e. down 82.8%) and was also reputed to be responsible for the subsequent departure of the whales from the fishing grounds (Moreno et al., 2008). The net sleeves were fitted over the branch lines and remained near the mainline end during the deployment and soak phases of the set, then descended under their own weight during the haul to cover the clusters of hooks and caught fish (Figure 11). The success of this method was facilitated by the fact that the fishery operated in waters depths beyond the diving limit of the depredating whales, thus making it necessary only to protect the fish as they were hauled.

Unlike demersal longlines that are able to avoid depredation by odontocetes during the soak due to the depths at which they are set, pelagic longline fisheries are exposed to depredating whales the entire time they are in the water. Solutions for this situation have been more even more difficult to identify than in demersal longline fisheries, because the trigger for the PDMD must be the fish taking the baited hook, rather than gravity during the haul. In the absence of solutions to report in pelagic longline fishery, some clues can be found in recent attempts to mitigate catch depredation by bottlenose dolphins (*Tursiops truncatus*) in the Florida king mackerel (*Scomberomorus cavalla*) troll fishery. Although only a small sample size was obtained, dolphins were deterred every time they approached a king mackerel protected by a 'metal wire' (Zollett and Read, 2006). The metal wire remained clear of the baited hook as it was towed through the water until a fish was caught, whereupon the pressure of the fish fighting against the hook triggered the outrigger clip to release the metal wire. The metal wire then descended toward and over the fish, thus deterring depredating dolphins from approaching (Figure 12). It is not known why the metal wire deterred the depredating dolphins, although it can be surmised that they were either avoiding physical injury or the risk of entanglement.

A recent exploratory trip on a pelagic longliner to the Coral Sea that fishes under management of the Eastern Tuna and Billfish Fishery (ETBF) revealed that depredating pilot whales and false killer whales may be avoiding areas of the gear where tangles have occurred (Hamer, 2009). Gear tangles appear to be caused by caught fish that have fought to get away. Depredating individuals may avoid these tangles to avoid the risk of becoming entangled and drowning. Based on this premise, preliminary development of a ‘streamer pod’ has commenced to deter whales from pelagic longlines (Figure 13). In a similar manner to the metal wire used in the Florida king mackerel fishery, the streamer pod is designed to remain clear of the baited hook until a fish is caught, whereupon the pressure of the fish fighting against the hook triggers the cap to open. This action results in the streamers emerging from the pod and the pod descending toward the hook, so that the streamers can envelope the caught fish and thus deter the depredating whales.

Although the development of PDMDs is still in its infancy, it seems these tools may not be incumbered with the problems experienced in the development of acoustic depredation mitigation tools. Successful acoustic approaches (i.e. AHDs, ADDs, pingers and detection) to the problem of odontocete depredation and by-catch will remain problematic until there is a greater understanding of the response of these animals to noise. In contrast, physical approaches (i.e. PDMDs) have a clear mechanism that can be easily applied; they simply need to obstruct access to caught fish. Future research of PDMDs would benefit from controlled experiments, where normal fishing gear (the control) would be compared with fishing gear fitted with PDMDs (the treatment), by calculating the (i) proportion of fish damaged by depredating whales and (ii) overall target fish catch rate. The main challenge for ensuring development and uptake of PDMDs in longline fisheries will hinge on the ability of researchers, gear technologists and fishers to produce derivatives that are functional, durable, simple, efficient and cheap (Hamer, 2009). All of these criteria will need to be addressed before the longline industry will see the benefits of adopting PDMDs into ‘normal’ fishing practices.

8. SUMMARY AND FUTURE DIRECTIONS

Sufficient quantitative and anecdotal evidence now exists to suggest that some degree of operational interaction occurs between odontocetes and longline fisheries wherever the two overlap. The need to address the issues surrounding catch depredation by odontocetes and surrounding by-catch of depredating odontocetes is becoming an increasingly higher priority as longline fishery profit margines dwindle and as information emerges that the conservation of some odontocete populations may be at risk. Despite this situation, caution should be taken not to overestimate the magnitude of the problem for the longline industry. Some fishers or fisheries may blame depredation by odontocetes for poor catch rates, when in fact the situation may be attributable to poor operational (i.e. where, when and how to fish) or management (i.e. setting TACCs too high) decisions, or to other depredating taxa such as sharks or scavenging fish (Hamer, 2009). In contrast, caution should be taken not to underestimate the magnitude of the problem for the odontocete populations that contain depredating individuals, because the loss of just a few of them may result in population decline, or extinction in the long term (Reeves and Leatherwood, 1983; Miller, 2007). An earlier review of this issue indicated that mitigation should come about through changes in fishing practices, although it lamented that little had been done to determine the efficacy and economic viability of mitigation tools (Gilman et al., 2006). Given the volume of information now available, all stakeholders should prioritise this issue without delay, for the sake of sustaining the fisheries and odontocete populations involved, and should focus on identifying, developing and implementing mitigation strategies.

A recent report suggested that efforts be made to determine why some vessels experience higher rates of depredation than others, stating that differences in design and operation may provide some clues for developing mitigation solutions (Gilman et al., 2006; McPherson et al., 2008). Noise generated by longliners is likely to be the principal attractant for depredating whales (Hamer, 2009), suggesting that comparisons of sound levels and signatures could be a useful approach to answering this question. However, there are conflicting views among fishers about how much can actually be done to minimise noise, with significant practical and economic constraints being cited. Some fishers argue that noise is irrelevant to habituated depredating odontocetes that are already present in the fishing grounds (Personal communications: John Collinson, former longline skipper from southern Australia; Will Mure, Mures Fishing; Mark Coker, Debrett Seafoods; refs.). The overall uncertainty associated with acoustics research aimed at identifying solutions to this issue suggest there may be some benefit in considering alternatives for mitigation.

One such alternative may be PDMDs, which have recently yielded promising results in a demersal longline and a troll fishery (Zollett and Read, 2006; Moreno et al., 2008). The key to their successful application may have been their design simplicity. In both cases, the PDMDs could be made by the fishers themselves, rather than fishers having to depend on the production of complex electronics which can only be produced by external manufacturers. Nonetheless, development and production of PDMDs may be cost prohibitive for pelagic longline fisheries, because they would need to (i) be fitted to each snood, (ii) contain moving parts and a trigger mechanism and (iii) as a result would have considerable set up and maintenance costs. However, externally funded, independent research that applies rigorous trialling may be first be necessary to provide greater certainty in the efficacy of particular designs (i.e. maximising functionality, durability, simplicity, efficiency and value). Only when longline fishers begin to appreciate that PDMDs may result in an improved economic bottom line (i.e. use of PDMDs equals increased returns to and from the boat) will voluntary uptake occur.

Despite the need to focus on the development of PDMDs for mitigating operational interactions between odontocetes and longline fisheries, stakeholders should be encouraged to explore and subsequently adopt a suite of tools to achieve this (Dahlheim, 1988; Gilman et al., 2006; McPherson et al., 2008; Hamer, 2009). How these are utilised will depend on the peculiarities of each fishery, such as the incumbent management strategy, gear configuration, target species, odontocete species and the resources available to address the problem (Gilman et al., 2002; Gilman et al., 2006; Campbell and Cornwall, 2008). Future development and adoption of these mitigation measures should be guided by the experience of fishers, who hold a wealth of information about the nature of the operational interactions, how mitigation measures might be incorporated into their fishing practices, how those measures might affect their fishing operations and how well they might work to mitigate depredation by and by-catch of odontocetes (Gilman et al., 20006; Hamer, 2009). Longline fishers have already demonstrated their willingness to be involved in formal by-catch reduction programs for protected species such as whales (Moreno et al., 2008; McPherson et al., 2008; Hamer, 2009) and seabirds (Robertson et al., 2006; Gilman et al., 2007). All stakeholders should aim to develop these mitigation strategies with a view to providing generic solutions that not only assist in the sustainable development of the fishery, but that assist in the conservation of odontocete populations. Governments, research institutions, fisheries and funding bodies that are associated with this problem are encouraged to participate and invest in international collaborations that are focused on finding globally applicable solutions.

REFERENCES

AFMA (2005). Mammal depredation on demersal longlines: a review prepared by AFMA for the gillnet, hook and trap fishery. Report by Australian Fisheries Management Authority (AFMA). April 2005.

Ashford, J.R., Rubilar, P.S. and Martin, A.R. (1996). Interactions between cetaceans and longline fishery operations around South Georgia. *Marine Mammal Science*, **12**, 452-457.

Baird, R.W., Gorgone, A.M., McSweeney, D.J., Webster, D.L., Salden, D.R., Deakos, M.H., Ligon, A.D., Schorr, G.S., Barlow, J. and Mahaffy, S.D. (2008). False killer whales (*Pseudorca crassidens*) around the main Hawaiian Islands: long-term site fidelity, inter-island movements, and association patterns. *Marine Mammal Science*, **24**, 591-612.

Barlow, J. and Cameron, G.A. (2003). Field experiments show that acoustic pingers reduce marine mammal bycatch in the California Drift Gill net fishery. *Marine Mammal Science*, **9**, 265-283.

Barlow, J. and Rankin, S. (2007). False killer whale abundance and density: preliminary estimates for the PICEAS study area south of Hawaii and new estimates for the US EEZ around Hawaii. Southwest Fisheries Science Center Administrative Report, LJ-07-02.

Bakun, A., Babcock, E.A. and Santora, C. (2009). Regulating a complex adaptive system via its wasp-waist: grappling with ecosystem-based management of the New England herring fishery. *Journal of Marine Science*, **66**, 1768-1775.

Bell, C., Shaughnessy, P.D., Morrice, M. and Stanley, B. (2006). Marine mammals and Japanese longlining fishing vessels in Australian waters: operational interactions and sightings. *Pacific Conservation Biology*, **12**, 31-39.

Bilgmann, K., Moller, L.M., Harcourt, R.G., Gales, R. and Beheregary, L.B. (2008). Common dolphins subject to fisheries impacts in southern Australian are genetically differentiated: implications for conservation. *Animal Conservation*, **11**, 518-528.

Campbell, L.M. and Cornwell, M.L. (2008). Human dimensions of bycatch reduction technology: current assumptions and directions for future research. *Endangered Species Research*, **5**, 325-234.

Carwardine, M. (2006). *Whales, dolphins and porpoises (2nd ed.)*. Dorling Kindersley, London, UK.

Chivers, S. J., Baird, R.W., McSweeney, D.J., Webster, D. L., Hedrick, N. M. and Salinas, J. C. (2007). Genetic variation and evidence for population structure in eastern North Pacific false killer whales (*Pseudorca crassidens*). *Canadian Journal of Zoology*, **85**, 783-794.

Dahlheim, M.E. (1988). Killer whale (*Orcinus orca*) depredation on longline catches of sablefish (*Anoplopoma fimbris*) in Alaskan waters. Northwest and Alaska Fisheries Center (NWAFC) Processed Report 88-14. July 1988.

Dalla Rosa, L and Secchi, E.R. (2007). Killer whale (*Orcinus orcu*) interactions with the tuna longline fishery off southern and south-eastern Brazil: a comparison with shark interactions. *Journal of the Marine Biological Association of the UK*, **87**, 135-140.

Dawson, S. M., Read, A. and Slooten, E. (1998). Pingers, porpoises and power: uncertainties with using pingers to reduce bycatch of small cetaceans. *Biological Conservation*, **84**, 141-146.

Di Natale, A. and A. Mangano, A. (1983). Biological and distribution new data on the sperm whale, *Physeter macrocephalus* L., in the central Mediterranean Sea**.** *Rapports et Proces-Verbaux des Reunions, Conseil International pour L'Exploration scientifique de la Mer Medeterranee (CIESM)*, 2**8**(5), 183-184.

Duarte, C.M., Holmer, M., Olsen, Y., Soto, D., Marba, N., Guiu, J., Black, K. and Karakassis, I. (2009). Will the oceans help feed humanity? *Bioscience*, **59**, 968-976.

Duguy R. and Hussenot, E. (1982). Occasional captures of delphinids in the Northeast Atlantic. *Reports of the International Whaling Commission*, **32**, 461-462.

Donoghue, M; Reeves, Randall R; Stone, Gregory S (eds.) (2003). *Report of the Workshop on Interactions between Cetaceans and Longline Fisheries*. New England Aquarium Press, Boston, USA.

Earle, M. (1996). Ecological interactions between cetaceans and fisheries. In: Simmonds, M.P. and Hutchison, J.D. (eds.). *The conservation of whales and dolphins: science and practice*. John Wiley and Sons, Chichester, UK.

Ebert, S., Metschies, G.P., Schmid, D. and Wagner, A. (2009). International fuel prices 6th Edition. Report to Federal Ministry for Economic Cooperation and Development, Germany. Transport Policy Advisory Services.

FAO (2009). The state of world fisheries and aquaculture 2008. United Nations (UN) Food and Agriculture Organisation (FAO), Rome, Italy.

Garrison, L. (2007). Interactions between marine mammals and pelagic longline fishing gear in the U.S. Atlantic Ocean between 1992 and 2004. *Fishery Bulletin*, **105**, 408-417.

Gearin, P.J., Gosho, M.E., Laake, J.L., Cooke, L., Delong, R.L. and Hughes, K.M. (2000). Experimental testing of acoustic alarms (pingers) to reduce bycatch of harbour porpoise, *Phocoena phocoena*, in the state of Washington. *Journal of Cetacean Research and Management*, **2**, 1-10.

Gerber, L.R., Keller, A.C. and DeMaster, D.P. (2007). Ten thousand and increasing: is the western Arctic population of bowhead whale endangered? *Biological conservation*, **137**, 577-583.

Gerber, L.R., Morissette, L., Kaschner, K. and Pauly, D. (2009). Should whales be culled to increase fishery yield? *Ecology*, **323**, 880-881.

Gilman, E., Gandini, P., Carboneras, C., Balogh, G., Leadbitter, D. and Neves, T. (2002). Invcentive instruments for sustainable bycatch of sensitive species in longline fisheries. *Proceedings of the Incentives Session, Second International Foshers' Forum*, *19-22 November 2002.* United States Western Pacific Regional Fishery Management Council, Honolulu, Hawaii, USA.

Gilman, E., Brothers, N., McPherson, G. and Dalzell, P. (2006). A review of cetacean interactions with longline gear. *Journal of Cetacean Research and Management*, **8**, 215-223.

Gilman, E., Brothers, N. and Kobayashi, D.R. (2007). Comparison of three seabird bycatch avoidance methods in Hawaii-based pelagic longline fisheries. *Fisheries Science*, **73**, 208-210.

Guinet, C., Domenici, P., de Stephanis, R., Barrett-Lennard, L., Ford, J.K.B. and Verborgh, P. (2007). Killer whale predation on bluefin tuna: exploring the hypothesis of the endurance-exhaustion technique. *Marine Ecology Progress Series*, **347**, 111-119.

Hamer, D.J., Ward, T.M., McGarvey, R. (2008). Measurement, management and mitigation of operational interactions between the South Australian Sardine Fishery and short-beaked common dolphins (*Delphinus delphis*). *Biological Conservation*, **141**, 2865-2878.

Hamer, D.J. (2009). Update #2 – November 2009: First steps toward mitigating catch depredation by whales. Non-lethal options for mitigating catch depredation by toothed whales from pelagic longlines. Australian Marine Mammal Centre, Australian Antarctic Division. http://www.marinemammals.gov.au/regional-initiatives/depredation-project

Hernandez-Milian, G.,

Hucke-Gaete, R., Moreno, C.A and Arata, C.J. (2004). Operational interactions of sperm whales and killer whales with the Patagonian toothfish industrial fishery off southern Chile. *CCAMLR Science*, **11**, 127-140.

Holt, S.J. (2007). Whaling: will the phoenix rise again? *Marine Pollution Bulletin*, **54**, 1081-1086.

ICRW (1946). *International Convention for the Regulation of Whaling*. Washington, 2 December 1946.

IOTC (2007). Report of the workshop on the depredation in the tuna longline fisheries in the Indian Ocean. Indian Ocean Tuna Commission (IOTC), Victoria, Seychelles.

Iwashita, M., Iuone, M. and Iwasaki, Y. (1963). On the distribution of *Orchinus* in the Northern and Southern Pacific equatorial waters as observed from reports on *Orchinus* predation. *Bulletin of the Fisheries Research Laboratory, Tokai University*, **1**, 24-30.

Jefferson, T. A. and Curry, B. E. (1996). Acoustic methods of reducing or eliminating marine mammal-fishery interactions: do they work? *Ocean and Coastal Management*, **31**, 41-70.

Johnson, C.S., McManus, M.W. and Scronce, B.L. (1982). Study of fish bite on AN/BQR -15 towed array. Technical Report, US Naval Ocean Systems Center NOSC-TR-867.

Johnston, D.W. and Woodley, T.H. (1998). A survey of acoustic harassment device (AHD) use in the Bay of Fundy, NB, Canada. *Aquatic Mammals*, **24**, 51-61.

Kailola, P., Williams, M., Stewart, P., Reichelt, R., McNee, A. and Grieve, C. (1993). *Australian fisheries resources.* Bureau or Resource Sciences and Fisheries Research and Development Corporation, Canberra, Australia.

Kaschner, K. (2004). Modelling and mapping resource overlap between marine mammals and fisheries on a global level. PhD thesis, University of British Columbia.

Kastelein, R.A., Jennings, N., Verboom, W.C., De Haan, D. and Schooneman, N.M. (2006). Differences in the response of a striped dolphin (*Stenella coeruleoalba*) and a harbour porpoise (*Phocoena phocoena*) to an acoustic alarm. *Marine Environmental Research*, **61**, 363-378.

Klein, C.J., Chan, A., Kircher, L., Cundiff, A.J., Gardner, N., Hrovat, Y., Scholz, A., Kendall, B.E. and Airame, S. (2008). Striking a balance between biodiversity and socioeconomic viability in the design of marine protected areas. *Conservation Biology*, **22**, 691-700.

Kraus, S.D., Read, A.J., Solow, A., Baldwin, K., Spradlin, T., Anderson, E. and Williamson, J. (1997). Acoustic alarms reduce porpoise morality. *Nature*, **388**, 525.

Krebs, J.R., 1985. *Ecology: the experimental analysis of distribution and abundance. 3rd Edition.* Harper and Row, New York, USA.

Krutzen, M., Sherwin, W.B., Berggren, P. and Gales, N. (2004). Population structure in an inshore cetacean revealed by microsatellite and mtDNA analysis: Bottlenose dolphins (Tursiops sp.) in Shark Bay, Western Australia. *Marine Mammal Science*, **20**, 28-47.

Lauriano, G., Caramanna, L., Scarno, M. and Andaloro, F. (2009). An overview of dolphin depredation in Italian artisanal fisheries. *Journal of the Marine Biological Association of the United Kingdom*, **89**, 921-929.

Lien, J., Hood, C., Pittman, D., Ruel, P., Borggaard, D., Chisholm, C., Weisner, L., Mahon, T. and Mitchell, D. (1995). Field tests of acoustic devices on groundfish gillnets: assessment of effectiveness in reducing harbour porpoise by-catch. In: Kastelein, R.A., Thomas, J.A. and Nachtigall P.E. (eds.). *Sensory Systems of Aquatic Mammals*. De Spil, Woerden, Netherlands. 349-364.

Martinez, M.L., Intralawan, A., Vazquez, G., Perez-Maqueo, O., Sutton, P. and Landgrave, R. (2007). The coasts of our world: ecological, economic and social importance. *Ecological Economics*, **63**, 254-272.

Matkin, C.O. (1986). Killer whale interactions with the sablefish longline fishery in Prince William Sound, Alaska, 1985, with comments on the Bering Sea. Report to the National Marine Mammal Laboratory, National Marine Fishery Service, NOAA, 7600 Sand Point Way, N.E. Seattle. WA98115-0700. Contract 40-HANF-6-0068.

McGranahan, G., Balk, D. and Anderson, B. (2007). The rising tide: assessing the risks of climate change and human settlements in low elevation coastal zones. *Environment and Urbanization*, **19**, 17-37.

McPherson, G.R., Clague, C.I., McPherson, C.R., Madry, A., Bedwell, I., Turner, P., Cato, D.H. and Kreutz, D. (2008). Reduction of interactions by toothed whales with fishing gear. Phase 1. Development and assessment of depredation mitigation devices around longlines. Final report to Fisheries Research and Development Corporation (FRDC) for project # 2003/016. Department of Primary Industries and Fisheries, Queensland, Australia.

Miller, D.L. (2007). *Reproductive biology and phylogeny of cetacea: whales, porpoises and dolphins*. Science Publishers, Enfield, UK.

Mitchell, E.D. (1975). Porpoise, dolphin and small whale fisheries of the world. Status and problems. International Union for the Conservation of Nature (IUCN) Monographs #3. 129p

Mooney, T.A., Pacini, A.F and Nachtigall, P.E. (2010). False killer whale (*Pseudorca crassidens*) echolocation and acoustic disruption: implications for longline bycatch and depredation. *Canadian Journal of Zoology*, **87**, 726-733.

Moreno, C.A., Castro, R., Mujica, L.J. and Reyes, P. (2008). Significant conservation benefits obtained from the use of a new fishing gear in the Chilean Patagonian toothfish fishery. *CCAMLR Science*, **15**, 79-91.

Morete, M.E., Bisi, T.L., Pace, R.M. and Rosso, S. (2008). Fluctuating abundance of humpback whales (*Megaptera novaeangliae*) in a calving ground off coastal Brazil. *Journal of the Marine Biological Association of the United Kingdom*, **88**, 1229-1235.

Morton, A.B. and Symonds, H.K. (2002). Displacement of *Orcinus orca* (L.) by high amplitude sound in British Columbia, Canada. *Journal of Marine Science*, **59** (1), 71-80.

Murase, H, Tamura, T., Kiwada, H., Fujise, Y., Watanabe, H., Ohizumi, H, Yonezaki, S., Okamura, H. and Kawahara, S. (2007). Prey selection of common minke (Balaenoptera acutorostrata) and Bryde's (Balaenoptera edeni) whales in the western North Pacific in 2000 and 2001. *Fisheries Oceanography*, **16**, 186-201.

Nielsen, B.K. and Mohl, B. (2006). Hull-mounted hydrophones for passive acoustic detection and tracking of sperm whales (*Physeter macrocephalus*). *Applied Acoustics*, **67**, 1175-1186.

Northridge, S. P. (1984). World review of interactions between marine mammals and fisheries. Food and Agriculture Organisation (FAO) Fisheries Technical Paper 251.

Northridge, S. P. (1991). An updated world review of interactions between marine mammals and fisheries. Food and Agriculture Organisation (FAO) Fisheries Technical Paper 251, supplement 1.

Nowacek, D.P., Thorne, L.H., Johnston, D.W. and Tyack, P.L. (2007). Response of cetaceans to anthropogenic noise. *Mammal Review*, **37**, 81-115.

Paterson, R., Paterson, P. and Cato, D.H. (1994). The recovery of humpback whales *Megaptera novaeangliae* in east Australia 30 years after whaling. *Biological Conservation*, **70**, 135-142.

Perves, M.G., Agnew, D.J., Baluerias, E. and Moreno, C.J. (2004). Killer whale (*Orcinus orca*) and sperm whale (*Physeter macrocephalus*) interactions with longline vessels in the Patagonian toothfish fishery at South Georgia, South Atlantic. *CCAMLR Science*, **11**, 111-126.

Pilot, M., Dalheim, M.E. and Heolzel, A.R. (2010). Social cohesion among kin, gene flow without dispersal and the evolution of population genetic structure in the killer whale (*Orcinus orca*). *Journal of Evolutionary Biology*, **23**, 20-31.

Ramos-Cartelle, A. and Mejuto, J. (2008). Interaction of the false killer whale (*Pseudorca crassidens*) and the depredation on the swordfish catches of the Spanish surface longline fleet in the Atlantic, Indian and Pacific Oceans. International Commission for the Conservation of Atlantic Tunas (ICCAT), Collective Volume of Scientific Paper (SCRS/2007/025), **62(6)**, 1721-1783.

Read, A.J. (2005). Bycatch and depredation. In: Reynolds, J.E., Perrin, W.F., Reeves, R.R., Montgomery, S., and Ragen, T.J. (eds.). *Marine mammal research: conservation beyond crisis.* Johns Hopkins University Press, Baltimore, Maryland, US. pp 5-17.

Read, A.J. (2008). The looming crisis: interactions between marine mammals and fisheries. *Journal of Mammalogy*, **89**, 541-548.

Reeves, R.R. and Leatherwood, S. (1983). *The Sierra Club handbook of dolphins and whales*. Sierra Club Books, San Francisco, USA.

Reeves, R.R. and Leatherwood, S. (1994). Dolphins, porpoises and whales. 1994-1998 Action Plan for the Conservation of Cetaceans. IUCN/SSC Cetacean Specialise Group. IUCN, Gland, Switzerland.

Reeves, R.R., Leatherwood, S. and Baird, R.W. (2009). Evidence of possible decline since 1989 in false killer whales (*Pseudorca crassidens*) around the main Hawaiian Islands. *Pacific Science*, **63**, 253-261.

Richards, A.H. (1994). Problems of drift-net fisheries in the South Pacific. *Marine Pollution Bulletin*, **29**, 106-111.

Ridgway, S.H. and Harrison, F.R.S. (1989). *Handbook of marine mammals. Volume 4: River dolphins and larger toothed whales*. Academic Press, London, UK.

Ridgway, S.H. and Harrison, F.R.S. (1999). *Handbook of marine mammals. Volume 6: The second book of dolphins and the porpoises*. Academic Press, London, UK.

Robertson, G., McNeil, M., Smith, N., Wieneke, B., Candy, S. and Oliver, F. (2006). Fast sinking (integrated weight) longlines reduce mortality of white-chined petrels (*Procellaria aequinoctialis*) and sooty shearwaters (*Puffinus greiseus*) in demersal longline fisheries. *Biological Conservation*, **132**, 458-471.

Roche, C., Guinet, C., Gasco, N. and Duhamel, G. (2007). Marine mammals and demersal longline fishery interactions in the Crozet and Kerguelen exclusive economic zones: an assessment of depredation levels. *CCAMLR Science*, **14**, 67-82.

Rothwell, D.R. (1996). The legal framework for ocean and coastal management in Australia. *Ocean and Costal Management*, **33**, 41-61.

Sands, A., Summerson, R., Vieira, S and Wilson, D. (2009). Eastern Tuna and Billfish Fishery. In: Wilson, D., Curtotti, R., Begg, G and Phillips, K. (eds.). Fishery status reports 2008: status of fish stocks and fisheries managed by the Australian Government. Bureau of Rural Sciences (BRS) and Australian Bureau of Agricultural and Resource Economics (ABARE), Canberra. Pp 283-305.

Schick, S.S., Halpin, P.N., Read, A.J., Slay,C.K., Kraus,S.D., Mate, B.R., Baumgartner,M.F., Roberts, J.J., Best, B.D., Good, C.P., Loarie, S.R. and Clark, J.S. (2009). Striking the right balance in right whale conservation. *Canadian Journal of Fisheries and Aquatic Sciences*, **66**, 1399-1403.

Secchi, E.R. and Vaske, T.J. (1998). Killer whale (*Orcinus orca*) sightings and depredation on tuna and swordfish longline catches in Southern Brazil. *Aquatic Mammals*, **24**, 117-122.

Secchi, E.R., Wang, J.Y., Dalla Rosa, L., Yang, S-C and Reeves, R.R. (2005). Global review of interactions between cetaceans and longline fisheries: preliminary data. Draft report (SC/57/SC3) derived from the workshop *Cetacean Interactions with Commercial Longline Fisheries in the South Pacific Region: Approaches to Mitigation*, Apia, Samoa, 11-15 Nov. 2002.

Shaughnessy, P.D., Kirkwood, R., Cawthorn, M., Kemper, C. & Pemberton, D. (2003). Pinnipeds, cetaceans and fisheries in Australia: a review of operational interactions. In: *Marine mammals: fisheries, tourism and management issues* (eds Gales, N., Hindell, M. & Kirkwood, R.). pp. 136-152. CSIRO Publishing, Melbourne, Australia.

Sivasubramaniam, K. (1964). Predation of tuna longline catches in the Indian Ocean, by killer whales and sharks. *Bulletin of the Fisheries Research Station*, **17**, 221-236.

SPREP (2002). Plan of action and priorities for research to reduce depredation on longlines by cetaceans. Report of the South Pacific Regional Environment Program (SPREP) Technical Workshop on Cetacean Interactions with Commercial Longline Fisheries in the South Pacific Region: Approaches to Mitigation, Apia, Samoa, 11-15 November 2002.

Stacey, P.J and Baird, R.W. (1991). Status of the false killer whale, *Pseudorca crassidens*, in Canada. *Canadian Field Naturalist*, **105**, 189-197.

Stobutski, I., Wilson, D., Begg, G., Morison, A., Bensley, N and Phillips, K. (2009). International fishery management arrangements. In: Wilson, D., Curtotti, R., Begg, G and Phillips, K. (eds.). Fishery status reports 2008: status of fish stocks and fisheries managed by the Australian Government. Bureau of Rural Sciences (BRS) and Australian Bureau of Agricultural and Resource Economics (ABARE), Canberra. Pp 269-282.

Thode, A., Straley, J., Tiemann, C.O., Folkert, K. and O'Connell, V. (2007). Observations of potential acoustic cues that attract sperm whales to longline fishing in the Gulf of Alaska. *Journal of the Acoustical Society of America*, **122**, 1265-1277.

Tixier, P., Gasco, N., Duhamel, G. and Guinet, C. (2009). Interactions of Patagonian toothfish fisheries with killer whales and sperm whales in Crozet Exclusive Economic Zone: and assessment of depredation levels and insights on possible mitigation solutions. Unpublished paper presented to the Secretariat of the Convention for the Conservation of Antarctic Marine Living Resources (CCAMLR), Document No. WG-IMAF-09/12, 26 September 2009.

Trippel, E.A., Strong, M.B., Terhune, J.M. and Conway, J.D. (1999). Mitigation of harbour porpoise (*Phocoena phocoena*) by-catch in the gillnet fishery in the lower Bay of Fundy. *Canadian Journal of Fisheries and Aquatic Sciences*, **56**, 113-123.

Tuck, G.N., Polacheck, T. and Bulman, C.M. (2003). Spatio-temporal trends of longline fishing in the Southern Ocean and implications for seabird bycatch. *Biological Conservation*, **114**, 1-27.

Twiss, J.R., Reeves, R.R. (1999). *Conservation and Management of Marine Mammals*. Melbourne University Press, Melbourne, Australia.

United Nations (2009). World Population Prospects: the 2008 revision. Population Newsletter No. 87. Department of Economic and Social Affairs, Population Division, United Nations (UN). June 2009.

Ward, P. and Hindmarsh, S. (2007). An overview of historical changes in the fishing gear and practices of pelagic longliners, with Particular reference to Japan's Pacific fleet. *Reviews in Fish Biology and Fisheries*, **17**, 501-516.

Waring, G. T., Josephson, E., Fairfield, C.P. and Foley, K.M. (2006). U.S. Atlantic and Gulf of Mexico marine mammal stock assessments – 2005. NOAA Technical Memo. NMFSNE-194.

Watson J.W. and Kerstetter D.W. (2006). Pelagic longline fishing gear: a brief history and review of research efforts to improve selectivity. *Marine Technology Society Journal*, **40**, 6-11.

Watson, L. (1981). *Sea guide to the whales of the world*. Dutton Press, London, UK.

Williams, A.J., Petersen, S.L., Goren, M. and Watkins, B.P. (2009). Sightings of killer whales *Orcinus orca* from longline vessels in South African waters, and consideration of the regional conservation status. *African Journal of Marine Science*, **31**, 81-86

Yamaguchi, Y. (1989). Tuna long-line fishing I: historical aspects. *Marine and Freshwater Behaviour and Physiology*, **15**, 1-11.

Yano, K. and Dahlheim, M.E. (1995). Killer whale, *Orcinus orca*, depredation of longline catches of bottom fish in the southeastern Bering Sea and adjacent waters. *Fishery Bulletin*, **93**, 355-372.

Zollett, E.A. and Read, A.J. (2006). Depredation of catch by bottlenose dolphins (*Tursiops truncatus*) in the Florida king mackerel (*Scomberomorus cavalla*) troll fishery. *Fishery Bulletin*, **104**, 343-349.

Table 1 Summary of catch depredation and/or by-catch of odontocetes in pelagic and demersal longline fisheries that has been inferred or quantified in peer reviewed literature.

Whale	**Fishery details**			**Catch depredation details**		**Whale by-catch details**			
species involved	**species targeted**	**region of interaction**	**gear configuration**	**% of sets affected[3]**	**% of catch damaged[3]**	**# of whales hooked**	**rate (whales/set)**	**Source author(s)**	**year**
?	?	IO	?		<55			Sivasubramaniam	1964
KW, FKW	T	IO	P					Mitchell	1975
GTB	?	Tc	?			2[8]		Watson	1981
CD	S	FAc	P			2[8]		Duguy & Hussenot	1982
SW		cMed	P				1	Di Natale & Mangano	1983
KW	SF	PWS	D		25			Matkin	1986
KW	SF	BS, PWS	D	(15-25)				Dahlheim	1988
KW	SF, GT, AF	BS, GA	D		(13-45)			Yano and Dahlheim	1995
SW, KW	PT	SG	D	93	>90	2[8]	0.07	Ashford et al.	1996
KW	T, SF	sB	P		(50-100)			Secchi & Vaske	1998
KW	SS, BET	NZ	D		5-10			Visser	2000
SW	SF	GA	D		23[5]			Straley et al.	2002
KW, B	T, SF	eA	P			2[8]		Shaughnessy et al.	2003
SW, KW	PT	sC	D	16	3 (0-100)			Hucke-Gaete et al.	2004
SW, KW	PT	SG	D	13				Perves et al.	2004
KW, PW	BET, L	sA	D	6-80[4]				AFMA	2005
KW, FKW, B, D	T, SF	eA	P			5[9]		Bell et al.	2006
SW, KW	PT	SG, PEI	D		>50			Kock et al.	2006
BD	KM	Fl	P		6-20			Zollett and Read[13]	2006
KW	T, SF	sB	P		12 (1-47)			Dalla Rosa & Secchi	2007
KW	T, SF, S	SA			<1[6]			Williams et al.	2007
KW	PT	CA	D		42			Roche et al.	2007
Various[1]						67[10]	0.003[12]	Forney and Kobayashi	2007
FKW	T, SF, S	B, AA	P	(1-9)	<9	2[8]		Hernandez-Milian et al.	2008
FKW	SF	A, IO, P		2	4-16	18[11]	0.002[12]	Ramos-Cartelle & Mujeto	2008
SW	SF	BS, GA, AI	D		<1			Sigler et al.	2008
SW, KW	PT	sC	D		<1[7]			Moreno et al.	2008
SW, KW	PT	CA			41			Tixier et al.	2009
CD, BD, SD	Various[2]	Ic	D, P		40			Lauriano et al.	2009
FKW, PW	T, BF	CS	P	<16	<10	3[8]	0.231	Hamer	2009

Whale species abbreviations

KW	Killer whale (*Orcinus orca*)
FKW	False killer whale (*Pseudorca crassidens*)
PW	Pilot whale (*Globicephala* spp.)
CD	Common dolphin (*Delphinus delphis*)
BD	Bottlenose dolphin (*Tursiops truncatus*)
SD	Striped dolphin (*Stenella coeruleoalba*)
SpD	Pantropical spotted dolphin (*Stenella attenuata*)
RD	Risso's dolphin (*Grampus griseus*)
GTB	Ginko-toothed beaked whale (*Mesoplodon ginkgodens*)
BBW	Blainsville's beaked whale (*Mesoplodon densirostris*)
SW	Sperm whale (*Physeter macrocephalus*)
BW	Bryde's whale (*Balaenoptera edeni*)
HW	Humpback whale (*Megaptera novaengliae*)
D	Unidentified dolphin species (Odontoceti)
B	Unidentified baleen whale species (Mysticeti)

Fish species abbreviations

T	Tuna (*Thunnus* spp.)
SF	Sablefish (*Anoplopoma fimbria*)
PT	Patagonian toothfish (*Dissostichus eleginoides*)
GT	Greenland terbot/halibut (*Reinhardtius hippoglossoides*)
AF	Arrowtooth flounder (*Atheresthes stomias*)
SS	School shark (*Galeorhinus galeus*)
BET	Blue-eye trevalla/bluenose (*Hyperoglyphe antarctica*)
KM	King mackerel (*Scomberomorus cavalla*)
SF	Swordfish (*Xiphias gladius*)
BF	Billfish (Istiophoridae & Xiphiidae)
L	Unspecified ling species (*Genypterus* spp.)
S	Unspecified shark species (Selachimorpha)

Region abbreviations

IO	Indian Ocean
Tc	Taiwanese coast
FAc	French Atlantic coast
cMed	central Mediterranean
PWS	Prince William Sound
BS	Bering Sea
GA	Gulf of Alaska
SG	South Georgia
sB	southern Brazil
NZ	New Zealand
eA	eastern Australia
sC	southern Chile
sA	southern Australia
PEI	Prince Edward Islands
Fl	Florida
SA	South Africa
CA	Crozet Archipelago
B	Brazil
AA	Azores Archipelago
A	Atlantic
P	Pacific
AI	Aleutian Islands
Ic	Italian coast
CS	Coral Sea

Further explanation

1 PW, FKW, SpD, BD, BBW, RD, SW, BD, CD and HW.

2 Unspecified fish species.

3 Values are averages or estimates; values in parentheses are ranges.

4 6% of sets affected, calculated from industry data; 80% of sets affected, derived from anecdotal information from fishers.

5 Inferred from a reduction in the catch rate of the targeted fish.

6 Exact figure: 0.50%.

7 Exact figure: 0.36%.

8 Dead animals recorded.

9 5 animals hooked; 2 dead (1 KW and 1 Bal) and 9 released alive.

10 67 hooked; 7 dead (2 PW, 2 FKW, 1 SpD, 1 BD and BBW) and 60 released alive.

11 18 animals hooked; proportion dead and released alive not specified.

12 Derived retrospectively from figures presented in the results of the study.

13 Study of a troll fishery – included here due to the relevance of the depredation mitigation strategy to longline fishing.

Table 2 Summary of methods previously considered or trialled by fishers and researchers to mitigated catch depredation by whales from longlines.

Method		**Result**	**Problems**	
category and type	**description**	**success/failure**	**realised or perceived**	**Source**
Physical				
Net sleeve	Branch line mounted. Prevents access. Passively drops over hooks and caught fish during hauling.	Success [+]	• Intelligent animals have learned to damage tail of fish • Refinements needed – longer sleeve	1
Metal wire	Line mounted. Flaps about to deter cetacean. Descends troll line when fish is caught.	Success [* +]	• Dependent on whales being deterred by the presence of streamers.	2
Streamers/tangles	Snood mounted. Flaps about to deter cetacean. Descends snood when fish caught.	Pending outcome [+]	• Dependent on whales being deterred by the presence of streamers. • Requires complex device, so may have maintenance problems.	3,7,8
Chemical				
Lithium chloride / ether	Elicits vomit response. Mounted near hook. Activated when fish caught.	Not trialled	• Unknown health issues for depredating whales and humans. • Potential ethical issues.	3,4,8
Stress / decay marker	Elicits escape/exit response. Mounted near hook. Activated when fish caught.	Not trialled	• May dissipate too quickly, or have adverse effects over wide area.	4,8
Electrical				
Stinger	Snood mounted. Deployed when fish caught and activated when cetacean approaches.	Pending outcome [+]	• Potential ethical issues for cetaceans and safety issues for crew. • May be difficult to maintain.	3,4
Visual				
Bubble screen	Interferes with visual sense.	Not trialled	• Logistically difficult to achieve over wide area.	
Acoustic				
Detection	Use of listening devices to pick up echolocation signals from cetaceans in the area.	Limited success [+]	• Results are often ambiguous and inconclusive. • Works over an insufficient distance.	4,7
Predator playback	Use of predator noises to elicit escape response such as killer whale calls to deter pilot whales.	Not trialled	• Individuals may become habituated, making them vulnerable. • Works over insufficient distance.	4
Masking / disruption	Producing predominant 'white noise' to mask noises produced by vessel activities.	Initial success	• Trialled on a captive animal only. • Demonstrated learning by individual reduced device performance.	4,6
Harassment	Annoying and potentially damaging sound forces cetaceans to leave the area.	Unsuccessful [+]	• May cause hearing damage and stranding. • May have adverse effects on other animals.	4
Accessory skiffs	Acoustic novelty draws cetaceans away from fishing gear.	Not trialled	• Would only work on demersal longlines where line comes up to boat. • Logistically difficult to achieve for pelagic longlines.	4
Quiet operations	Modify vessels to make less noise.	Initial success	• Individuals may learn to detect signatures in background noise.	3,5,8
Explosives / seal bombs	Loud noise causes flight response.	Unsuccessful	• May cause hearing damage and stranding. • May have adverse effects on other animals.	4
Behavioural				
Operant conditioning	Behavioural modification using signal cues.	Not trialled	• Requires high proportion of animals in the population to learn.	4
Blank sets	Gear set without baits to confuse whales.	Unsuccessful	• Depredating individuals soon learned to search for baited sets.	
Management				
Spatial closures	Away from areas frequented by depredating cetaceans.	Not trialled	• Moves effort to a different location – may cause other problems. • Often puts effort outside prime fishing ground.	7,8
Temporal closures	Away from areas frequented by depredating cetaceans at certain times of the year.	Not trialled	• Moves effort t a different time of year – may cause other problems. • Often puts effort outside prime fishing period.	7,8
Move fishery	Away from traditional fishing grounds to areas not frequented by depredating cetaceans.	Limited success	• Large volume of fuel to move >60 nm. • Often puts vessels outside prime fishing ground.	4,9
Change target species	To a species thought to be unattractive to depredating cetaceans.	Mixed results	• Alternative species often more difficult to catch or less valuable. • Depredating whales learn to take advantage of new food source.	4,8
Change time of fishing	Fish at night instead of during the day.	Unsuccessful	• May only be effective for species that only feed during the day.	4
Change depth of set	Out of depth range of depredating cetaceans.	Limited success	• May also put gear beyond depth of target fish species.	8,9
Change gear type	Use pots to catch the fish instead of longlines.	Limited success	• Possible only in demersal fisheries • Often results in reduced catch.	4,7
Culling	Shooting or harvesting of cetaceans.	Not trialled	• Illegal and unethical.	4

Information source		**Information source (continued)**	
1	Moreno et al., 2008	6	Mooney et al., 2009
2	Zollett and Read, 2006*	7	McPherson et al., 2008
3	Hamer, 2009	8	Gilman et al., 2006
4	Dahlheim, 1988	9	Tixier et al., 2009
5	AFMA, 2005		

Further explanation

* Study of a troll fishery – included here due to the relevance of the depredation mitigation strategy to longline fishing.

\+ Outcome based on experimental trials.

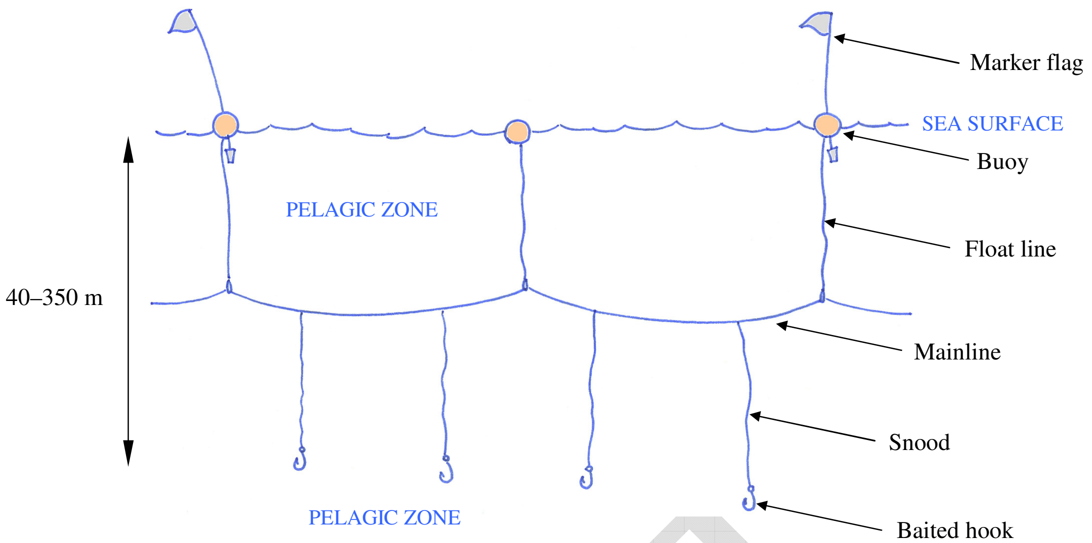

Figure 1 Schematic diagram of part of a typical pelagic longline (not to scale), which is suspended in the water column (well off the benthos) and drifts with local currents.

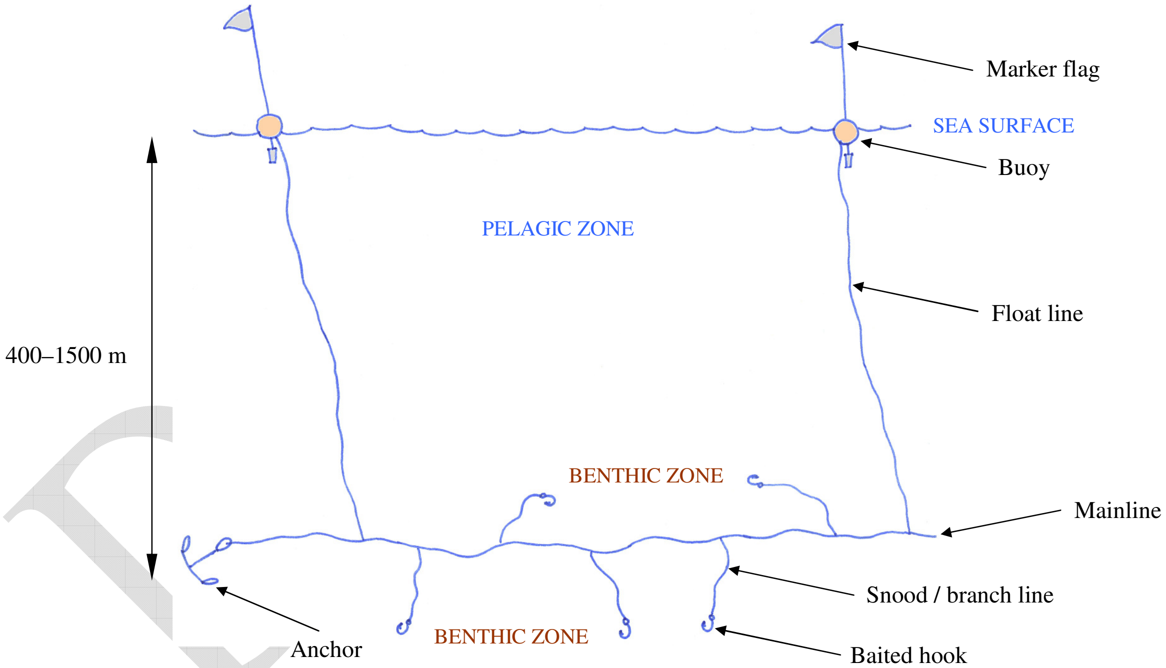

Figure 2 Schematic diagram of part of a typical demersal longline (not to scale), where the hooks are placed on the benthos and the entire set of gear is made fast with weights or anchors.

Figure 3 Pelagic longline vessels vary in size, because they operate in a variety of environments, from protected coastal waters to open waters at low latitudes. Pictured are (a) a 24 m long modern steel monohull built in Australia and owned by an Australian fishing company, (b) a 17 m long fibreglass monohull originally built in Japan and now owned by a Fijian fishing company and (c) several 11 m long open aluminium catamarans each built in Samoa and owned by local Samoan families.

Figure 4 Demersal longline vessels tend to be large, because most of the fisheries occur in open and exposed waters at high latitudes. Pictured are four demersal longliners owned by Korean and Japanese fishing companies that are approximately 40 m long, preparing to depart for the Southern Ocean in search of Patagonian toothfish.

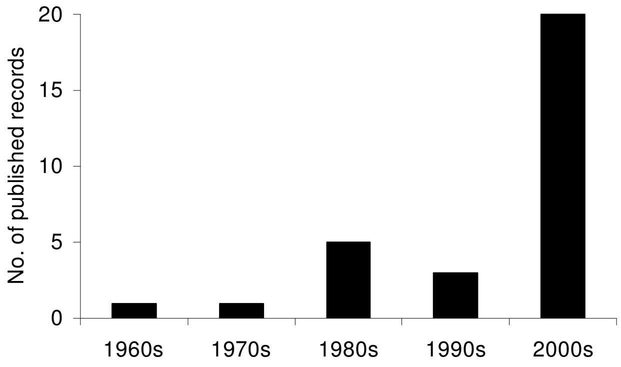

Figure 5 A decadal summary of the number of reports in the peer reviewed literature of operational interactions between odontocetes and longline gear (including catch depredation and/or by-catch) over the last 50 years. Note the marked increase over the most recent decade.

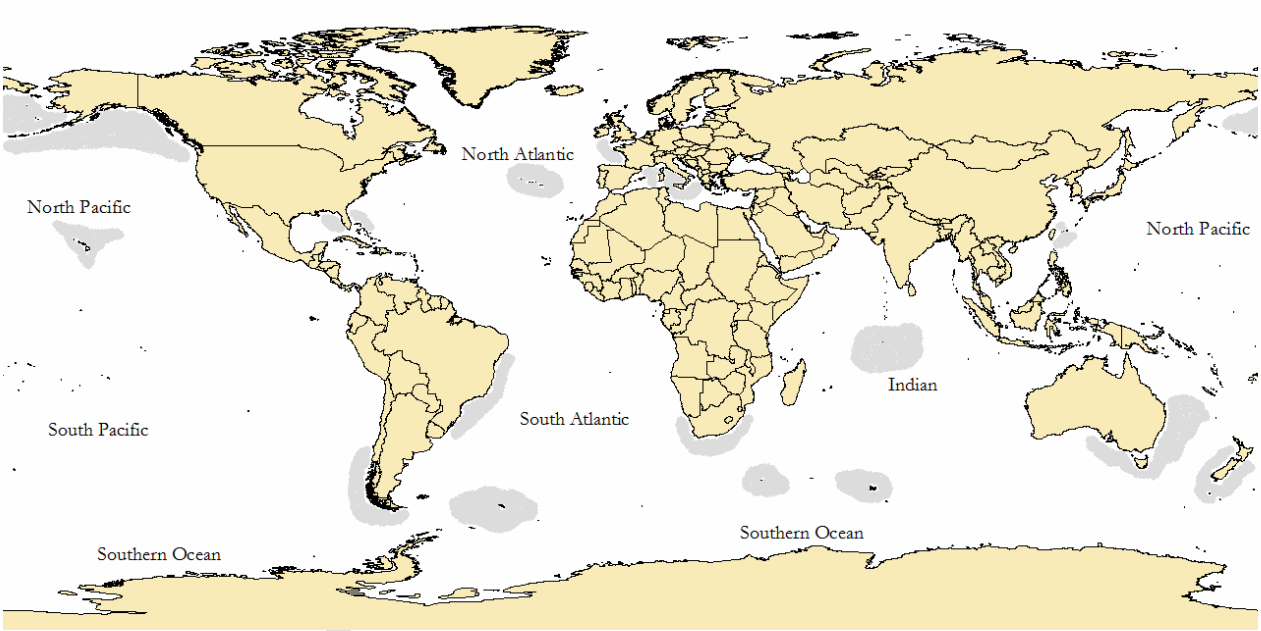

Figure 6 Geographic distribution of depredation and/or by catch of odontocetes in pelagic and demersal longline fisheries (grey areas) that has been inferred or quantified in peer reviewed literature.

Figure 6 A false killer whale (*Pseudorca crassidens*) caught on a pelagic longline hook in an Hawaiian-based fishery operating within the United States Exclusive Economic Zone (EEZ). (Source: National Marine Fisheries Service [NMFS], United States Federal Government).

Figure 7 Depredation damage caused by false killer whales (*Pseudorca crassidens*) and pilot whales (*Globicephala* spp.) on albacore tuna (*Thunnus alalunga*) caught on a pelagic longline. Of the depredated fish recovered, the most common type of damage is the complete removal of the torso from behind the gill plates (a), although some fish receive extensive tooth lacerations to the torso (b). Note how the canine-like teeth of depredating whales tend to rip the flesh (c).

Figure 8 Depredation damage caused by sharks on albacore tuna (*Thunnus alalunga*) caught on a pelagic longline. Note how the blade-like teeth of depredating sharks tend to cut flesh and bone cleanly.

Figure 9 Depredation damage alleged to be caused by toothed whales on sardine (*Sardinops sagax*) bait used on a pelagic longline. Of the depredated bait recovered, the most common damage was the complete removal of the torso with gills and gill plates remaining (a) and partial removal of flesh from the torso (b). Note the small bite marks on the latter. A recent study concluded that much of the bait damage was unlikely to be caused by depredating whales, instead suggesting it was caused by smaller pelagic fish that were occasionally observed in the vicinity of vessel (c).

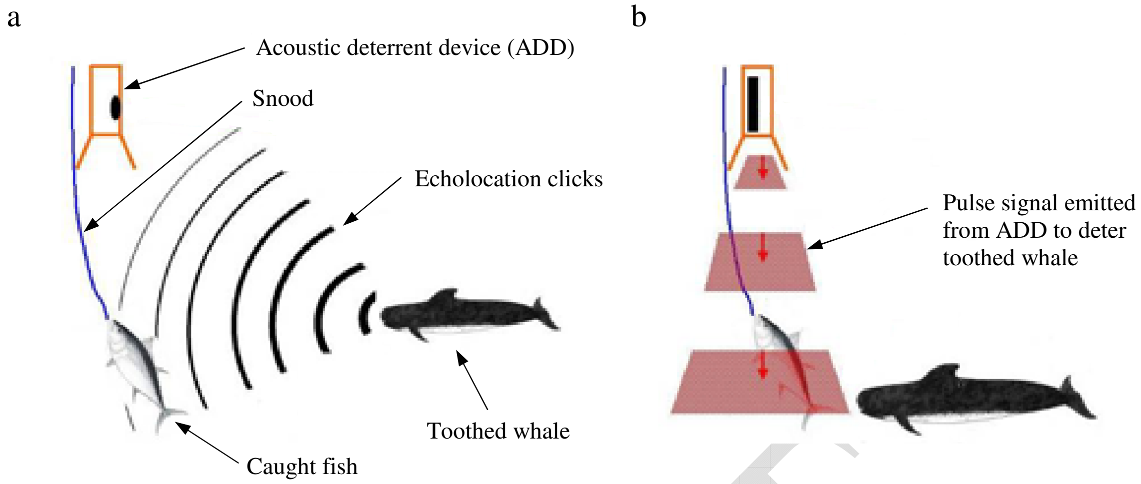

Figure 10 Schematic diagram of an acoustic deterrent device (ADD) fitted to pelagic longline snood. These devices are designed to emit a pulsed noise or signal that annoys (or disrupts the echolocation capacity of) an approaching odontocete that intends to depredate the catch. In the case illustrated, the device remains on standby until it detects the echolocation pulses of an approaching whale (a). It then begins to emit a directed pulse signal around the caught fish that prevents the whale from continuing its approach (b). (Source: McPherson et al., 2008 [modified]).

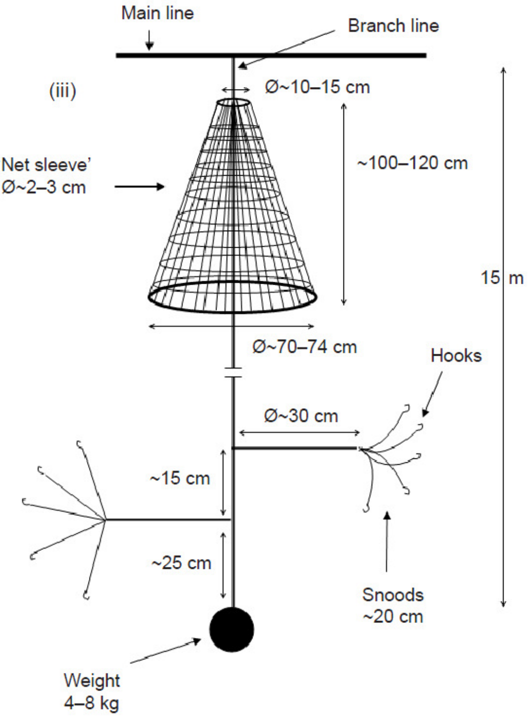

Figure 11 Schematic diagram of a robustly constructed 'net sleeve' (or physical depredation mitigation device; PDMD) fitted to a demersal longline used in the Chilean Patagonian toothfish (*Dissostichus eleginoides*) fishery. The net sleeve is designed to provide a physical barrier that prevents killer whales (*Orcinus orca*) and sperm whales (*Physeter macrocephalus*) from depredating the catch. It remains clear of the hooks during the soak period (when the gear is on the benthos) and then slides down the branch line and over the caught fish during the haul. (Source: Moreno et al., 2008).

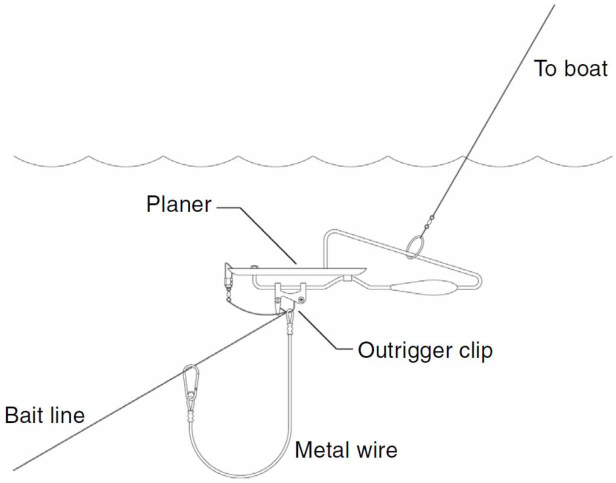

Figure 12 Schematic diagram of a fine 'metal wire' (or physical depredation mitigation device; PDMD) fitted to a commercial troll line used in the Florida king mackerel (*Scomberomorus cavalla*) fishery. The metal wire is designed to provide a physical barrier that prevents bottlenose dolphins (*Tursiops truncatus*) from depredating the catch, but remains clear of the hook until a fish is caught on the baited hook. The pressure of the caught fish fighting against the hook causes the outrigger clip to release the metal wire, which then descends the bait line toward the hook. (Source: Zollett and Read, 2006).

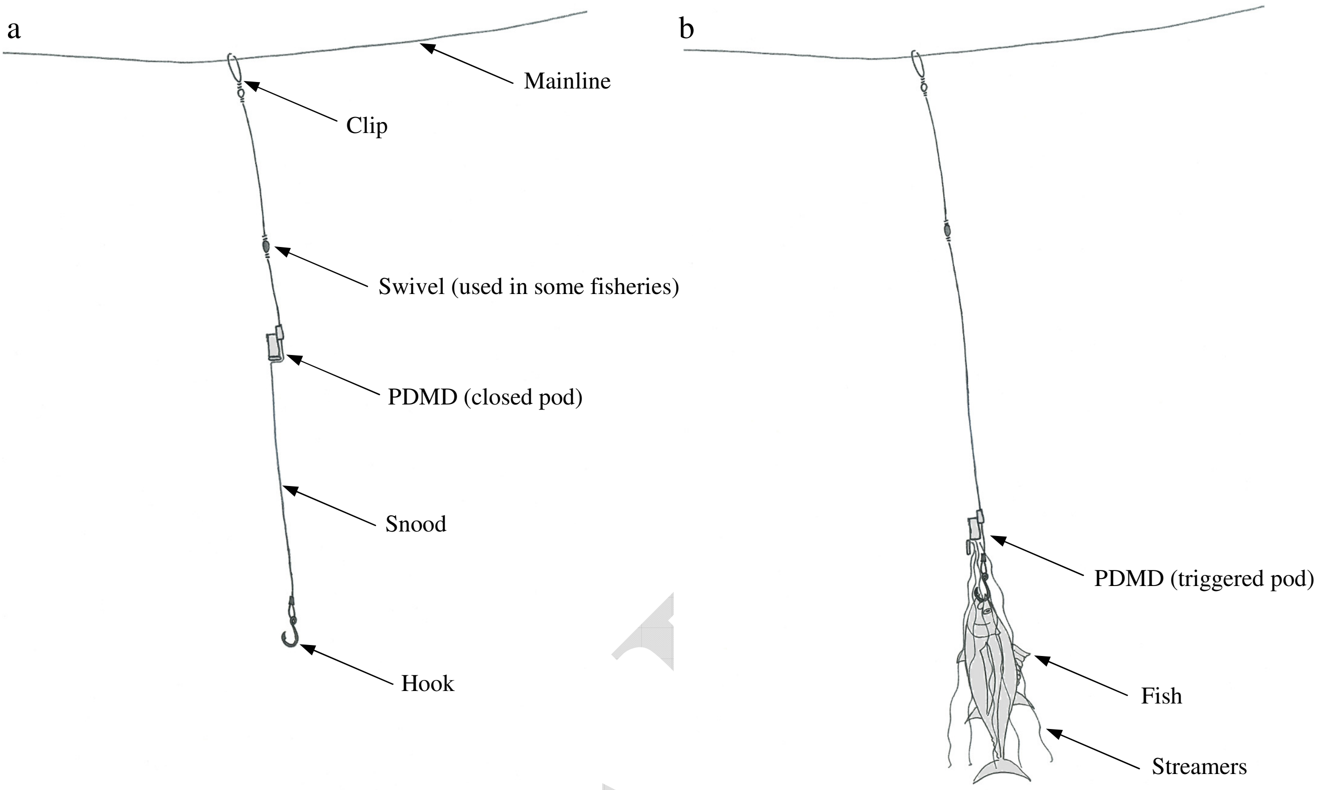

Figure 13 Schematic diagram of a physical depredation mitigation device (PDMD) fitted to a pelagic longline snood and soon to be trialled in the Coral Sea. The PDMD remains clear of the baited hook (a) until a fish is caught (b). The pressure of the caught fish fighting against the hook causes the cap of the pod to open and release the streamers, and the pod to descend the snood toward the hook. Observation of depredated fish on longlines suggests that depredating whales will be deterred by the streamers, because they flap around next to the caught fish and mimic tangles in the fishing gear. This PDMD is currently being developed by the Australian Marine Mammal Centre (AMMC). (Source: Hamer, 2009).