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Title:

Odontocete bycatch and depredation in longline fisheries: a review of available literature and of potential solutions.

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Abstract

Operational interactions between odontocetes (*i.e.*, toothed whales) and longline gear are a global phenomenon that may threaten the conservation of odontocete populations and the economic viability of longline fisheries. This review attempts to define the issue, summarize the trends and geographical extent of its occurrence over the last half century, explore the potential impact on odontocetes and on fisheries, and describe potential acoustic and physical mitigation solutions.

Reports of odontocete bycatch rates are highly variable (between 0.002 and 0.231 individuals killed per set) and at least 20 species may be involved. Information about population size, migration patterns and life history characteristics are scarce, although at least one population may be in decline due to losses attributable to longline bycatch. Information about the financial impact of depredation on pelagic longline fisheries is also scarce, although estimates of daily fleet-wide losses range between US$1,034 and US$8,449 (overall income was not reported). Such biological and financial losses may be unsustainable.

Recent developments in acoustic and physical mitigation technologies have yielded mixed results. Acoustic mitigation technologies have no moving parts but require complex electronics. To date, they have been insufficiently developed and their efficacy has been difficult to assess. Physical mitigation technologies generally require complex moving parts, although they are relatively simple to develop and assess. Both require considerable further development and testing before widespread commercial production and use is possible. Development of these approaches should be prioritized and a 'toolbox' of various partial solutions should be compiled, because a single panacea to the problem is unlikely to emerge.

Key words: Operational interactions, odontocete, toothed whale, longline, fishing, depredation, bycatch mortality, physical, acoustic.

Introduction to operational interactions between odontocetes and longlines

The occurrence of operational interactions between cetaceans (*e.g.*, whales, dolphins and porpoises) and commercial fisheries has received considerable attention in the published literature and is a familiar problem to many fishing, management and research communities (*e.g.*, Northridge 1984, 1991; Beverton 1985; Reeves *et al.* 1994; Northridge and Hofman 1999; Donoghue *et al.* 2003; Shaughnessy *et al.* 2003; Read 2005; Gilman *et al.* 2006). Operational interactions involve the simultaneous physical convergence of cetaceans and commercial fisheries upon the same spatially retracted area, often when both are in pursuit of the same fish (Northridge and Hofman 1999, Shaughnessy *et al.* 2003, Hamer *et al.* 2008, Moreno *et al.* 2008). Positive outcomes include (i) fisheries using cetaceans to indicate the presence of fish (Gosliner 1999, Northridge and Hofman 1999) and (ii) cetaceans using fisheries to access an otherwise inaccessible food resource (Gilman *et al.* 2006, Moreno *et al.* 2008). Negative outcomes include threats to the viability of (i) cetacean populations when depredating individuals are injured by or drown in fishing gear (Gosliner 1999, Shaughnessy *et al.* 2003, Hamer *et al.* 2008) and (ii) fisheries when depredating whales remove or damage the catch (Hucke-Gaete *et al.* 2004, Ramos-Cartelle and Mejuto 2008). These negative outcomes may be the result of trophic interactions, which involve competition for the same fish stock and result in either direct reduction (through removal of fish), or indirect reduction (through trophic cascades) of fish stocks (Northridge and Hofman 1999, Kaschner 2004). Both scenarios could reduce the overall quantity of fish available to cetacean populations (Kaschner 2004, Bakun *et al.* 2009) and fisheries (Ashford *et al.* 1996, Earle 1996), thus increasing the likelihood of operational interactions.

A growing body of information concerning the nature and extent of operational interactions between odontocetes (*i.e.*, toothed whales, dolphins and porpoises) and longline gear has been emerging in the literature, since longlining commenced modernization in the 1950s (Yamaguchi 1989; Ward and Hindmarsh 2007). The main areas of concern appear to be depredation and bycatch. Depredation occurs when an individual odontocete partially or completely consumes caught fish from the longline, or deters free swimming fish that may otherwise have become caught (Yano and Dahlheim 1995, Northridge and Hofman 1999, Read 2005, Gilman *et al.* 2006, Lauriano *et al.* 2009). Although depredation of bait has also been identified as an issue, there is insufficient data and information currently available to warrant further consideration here. Bycatch occurs when a depredating odontocete becomes caught on a longline hook when attempting to remove the catch (Beverton 1985, Shaughnessy *et al.* 2003, Read 2005, Secchi *et al.* 2005, Indian Ocean Tuna Commission 2007).

The modernization of longlining resulted in rapid geographic expansion and reports of odontocetes depredating catch from longlines began to emerge soon after (*e.g.*, Iwashita *et al.* 1963, Sivasubramaniam 1964, Mitchell 1975). The growing number of reported incidences since that time suggests the phenomenon may have become a significant economic problem for affected longline fisheries and a significant conservation and welfare problem for affected odontocete populations. This review attempts to (i) define the issue, (ii) summarize the available literature to determine trends and geographical extent of catch depredation by and odontocete bycatch of odontocetes, (iii) explore the impacts of depredation on fisheries and bycatch on odontocete populations and (iv) describe the acoustic and physical tools available that have been developed to mitigate the problem.

Summary of odontocete depredation and bycatch reports in the reviewed literature

The compilation and interpretation of the accessible literature may be useful in revealing the nature and extent of the problem and may provide insights into how to mitigate the impact of one or both. The literature cited was restricted to peer reviewed documents (articles and reports) that referred to fishery logbook or observer data, specifically relating to operational interactions between odontocetes and longline fisheries. Electronic search engines and databases were used, such as Web of Science, Current Contents, Google Scholar and general internet searches, using keywords such as: whale, cetacean, odontocete (and individual species names), depredation and bycatch.

The literature search identified 32 peer reviewed documents matching the criteria, published between 1964 and 2010 (Table 1). Early documents merely acknowledged the occurrence of catch depredation, with the first specific account of an odontocete being bycaught on a longline hook emerging in 1983 (Di Natale and Mangano 1983). Nonetheless, the literature has remained focused on the effects on the fishery, with 23 reports of depredation compared with 12 reports of bycatch (Table 1). Twenty two reports have emerged since 2000, amounting to over twice the number produced over the previous four decades combined (Fig. 1). This recent spike suggests an increase in awareness and interest in the issue.

The literature cited indicates that 20 odontocete species have been involved in operational interactions with longline gear. Fifteen species were confirmed to have either depredated from, or have become bycaught on, longline hooks (Table 1). The five remaining species (*i.e.*, rough toothed dolphin *Steno bredanensis*, spinner dolphin *Stenella longirostris*, Atlantic humpback dolphin *Sousa teuszii*, melon-headed whale *Peponocephala electra* and pygmy killer whale *Feresia attenuata*) were involved in unverified, anecdotal and unquantified bycatch events (Northridge 1984, Nishida and Tanio 2001, South Pacific Regional Environment Program 2002, Culik 2004, Secchi *et al.* 2005, Watson and Kersletter 2006, Moore *et al.* 2010). Based on the literature obtained, killer whales (*Orcinus orca*) and sperm whales (*Physeter macrocephalus*) appear to be the main species involved with demersal longline fisheries at higher latitudes, while false killer whales (*Pseudorca crassidens*) and pilot whales (*Globicephala* spp.) appear to be the main species involved with pelagic longline fisheries at lower latitudes. The problem also appears to be geographically widespread, with reports of depredation from and bycatch on longlines confirmed in 25 locations, from the equator to high latitudes in both hemispheres and in all of the world's major oceans (Fig. 2).

Some key advents may explain the recent increase in the number of reports emerging in the available literature. Since the 1940s and 1950s, some odontocete populations have benefited from increased international protection instruments, such as the Convention on International Trade in Endangered Species (CITES) and the International Convention for the Regulation of Whaling (ICRW). During the same period, fishing effort has increased to meet the demands of a burgeoning human population (United Nations 2009) with changing dietary needs (Duarte *et al.* 2009). This situation is likely to have increased the probability of odontocetes encountering fishing gear, thus resulting in increased incidences of depredation and bycatch (Northridge 1984, 1991; Jefferson *et al.* 1994; Reeves et al. 1994; South Pacific Regional Environment Program 2002; Donoghue *et al.* 2003; Gilman *et al.* 2006). As such, the growing volume of literature reflects the consequential increase in fisher motivation to find ways of mitigating catch depredation in a bid to improve or maintain 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, Food and Agriculture Organization 2009). The emergence of this information has encouraged relevant conservation and management groups to characterize the problem and explore mitigation strategies to ensure the continued conservation of recovering cetacean populations and to minimize mounting pressure on the economic viability of fisheries. Mitigation of odontocete bycatch and catch depredation has been prioritized by some fisheries in recent times, thus indicating its importance relative to other issues that impact fishery viability (Donoghue *et al.* 2003, Australian Fisheries Management Authority 2005).

Impacts of bycatch on odontocetes

Longline gear poses a significant entanglement and drowning risk to depredating odontocetes, which affect the welfare of individuals and the conservation of populations (Ashford *et al.* 1996, Northridge and Hofman 1999, Visser 2000, South Pacific Regional Environment Program 2002, Secchi *et al.* 2005, Gilman *et al.* 2006, Forney and Kobayashi 2007, Hamer 2009*a*, 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, Fig. 3a). These events may lead to internal injuries, infections, starvation or even eventual death (Best *et al.* 2001). Some hooked individuals may be unable to reach the surface to breathe, thus leading to a more immediate death by drowning (Hamer 2009*a*). Depredating odontocetes are also often conspicuous, especially during hauling when they are close to the vessel, which may lead to fishers becoming frustrated and attempting to shoot individuals (Northridge and Hofman 1999). The impact of these mortalities at a population level is difficult to determine, because there are currently inadequate data available to estimate total mortality levels or to determine historical levels and current trajectories for most of the populations involved.

The distributions of most of the 72 extant odontocete species overlap geographically with longline fishing activities in some part of their range (Northridge 1984, Bjordal and Lokkeborg 1996, Culik 2004, Carwardine 2006). As indicated here, at least 20 species (28%) are reported to have operational interactions with longline fisheries (Table 1). The literature cited provides insights into this issue, although much of it is qualitative or based on small or incomplete data sets, indicating the occurrence of a much larger and chronic welfare or conservation problem.

A recent and comparatively intensive study of operational interactions between odontocetes and a pelagic longline fishery in Hawaiian waters, based on independent longline observer programs and odontocete population surveys during the 1990s and 2000s, indicated that that the decline of two odontocete populations may be attributable to bycatch mortalities on pelagic longline hooks (*e.g.*, pilot whale: Waring *et al.* 2006, Garrison 2007; false killer whale: Forney and Kobayashi 2007, Reeves *et al.* 2009). Nonetheless, establishing a robust quantitative link is difficult in the absence of estimates of bycatch and population size over long time periods, due to the bias and variance that is likely to be present in the available data (Hamer *et al.* 2008, 2009; Indian Ocean Tuna Commission 2010). This problem is further exacerbated by under reporting in fishery logbooks, which occurs because fishers are typically fearful of the negative consequences of reporting accurately (Moore *et al.* 2010).

Recent advances in population genetics have made it possible to identify 'management units', which may assist in ensuring the biological importance of subpopulations is not underestimated (Pimper *et al.* 2010). Notwithstanding, most odontocete species have low reproductive rates and correspondingly low intrinsic capacities for increase, suggesting that even low levels of additional or unnatural mortality may cause decline (Leatherwood *et al.* 1983, Culik 2004, Miller 2007, Wade 2002). This is further complicated by the growing number of reports of genetic subdivision within what were previously thought to be single populations (*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). Nonetheless, this technology will allow more appropriate management strategies that take into account the genetic diversity *within* a species to be developed and implemented in the future.

Although an individual odontocete is faced with the risk of injury and death when depredating from longlines, it may receive considerable foraging and energetic benefits by doing so. Some fish species caught on longlines may be unavailable to depredating odontocetes under natural conditions, because those fish are too large, too fast to catch, or occur in very deep waters (Gilman *et al.* 2006, Tixier *et al.* 2009). Fish caught on longlines may offer an energetic advantage to depredating odontocetes, because they can be consumed without the need for dives or pursuits (Guinet *et al.* 2007). If an individual odontocete can develop a strategy to avoid becoming bycatch and the activities of the longline fishery they depredate from is frequent and predictable, then they may be at an advantage compared with other individuals of the same species that forage naturally.

Impacts of depredation on longline fisheries

Although concerns about the welfare and conservation of depredating odontocetes have become more common in recent times, concerns about the economic impact of depredation on affected longline fisheries have persisted since the 1960s (Dahlheim 1988, Yano and Dahlheim 1995, South Pacific Regional Environment Program 2002, Australian Fisheries Management Authority 2005, Indian Ocean Tuna Commission 2007). Depredation can reduce the overall size and condition of the landed catch, because target fish may be deterred from taking baited hooks, or caught fish may be damaged or removed completely (Yano and Dahlheim 1995, Northridge and Hofman 1999, Gilman *et al.* 2006, Hamer 2009*b*, Lauriano *et al.* 2009). When depredation occurs, affected fisheries are likely to experience sporadic, seasonal or ongoing reductions in profit, which may lead to economic decline.

When depredating odontocetes attack fish caught on longline hooks, they often remove the entire torso from behind the gill plates (Fig. 3b), or sometimes leave tooth lacerations on the torso (Fig. 3c). Odontocete teeth are pencil-like and tend to tear the skin and flesh of the caught fish, extensively damaging the remaining flesh. The nature of this damage is distinct from that caused by sharks, which tend to remove bite-shaped portions of flesh from the torso of caught fish with their blade-like teeth, leaving the surrounding flesh relatively undamaged (Fig. 3d). Distinguishing between odontocete and shark depredation is important for (i) ensuring the correct attribution of damage to each depredating taxa and (ii) selecting the correct mitigation method. Anecdotal accounts suggest that odontocetes are often also blamed for shark depredation, which may have arisen because depredating whales surface frequently to breath in the vicinity of fishing vessels, thus are much more conspicuous (thus the adage applies to depredating sharks: 'out of sight – out of mind'). Such instances may result in the overestimation of whale depredation and the underestimation of shark depredation.

In addition to impacting directly on the catch, depredating odontocetes may damage the fishing gear when they remove caught fish, specifically hooks, or larger portions of the longline gear, especially if they become caught themselves (Northridge and Hofman 1999, Gilman *et al.* 2006). Furthermore, small odontocetes (*i.e.*, dolphins) may partly (Fig. 3e) or completely remove baits directly from the hook (Secchi *et al.* 2005, McPherson *et al.* 2008). However, large quantities of small pelagic fish have been observed grazing on discarded baits and around baited hooks as they are hauled aboard the vessel at the end of a set (Hamer, pers. obs., Fig. 3f). This suggests small pelagic fish, rather than odontocetes, may be responsible for depredating baits.

The damage to caught fish and deterrence of target fish by depredating toothed whales is likely to result in financial losses to affected fisheries. Two studies conducted in the Bering Sea, northeast Pacific, between 1977 and 1989 estimated the daily economic cost of killer whale depredation to each vessel across a Greenland groundfish fishery (for halibut *Reinhardtius hippoglossoides* and arrowtooth flounder *Atheresthes stomias*) was between US$1,034 and US$8,449 (Dahlheim 1988, Yano and Dahlheim 1995). These figures were based on one set per day and 78.9% inflation between 1989 and 2010 for the earlier study and 44.2% between 1995 and 2010 for the later study. Two other studies conducted around the Crozet (46°25'S, 50°59'E) and Kerguelen Islands (49°19'S, 69°28'E), Southern Ocean, between 2003 and 2008 estimated the daily cost of killer whale and sperm whale depredation to the fishery across a Patagonian toothfish fishery was between US$6,052 and US$8,495 (Roche *et al.* 2007, Tixier *et al.* 2009). These figures were adjusted from a multiyear to a one set per day estimate, then 1.5:1€ to US$ exchange conversion and 13.6% inflation between 2005 and 2010 for the earlier study and a 1.3:1€ to US$ exchange conversion and 2.7% inflation between 2008 and 2010 for the later study. It is important to note that these figures are at best informative and represent a snapshot in time for two demersal longline fisheries in the northeast Pacific and Southern Ocean. They are unlikely to reflect the losses sustained by other demersal or pelagic longline fisheries in other locations at other times. In addition, neither study reported the overall catch figures, so it was not possible to determine the percentage of catch that was lost. Furthermore, the economic cost of depredation is likely to be an underestimate, because it is not possible to quantify the number of caught fish that are completely removed from the hook, the number of target fish that are deterred from taking a baited hook altogether, the amount of fishing gear that is damaged, nor the various avoidance activities undertaken by skippers (Yano and Dahlheim 1995, Hamer 2009*b*). Despite the lack of data, the economic costs reported in the two studies detailed suggest that the fishery wide economic impact is likely to be significant.

When depredating whales completely remove caught fish from longline hooks, they may impede effective fishery management practices, such as setting accurate total allowable commercial catch (TACC) limits and calculating the catch per unit of effort (CPUE) for target fish stocks. Over fishing may occur, because the caught fish that are removed by depredating whales are not included when calculating the level of fishery exploitation (Gilman *et al.* 2006). This situation is possible especially when the TACC has already been set, because the depredated fish are not included in the catch declared by the fishery. Under fishing may occur, because the removal of caught fish by depredating whales will reduce the CPUE. This situation may lead to the false impression that there are less fish available than is actually the case, which may encourage the relevant fishery management agencies to reduce the TACC (Gilman *et al.* 2006, Roche *et al.* 2007). Therefore, the impact that catch depredation by odontocetes has on the management of the affected fishery should be taken into account when determining methods for long term sustainable fishery management.

Bycatch and depredation mitigation strategies

Until recently, few studies have attempted to identify solutions for mitigating operational interactions between odontocetes and longline fishing operations. Most simply flagged promising ideas (*e.g.*, Northridge and Hofman 1999, Visser 2000), while some compiled more detailed accounts of mitigation measures implemented directly by individual longline fishers and by fisheries in an ad hoc and untested manner (*e.g.*, Dahlheim 1988, Secchi *et al.* 2005, Table 2). Independent experimental trials that quantify the effectiveness of potential depredation mitigation strategies in the longline industry remain in their infancy (*e.g.*, Moreno *et al.* 2008, Mooney *et al.* 2009). In contrast, the available literature indicates that the development and implementation of cetacean depredation and bycatch mitigation strategies in other fisheries is more advanced (*e.g.*, purse seine: Gosliner 1999, Hamer *et al.* 2008; gill net: Trippel *et al.* 1999, Barlow and Cameron 2003).

Fishers, fishery managers and researchers have proposed a number of techniques for mitigating odontocete depredation and bycatch in longline fishing gear, which can be broadly categorized as (i) behavioral, (ii) spatial, (iii) acoustic, or (iv) physical. Behavioral techniques have been successfully used in active fishing methods, such as trawl (Tilzey *et al.* 2006) and purse seine (Hamer *et al.* 2008), because the fishing gear can be manipulated during a fishing event to mitigate the likelihood of bycatch. Unfortunately, there is limited scope for fisher behavior to change the way longline gear behaves when it is deployed, because it hangs passively in the water column and is not attached to the vessel. Nonetheless, fishers could make decisions about where to fish and for how long to deploy the gear in order to avoid odontocetes, although such practices are yet to be quantified and are unlikely to be implemented voluntarily, especially in the long term, unless the economic benefits are immediately apparent. The 'move on' tactic has been used by some longline fishers in a bid to outrun depredating whales, although the success of this strategy seems to be ambiguous at best and is likely to be costly, thus affecting profit margins[1]. A study of this method for avoiding pinniped depredation and bycatch in a trawl fishery found it was only occasionally successful, because depredating individuals were also able to travel long distances to remain with the vessel (Tilzet *et al.* 2006).

Spatial closures, typically known as marine protected areas (MPAs), are designed to spatially separate marine mammal populations and fishing effort so as to reduce the likelihood of bycatch mortalities. However, effective MPAs are difficult to implement, because (i) knowing where to put them is dependent on the odontocete migration and movement patterns, which have largely not been determined with any degree of accuracy to date (Dulau-Drouot *et al.* 2008), (ii) they are often smaller than required to protect odontocetes, due to stakeholder pressure to minimize their impact on fisheries (Klein *et al.* 2008), (iii) monitoring compliance by fishers is difficult due to the lack of financial and logistical resources (Le Quesne 2009) and (iv) quantitative performance assessment is hampered by the statistical uncertainties due to the general lack of data on the odontocetes and fisheries involved (Claudet *et al.* 2006). In contrast, the implementation of MPAs to protect pinnipeds from fishing activities has proven easier, because they are central place foragers whose foraging ranges and population trends can be determined with comparative ease (Baylis *et al.* 2008, Shaughnessy *et al.* 2011, Hamer *et al.* 2011).

Acoustic technologies

[1] Personal communication: Mark Coker and Niki McCulloch (Debreet Seafoods, Queensland, Australia).

Acoustic technologies for mitigating odontocete depredation and bycatch in longline fisheries appear to have received the most attention in the literature. In general, high intensity sounds are used to deter depredating odontocetes from approaching fishing gear, while comparatively low intensity sounds are used to alert odontocetes (and other cetaceans) to the presence of fishing gear to prevent them from becoming incidental bycatch.

The majority of the literature in this field reports on ways to mitigate catch depredation and typically focus on four strategies, which are harassment, deterrence, echolocation disruption and avoidance. Their development has generally been encouraged by fishery stakeholders who hope to reduce the economic impact of depredation on their fishing enterprise. Most effort has focused on the development of acoustic harassment devices (AHDs), which are designed to encourage or force depredating odontocetes to leave the vicinity of the fishing gear (Nowacek *et al.* 2007). In the absence of information on odontocete hearing range and capacity, AHD development seems to have been based on human characteristics. As such, they typically transmit sounds greater than 180dB (at 1 m from the source), which are beyond the 145 dB at which human hearing structures can be permanently damaged (Price 1981, Nowacek *et al.* 2007).

Acoustic deterrence devices (ADDs) emit moderately high sounds that are typically lower than 180 dB (at 1 m from the source). Similarly to AHDs, ADDs are designed to annoy depredating odontocetes and encourage them to leave or remain clear of an area, typically where floating structures such as fish pens are located (Dawson *et al.* 1998, Nowacek *et al.* 2007). Unlike AHDs and ADDs, echolocation disruption devices (EDDs) are claimed to prevent depredating odontocetes from accurately determining the location of a caught fish, thus reducing the likelihood of a successful depredation attempt (Mooney *et al.* 2009). Nonetheless, the distinction between ADDs and EDDs remains unclear, because the functional mechanisms that elicit specific behavioral outcomes in depredating odontocetes in response to the sound emitted by them and other devices remains unclear (Jefferson and Curry 1996).

Steps have also been taken to avoid depredation altogether. Passive listening arrays (PLAs) are designed to assist affected fishing vessels in acoustically detecting depredating odontocetes, thus allowing the vessel to leave or move on from a fishing area when individuals are detected in the vicinity (McPherson *et al.* 2008). Unlike AHDs, ADDs and EDDs, PLAs are not a deterrent mechanism, instead leaving the decision to the vessel operator to reduce the level of physical overlap with depredating odontocetes. Despite the apparent benefits, fishing industries have generally resisted uptake of PLAs, as discussed earlier, because of the significant costs (mainly fuel) associated with moving on. Additionally, it has been difficult to reliably confirm the presence or absence of highly mobile odontocetes, with depredation occurring at times when odontocetes are not observed or detected and depredation not occurring at times when odontocetes are observed or detected[2]. In addition, PLAs have been slow to develop, because the associated structures and equipment are typically complex and expensive (Nielsen and Mohl 2006), they can be damaged by marine predators such as sharks (Johnson *et al.* 1982) and sound interference from the fishing vessel and from the broader marine environment can mask the vocalizations of depredating whales (Thode *et al.* 2007).

An alternative strategy for avoiding depredating odontocetes would involve masking or minimizing the sound signature of fishing vessels that are thought to attract depredating odontocetes, so that the individuals involved can no longer detect the vessels presence (McPherson *et al.* 2008). However, identify a parsimonious suite of sound signature and suppression factors that may assist in mitigating depredation have proven to be logistically and technically challenging[3].

2 Personal communication: Mark Coker (Debreet Seafoods, Queensland, Australia).
3 Personal communication: Mark Coker (Debreet Seafoods, Queensland, Australia); Will Mure (Mures Fishing, Tasmania, Australia).

Acoustic technology has also been used to mitigate incidental bycatch of odontocetes, with the main strategy being to warn individuals of the presence of fishing gear in their vicinity (Kraus *et al.* 1997, Barlow and Cameron 2003). Such devices are referred to as 'pingers'. Their development has predominantly occurred in gill net and drift net fisheries, where incidental bycatch of odontocetes seems to have been greatest (Read *et al.* 2006). A number of studies have shown that pingers significantly reduce incidental bycatch of harbor porpoise (*Phocoena phocoena*) in demersal gill nets (Lien *et al.* 1995, Kraus *et al.* 1997, Trippel *et al.* 1999, Gearin *et al.* 2000) and common dolphins in drift gill nets (Barlow and Cameron 2003). However, other studies have shown that assessing the effectiveness of pingers is difficult, due to the lack of statistical power caused by typically low rates of bycatch, habituation of individuals to the noises made by pingers and a lack of understanding of the processes that lead to bycatch (Dawson *et al.* 1998). Pingers may also be species specific in their application, thus making it difficult to address bycatch effectively, especially in situations where more than one species is involved (Kastelein *et al.* 2006). Despite the potential usefulness of pingers in some fisheries, they are unlikely to be useful in longline fisheries, where most bycatch occurs when depredating odontocetes are actively attempting to remove caught fish from hooks.

Despite the considerable efforts to develop acoustic strategies for mitigating depredation and bycatch, to date their successful application has generally proven to be difficult. The use of AHDs raises concerns about the effect of high level noise on odontocetes and the wider marine environment (Johnston and Woodley 1998, Morton and Symonds 2002). One study of the use of ADDs in a gill net fishery suggested that the subsequent reduction in dolphin bycatch may have occurred because the devices deterred the target fish, thus encouraging the dolphins involved to forage elsewhere (Kraus *et al.* 1997). Over time, odontocetes may become habituated to noises emitted by ADDs, EDDs and pingers, thus rendering them ineffective (Jefferson and Curry 1996). These devices may eventually become attractants or a 'dinner bell' to foraging odontocetes, if animals learn to associate the sounds emitted with the presence of palatable fish (Jefferson and Curry 1996, Mooney *et al.* 2009).

Assessing the efficacy of acoustic devices has been hampered by the lack of experimental replication, mainly due to the variety of odontocete species involved, the number of devices currently available in the market place, variations in the configuration of gear used in each fishery and the unique environmental conditions in each coastal or oceanic region (Jefferson and Curry 1996, Dawson *et al.* 1998, Nowacek *et al.* 2007, Kastelein *et al.* 2006). Current technology also constrains the testing and application of acoustic devices, because integral components such as the transponder and batteries are currently large and expensive (McPherson *et al.* 2008, Mooney *et al.* 2009). These problems are further exacerbated by the current lack of understanding of the mechanisms that underpin how noise harasses, deters or warns odontocetes that are close to fishing gear. While there is a need to continue developing and assessing acoustic depredation and bycatch mitigation strategies in longline fisheries, success, and ultimately implementation, will only be possible if a case-by-case approach is adopted, experiments are controlled and replicated, and the necessary components are sufficiently small and cheap for devices to be deployed in large numbers on the gear.

Physical technologies

Physical technologies for mitigating depredation and bycatch of odontocetes have received comparatively little attention, although recent innovations in developing physical depredation mitigation devices (PDMDs) have proven promising (Moreno *et al.* 2008, Hamer 2010). In longline fisheries, the baited hook must remain unimpeded prior to catching a target fish, thus requiring potential solutions to include moving parts and trigger systems (Moreno *et al.* 2008, Hamer 2011). A device known as the 'net sleeve' was recently trialed for mitigating depredation in the Chilean Patagonian toothfish demersal longline fishery and was found to reduce sperm whale depredation by 82.8% (Moreno *et al.* 2008). The net sleeve was developed on the premise that sperm whales were unable to depredate the catch while the gear was deployed on the benthos and only had access to caught fish during the haul. The net sleeve remained clear of the baited hooks on the benthos during fishing, then descended the branchline under the influence of gravity the haul, thus preventing access to the caught fish by depredating sperm whales.

Developing solutions for pelagic longline gear is likely to be more challenging than for demersal longline gear. Pelagic longlines are set at much shallower depths (*i.e.*, between 30 m and 300 m from the surface) and in the pelagic zone and as such are accessible by most depredating odontocete species throughout the fishing period (Hamer 2010). As such, the device must remain clear of the baited hook to allow it to function unimpeded. The device must also include a trigger mechanism that is activated by pressure when a target fish becomes caught and attempts to escape. The current absence of solutions for pelagic longline fisheries provides encouragement to investigate progress toward solving similar issues in other fisheries. A recent study reported on attempts to mitigate catch depredation by bottlenose dolphins (*Tursiops truncatus*) in the Florida king mackerel (*Scomberomorus cavalla*) troll fishery and found that dolphins were deterred from depredating by a 'metal wire' that moved around in the water next to the caught fish (Zollett and Read 2006). In order to allow the baited hook to fish unimpeded, the metal wire was held clear in a pressure sensitive mechanism. When a fish was caught and the pressure increased on the mechanism, the metal wire was released and then descended the line towards the caught fish. It was assumed that dolphins were deterred from depredating the caught fish due to fear of physical injury or entanglement.

Although the development of PDMDs (to mitigate both bycatch of and depredation by odontocetes) is in its infancy, they offer a comparatively realistic, applicable and generic approach when compared with the current generation of available acoustic technologies. This is because it is possible to manufacture small and cheap PDMDs, which increases the possibility of placing them on each snood immediately adjacent the hook, where depredation and bycatch events take place. Testing their efficacy is also relatively simple, with the use of rigorous and controlled experimental trials that measure bycatch rates, depredation rates and target fish catch rates. In contrast, the efficacy of acoustic devices is more difficult to determine, because it is not possible to ascertain whether the presence of a device is directly responsible for the results obtained.

Despite the conceptual and experimental advantages associated with developing PDMDs, the necessary physical complexity may prove challenging to accommodate in pelagic longline fisheries. Unlike acoustic devices that generally have no external moving parts, PDMDs may contain many. A conventional pelagic longline operation involves the deployment of between 1,800 and 3,600 hooks, each set between about six to eight seconds apart, indicating that the addition of the few extra seconds needed between each hook to attach or remove PDMDs may considerably increase the duration of daily fishing activities (Hamer 2009*b*). In addition, PDMDs may be small and delicate, which may have a negative impact on their durability in the harsh marine environment.

Pelagic longliners targeting tuna and billfish in the Tropical South Pacific Ocean (TSPO) have reported depredation by pilot whales and false killer whales for over a decade. In more recent times, a number of anecdotal reports have indicated that depredating individuals may be avoiding sections of the longline where the gear has become tangled, often due to vigorous and prolonged swimming activity of caught billfish and sharks[4]. As such, an approach reminiscent of the Florida King Mackerel example may be worthwhile, where structures that simulate or mimic tangles are deployed near a caught fish to deter depredating odontocetes. The Australian Government has initiated a study of this nature in the TSPO, which currently

[4] Personal communication: Mark Coker (Debrett Seafoods, Queensland, Australia); Ueta Faasili (Samoa Ministry of Agriculture and Fisheries, Samoa).

focuses on the development of two compact PDMDs for this purpose, both of which will soon be trialed (Hamer 2011, Fig. 4).

The success of PDMDs is dependent on the level of industry uptake, through either voluntary (individual fishing enterprise) or mandatory (relevant fishery management agency) processes. Fishers are unlikely to purchase and implement this technology if the cost of doing so is more than the increases in revenue associated with reduced catch damage (cost benefit analysis), which indicates that per unit cost minimization will eventually become an important part of the development process. This is especially important when considering the large number of illegal, unregulated and unreported (IUU) pelagic longline fisheries around the world that avoid conventional management regulations (Food and Agriculture Organization 2001, Baker *et al.* 2006, Lukoschek *et al.* 2009).

Summary and future directions

The literature summarized here indicates that odontocete bycatch and depredation in longline fisheries is widespread, involving many fisheries and many odontocete species and populations. Mitigating this problem is becoming a higher priority for all stakeholders, especially as longline fishery profit margins dwindle and as competition and conflict between odontocetes and longline fisheries increases. Nonetheless, the problem of depredation may be overstated by some fishers who attribute poor catch performance to odontocete depredation, when the real cause may be depredation by other marine predators, or poor operational decisions (thus poor catch performance) on the part of the fishers (*i.e.*, where, when and how to fish), or incorrect assignment of depredation by other taxa (*i.e.*, sharks or scavenging fish). In contrast, the problem may be understated for odontocetes, because small populations that include depredating individuals may be at risk of decline with the loss of only a few individuals (Leatherwood *et al.* 1983, Beissinger and McCullough 2002, Miller 2007). An earlier review of this issue indicated that the successful mitigation of bycatch and depredation can only occur with changes in longline fishing practices, although it lamented that little had been done thus far to identify and test potential solutions (Gilman *et al.* 2006). Given the volume of information summarized here, the geographic extent of operational interactions and the efforts made to develop mitigation strategies to date, stakeholders are strongly encouraged to prioritize this problem without delay, with a view to sustaining effected odontocete populations and longline fisheries.

Both acoustic and physical mitigation technologies have shown some promise, although both appear have inherent problems that may hinder their development and implementation. Acoustic mitigation tools are simple in their application, although cumbersome and complex in their function and assessment. For example, the size of the batteries and transponders currently available are probably too big for most applications, while the types and levels of noises that deter specific odontocete species remain unclear and testing their efficacy in a highly dynamic marine environment is difficult. By comparison, PDMDs are simple in their function and assessment, although their practical application may be challenging. Perhaps the most important aspect of ensuring the success of any bycatch and depredation mitigation strategy, whether it be acoustic, physical, or any other form, is the need to keep purchase and implementation costs below the economic gains associated with increased catch revenue. Although some fishery management agencies may opt for mandatory implementation of these technologies, the reality is that lack of compliance is likely to be widespread if there are no economic benefits for the affected fishery. Longline fishers involved in IUU activities are likely to monitor developments in regulated or managed fisheries and will only adopt mitigation technologies if there is a perceived economic benefit. The goal of all stakeholders should be to ensure the cost of implementation remains below the economic benefits associated with using them. An alternative strategy may be for managed fisheries to receive subsidies in situations where mitigation strategies are comparatively high, especially in artisanal longline fisheries, although this approach may not be sustainable in the long term.

Individual longline operations and fisheries around the globe are likely to face a diversity of situations, such as differences in (i) the odontocete species they interact with and bycatch rates, (ii) target fish catch rates and value and (iii) overall operational costs (including repayments, fuel, wages, bait, etc.). Given that a single panacea to this diverse problem is unlikely to emerge, fishers and fishery managers are encouraged to maximize the chance of mitigating odontocete bycatch and depredation by using a suite or 'toolbox' of mitigation strategies, such as (i) acoustic, (ii) physical, (iii) fisher behavior (*i.e.*, move on) and (iv) MPAs (Dahlheim 1988, Gilman *et al.* 2002, Gilman *et al.* 2006, Campbell and Cornwall 2008).

The development and implementation of acoustic and physical mitigation methods has attracted the interest of a broad stakeholder base. At the policy end of the spectrum, regional partnerships and agreements are deemed necessary for facilitating research and securing necessary funds. For example, the joint tuna regional fishery management organizations (T-RFMOs) have implemented the 'Kobe process' to deal with issues of whale bycatch and depredation. However, a number of delegates at the *Kobe II Bycatch Workshop* (Brisbane, Australia) in 2010 criticized the process, citing (i) a lack of consensus about fundamental terminology (*e.g.*, what constitutes bycatch?), (ii) the overcomplicated and slow process, and (iii) the misguided focus on documentation rather than problem solving (Kobe II 2010).

At the operational end of the spectrum, longline fisheries and odontocete researchers appear to have made extensive inroads toward solutions by focusing a growing body of knowledge on the subject of odontocete bycatch and depredation (Moreno *et al.* 2008, McPherson *et al.* 2008, Hamer 2011). Researchers have acknowledged that the conceptualization and development of some solutions may lie with the fishers, whose knowledge, experience and enthusiasm should not be underestimated or undervalued (Gilman *et al.* 2006). Regardless of where one might sit on the policy and operations spectrum, it is clear that more resources and greater commitment need to be focused on assisting fishers and researchers to improve the situation at the boat or vessel. If this does not occur soon, it should be expected that operational interactions between odontocetes and longline fisheries will increase to the determent of both.

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Table 1 Summary of operational interactions (*i.e.*, catch depredation and bycatch) between odontocetes and pelagic and demersal longline fishing gear, inferred from or quantified in the literature reviewed.

Whale	Fishery details			Catch depredation details		Whale bycatch details			
species involved	species targeted	region of interaction	gear configuration	% of sets affected [3]	% of catch damaged [3]	# of whales hooked	rate (animals/set)	Source author(s)	year
?	?	IO	?		<55			Sivasubramaniam	1964
KW, FKW	T	IO	P					Mitchell	1975
GTB	?	TC	?			2 [6]		Watson	1981
CD	S	FAC	P			2 [6]		Duguy & Hussenot	1982
SW		CM	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 [6]	0.07	Ashford *et al.*	1996
KW	T, SwF	SB	P		(50-100)			Secchi & Vaske	1998
KW	SS, BET	NZ	D		5-10			Visser	2000
SRW			P			3 [7]		Best *et al.*	2001
SW	SF	GA	D		23 [5]			Straley *et al.*	2002
KW, B	T, SwF	EA	P			2 [6]		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	SAus	D	6-80 [4]				AFMA [13]	2005
KW, FKW, B, D	T, SwF	EA	P			5 [8]		Bell *et al.*	2006
SW, KW	PT	SG, PEI	D		>50			Kock *et al.*	2006
BD	KM	F	P		6-20			Zollett & Read [14]	2006
KW	T, SwF	SB	P		12 (1-47)			Dalla Rosa & Secchi	2007
KW	T, SwF, S	SA			0.50			Williams *et al.*	2007
KW	PT	CA	D		42			Roche *et al.*	2007
Various [1]						67 [9]	0.003 [11]	Forney & Kobayashi	2007
FKW	T, SwF, S	B, AA	P	(1-9)	<9	2 [6]		Hernandez-Milian *et al.*	2008
FKW	SwF	A, IO, P		2	4-16	18 [10]	0.002 [11]	Ramos-Cartelle & Mujeto	2008
SW	SF	BS, GA, AI	D		<1			Sigler *et al.*	2008
SW, KW	PT	SC	D		0.36			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 [6]	0.231	Hamer	2009*b*
DD	D ,S	PC	P			1	0.05 [12]	Mangel *et al.*	2010

Whale species abbreviations

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

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	Dead animals recorded.
7	Entanglement mortalities.
8	5 animals hooked; 2 dead (1 KW and 1 D) and 3 released alive.
9	67 hooked; 7 dead (2 PW, 2 FKW, 1 SpD, 1 BD and BBW) and 60 released alive.
10	18 animals hooked; proportion dead and released alive not specified.
11	Derived retrospectively from figures presented in the results of the study.
12	In addition, harpooning of dolphins for bait was occasionally observed.
13	Australian Fisheries Management Authority.
14	Study of a troll fishery – included here due to the relevance of the depredation mitigation strategy to longline fishing.

Fish species abbreviations

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

Region abbreviations

A	Atlantic
AA	Azores Archipelago
AI	Aleutian Islands
B	Brazil
BS	Bering Sea
CA	Crozet Archipelago
CM	central Mediterranean
CS	Coral Sea
EA	eastern Australia
F	Florida
FAC	French Atlantic coast
GA	Gulf of Alaska
IC	Italian coast
IO	Indian Ocean
NZ	New Zealand
P	Pacific
PC	Peruvian coast
PEI	Prince Edward Islands
PWS	Prince William Sound
SA	South Africa
SAus	southern Australia
SB	southern Brazil
SC	southern Chile
SG	South Georgia
TC	Taiwanese coast

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

Method category and type	Description	Result success/failure	Problems realized 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 trialed	• 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 trialed	• 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 trialed	• 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 trialed	• 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	• Trialed 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 trialed	• 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
Behavioral				
Operant conditioning	Behavioral modification using signal cues.	Not trialed	• 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 trialed	• 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 trialed	• 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 trialed	• Illegal and unethical.	4

Information source
1 Moreno *et al.* 2008
2 Zollett and Read 2006*
3 Hamer 2009*b*
4 Dahlheim 1988
5 AFMA 2005

Information source (continued)
6 Mooney *et al.* 2009
7 McPherson *et al.* 2008
8 Gilman *et al.* 2006
9 Tixier *et al.* 2009

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.

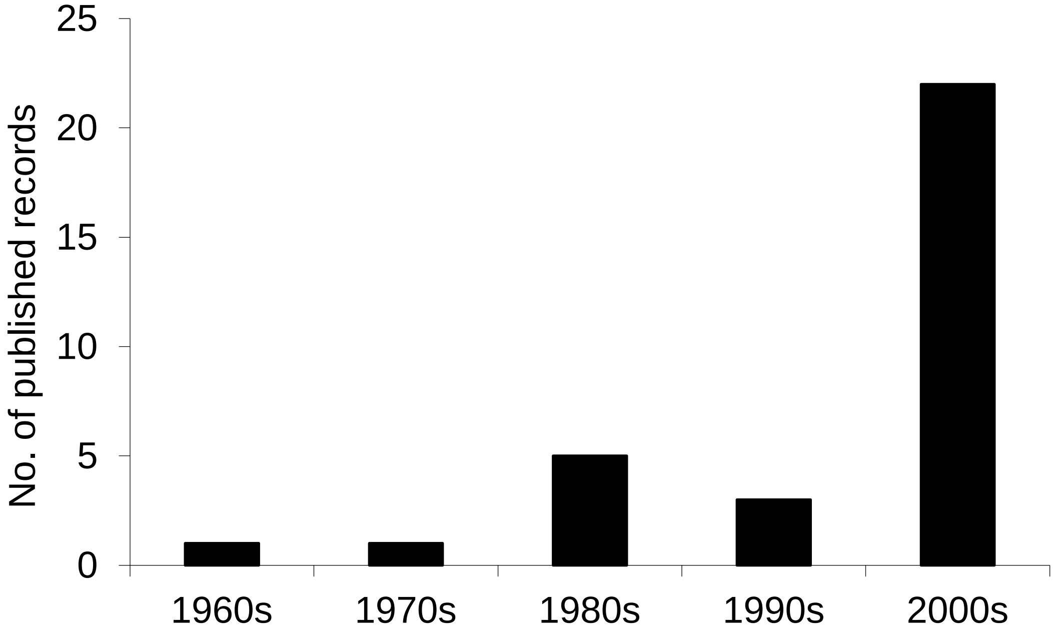

Figure 1 Decadal summary of the number of reviewed reports of operational interactions between odontocetes and longline gear over the last 50 years (the 2000s includes one study published in early 2010).

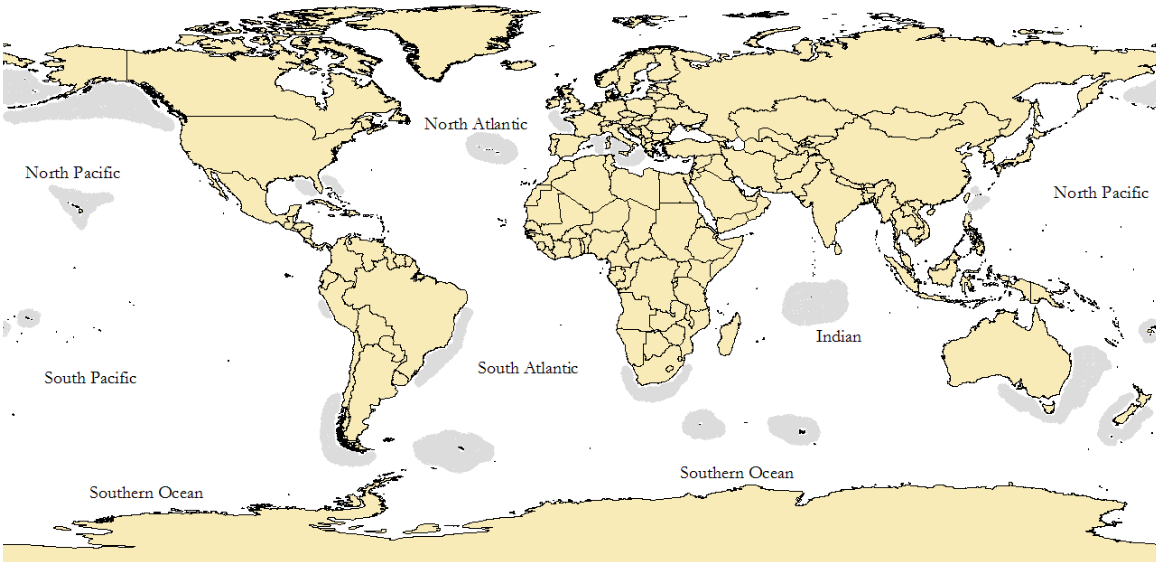

Figure 2 Geographic distribution of operational interactions (inferred and quantified) between odontocetes and longline gear (grey areas) in accessible reports.

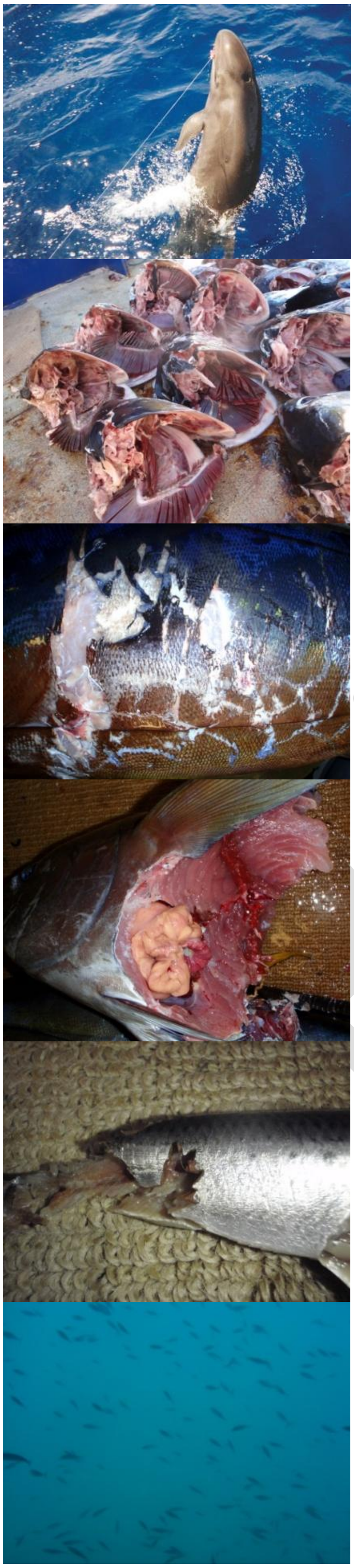

Figure 3 (a) False killer whale caught on a pelagic longline hook in Hawaiian waters (Source: National Marine Fisheries Service), (b) albacore depredated by odontocetes, with the torso completely removed from behind the gill plates, (c) odontocete tooth lacerations on torso of depredated albacore, (d) for comparison, damage caused by depredating shark, showing much cleaner removal of torso, (e) small bight marks on a sardine (*Sardinops sagax*) used for bait, probably caused by small depredating fish, (f) large numbers of small fish in the vicinity of longline fishing gear that may be involved in bait depredation.

Figure 4 Schematic diagram of the *Tuna Guard - Streamer Pod* and of the *Whale Shield – Jellyfish* (a,c: not triggered; b,d: triggered) currently under development by the Australian Government and soon to be trialed in the Tropical South Pacific Ocean. Before the devices are triggered by the pressure of a caught fish, they remain clear of the baited hook and close to the mainline. Upon being triggered, the devices release the streamers or cage and then descend the snood toward the caught fish, eventually enveloping it.