A review of cetacean interactions with longline gear

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ABSTRACT

Fishery-cetacean interactions, including those with longline gear, give rise to economic, ecological and social concerns. This paper reviews problems resulting from cetacean-longline interactions, considers potential strategies to reduce interactions and identifies research priorities and approaches. Depredation by cetaceans (removal and damage of hooked fish and bait from fishing gear) and damage and loss of fishing gear create economic problems; however, the magnitude of this problem is poorly understood. There is also insufficient information to determine whether there are population-level effects resulting from injury and mortality of cetaceans (from incidental entanglement and hooking and from deliberate actions to discourage depredation). Fishery-cetacean interactions may also: change cetacean foraging behaviour and distribution; increase fishing effort to make up for fish taken from gear by cetaceans; and create errors in fish stock assessments that do not account for cetacean depredation. Negative public perceptions of longline fishing can result from news of incidental and deliberate injury and mortality of cetaceans associated with longlining. Information on how to reduce cetacean interactions with longline gear is also limited, as is the understanding of the mechanisms responsible for them. Strategies already employed in some fleets include refraining from setting or cutting sets short when problematic species of cetaceans are observed and fleet coordination of daily fishing times and positions. Many fishermen perceive depredation as an inevitable part of fishing. This paper discusses a number of other possible cetacean avoidance strategies that warrant consideration, including: (1) fleet communication to enable vessels to avoid temporally and spatially unpredictable and sporadic hotspots of aggregations of cetaceans; (2) underwater acoustic masking devices to conceal the sound of the vessel, gear, and setting and hauling activities; (3) quieter vessels to reduce cetaceans' ability to target longline vessels; (4) encasement of caught fish to reduce cetacean access to or interest in the catch; (5) use of bait or gear with an unpleasant smell or taste to reduce the attractiveness of gear, bait and catch to cetaceans; (6) use of pre-recorded fishing vessel sounds played from stations throughout a fleet's fishing grounds to distract cetaceans from actual fishing vessels; (7) use of acoustic devices to mask returning cetacean echolocation signals; and (8) use of tethered sonobuoys to track cetaceans and enable fleet avoidance. Vessels with relatively low cetacean interaction rates should be examined for design and operational differences from vessels with high interaction rates, possibly allowing identification of effective avoidance methods. There is a need for experimentation in individual longline fisheries over several seasons to assess fishery-specific efficacy and commercial viability of cetacean avoidance strategies. This is necessary as different cetacean species likely respond differently to an avoidance method and cetaceans may habituate to an avoidance strategy, especially in fisheries interacting with resident cetaceans.

KEYWORDS: DEPREDATION; FISHERIES; INCIDENTAL CATCHES; ACOUSTICS; ECHOLOCATION; FEEDING

INTRODUCTION

Bycatch in marine fisheries is an increasingly prominent international ecological, social and economic issue (e.g. Alverson *et al.*, 1994; IUCN, 1996; Hall *et al.*, 2000; FAO, 1999a; FAO, 1999b; FAO, 2004; Gilman *et al.*, 2005). It has been recognised by many international organisations including the UN General Assembly, the United Nations Food and Agriculture Organisation (FAO), the World Conservation Union (IUCN), the International Whaling Commission (IWC), the Agreement on the Conservation of Small Cetaceans in the Baltic and North Seas Resolution on Incidental Take of Small Cetaceans (ASCOBANS) and the Agreement on the Conservation of Cetaceans of the Black Sea, Mediterranean Sea and contiguous Atlantic Area (ACCOBAMS).

Bycatch can harm ecosystems and the economic viability of commercial fisheries. In particular, some species of marine mammals, seabirds, sea turtles, sharks and other fish may be particularly vulnerable to increased mortality above natural levels because of their life history traits (e.g. Gilman and Freifeld, 2003) and this can lead to unsustainable levels of removal, affecting biodiversity. It also alters foraging habits of species that learn to utilise discarded bycatch (Hall *et al.*, 2000). In an attempt to reduce the amount of fisheries bycatch, some governments have introduced a range of restrictions with economic implications, such as closed areas, embargos and closures. Bycatch in one fishery can lead to a reduction in the target catch in another and bycatch of juvenile and undersized individuals of a commercial species can adversely affect future catch levels (Hall *et al.*, 2000). Bycatch is also a social issue, the disposal of millions of tons of fish is a waste of a valuable food source as well as a waste of animal lives; FAO (1999c) estimated that 1998 global marine fisheries fish discards totalled 20 million metric tons.

Interactions between marine mammals and fishing involve almost all existing fishing gear and typically result in negative economic, ecological and social consequences (e.g. Northridge, 1984; Perrin *et al.*, 1994; Northridge and Hofman, 1999; Reeves *et al.*, 1996; Reeves *et al.*, 2001; Read, 2002; Donoghue *et al.*, 2002; Australian Fisheries Management Authority, 2005). In addition to the primary interaction of bycatch, cetaceans may remove hooked fish and bait from fishing gear (referred to as depredation), fish confined in mariculture enclosures, and fish aggregated at natural and artificial constraints in river systems, such as below falls or fish ladders (Reeves *et al.*, 1996; Donoghue *et al.*, 2002). Other prominent issues resulting from marine mammal-fisheries interactions include the deliberate injury and mortality of marine mammals by fishermen and damage to and loss of fishing gear. This paper focuses on the problems of interactions between cetaceans and longline gear (Fig. 1) and potential strategies to abate them.

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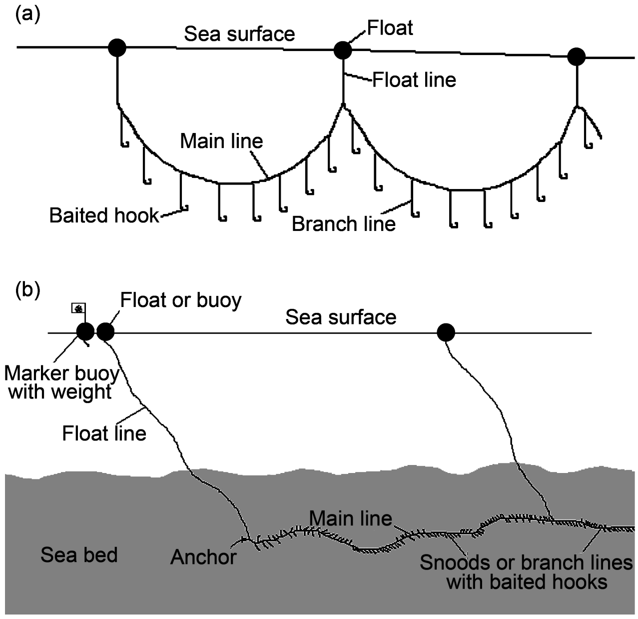

Fig. 1. Configuration of (a) pelagic and (b) demersal longline gear. Lengths and materials of float, main and branch lines; number of hooks between floats; amount and placement of weights on branch lines; depth of gear; types of hooks and bait; and methods of setting and hauling vary between fisheries and between vessels in a fishery. Longlining occurs throughout the world's oceans, has been used since the nineteenth century and ranges from small-scale domestic artisanal fisheries with small sometimes open vessels to modern mechanised industrialised fleets from distant-water fishing nations with large vessels. Pelagic longlines, where gear is suspended from line drifting at the sea-surface, mainly targets large tunas (*Thunnus* spp), swordfish (*Xiphus gladius*), other billfishes (*Istiorphoridae* spp) and dolphin fish (mahimahi) (*Coryphaena* spp), can be up to 100km long and carry up to 3,500 baited hooks. Demersal longlines, where gear is set on the seabed to target demersal species living at or near the seabed, such as Atlantic cod (*Gadus morhua*) and Pacific halibut (*Hippoglossus stenolepis*), might set up to 40,000 baited hooks per day.

Fig. 2. False killer whale hooked on a Hawaii pelagic longline hook. The linear mark on the side of the whale might be an abrasion from contact with a main or branch line (photo by US NOAA Fisheries Pacific Islands Regional Office).

PROBLEM IDENTIFICATION

Cetacean-longline interactions have been observed from as early as 1952 in the Japanese longline tuna fleet (Nishida and Shiba, 2002). Most cetacean-longline interactions are thought to be the result of odontocetes being attracted to the fishing gear or boat because of opportunities to remove bait or caught fish; this may occasionally (e.g. Northridge, 1984; Ashford *et al.*, 1996; Dawson *et al.*, 1998; Waring *et al.*, 1999; Baird *et al.*, 2002; Forney, 2004; Baird and Gorgone, 2005) also result in entanglement or hooking, injury and mortality of the cetaceans (Fig. 2). Odontocetes are thought to develop familiarity with the sounds of longline boats (including the engine, gear haulers, depth sounders and radio buoys) and target the catch and bait after homing in on the vessel or its gear. There is anecdotal evidence that some resident cetaceans can home-in on specific vessels, even singling out one vessel to target when several are fishing in the same area (e.g. Australian Fisheries Management Authority, 2005). Other observed cetacean behaviour includes following longline boats to gear that has been set soaking and waiting by buoys for the vessel to arrive and haul (Ashford *et al.*, 1996; Australian Fisheries Management Authority, 2005). The incidental entanglement and hooking of baleen whales has also occasionally been reported in longline gear (e.g. Bowman *et al.*, 1999; Forney, 2004), probably as a result of their swimming paths accidentally crossing gear.

Depredation

Depredation is usually identified when hauls reveal fish damaged in a particular way (e.g. Lauriano *et al.*, 2004). Fish damaged by cetaceans is usually distinguishable from shark-damaged fish with the latter typically being bitten in half with clean bites or multiple smaller bites. Some cetacean species (e.g. killer whales, *Orcinus orca*) often leave only the fish head up to the gills, or just the lips and upper jaw of the fish (Fig. 3) (Secchi and Vaske, 1998; Australian Fisheries Management Authority, 2005). Killer whales have also been observed to avoid the head and vertebral column and fins, preferentially eating only the flesh of hooked tuna and swordfish (Secchi and Vaske, 1998). Other species of odontocetes such as sperm whales (*Physeter macrocephalus*) are believed to pluck entire hooked fish, including the hook, off the line (Ashford *et al.*, 1996). Cetacean depredation on longline gear is believed to most frequently occur during gear hauling (e.g. Wang and Yang, 2002) but can also occur during the setting and soak of the line. This may be because depredation during hauling is easier and less costly energetically than diving deep to reach the hooked fish during the soak and set. In some areas, certain odontocetes have been observed to be less likely to depredate tuna entangled in fishing gear than tuna caught on a hook and not entangled (McPherson, 2003) although the reasons for this are not clear.

Killer whales have often been reported as interacting with longline fisheries taking a variety of fish species from gear (Northridge, 1984; Yano and Dahlheim, 1995; Ashford *et al.*, 1996; Secchi and Vaske, 1998; Donoghue *et al.*, 2002; Australian Fisheries Management Authority, 2005). In the tropical Pacific, there have been numerous observations of fishery interactions with false killer whales (*Pseudorca crassidens*), pilot whales (*Globicephala* spp.) and killer

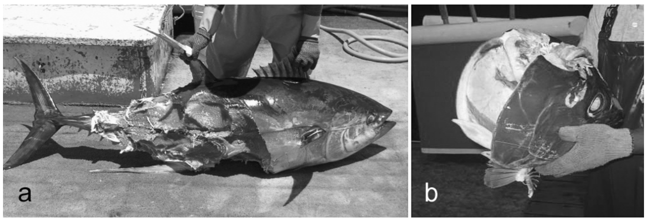

Fig. 3. Shark-depredated yellow fin tuna (left) and false killer whale-depredated tuna (right) from the Hawaii-based longline fishery (photos courtesy of US National Marine Fisheries Service Pacific Islands Regional Office).

whales and at least eight species of dolphins have been observed in the vicinity of longlines in the tropical Pacific, some of which may remove bait. Sperm whales have also been observed to take Patagonian toothfish (*Dissostichus eleginoides*) in the Southern Ocean and sablefish (*Anoplopoma fimbria*) and other fish species in the eastern Gulf of Alaska (Ashford *et al.*, 1996; Donoghue *et al.*, 2002).

Economic and social

Removal of or damage to fish clearly has economic implications for fishermen. Cetacean depredation in longline fisheries occurs worldwide; available estimates of depredation levels while extremely crude, suggest that it may result in substantial adverse economic effects in some fisheries (e.g. Nishida and Shiba, 2002; Donoghue *et al.*, 2002).

The few available estimates of cetacean depredation in longline fisheries employ a range of methods and quality of datasets to examine depredation levels, thus preventing appropriate comparisons between fisheries. Here, we present some of these estimates for information but do not attempt to review them. Sigler *et al.* (2002) estimated an annual 23% reduction in catch of sablefish in the Alaska demersal longline sablefish fishery due to depredation by sperm whales. Dalla Rosa and Secchi (2002) estimated between 5.6-100% (mean 45%) of total fish caught per set were damaged by killer whales in Brazil's pelagic longline tuna and swordfish fisheries. Nishida and Shiba (2002) estimated that between 1-19% of caught fish were depredated annually in Japanese longline fisheries operating in the Indian Ocean. Lawson (2002) estimated that 0.8% of caught fish in observed central and western Pacific longline fisheries are believed to be damaged by whale depredation. Depredation levels by killer whales have been reported to reach 100% in some hauls in the South Georgia demersal longline Patagonian toothfish fishery (Purves *et al.*, 2004).

Furthermore, cetacean-longline interactions often result in loss of or damage to fishing gear (Ashford *et al.*, 1996; Donoghue *et al.*, 2002) with resultant lost fishing time and increased vessel operating costs. This is a result of crew having to take the time to repair gear damaged and lost by cetaceans, time to move from areas with cetaceans and cost of complying with formal constraints such as area and seasonal closures.

A negative public perception of longline fishing has resulted in some cases, in response to the news of injury and mortality of marine mammals in longline gear. This may translate into poorer sales for such fisheries. The increase in eco-labelling efforts, such as these of the Marine Stewardship Council, have the potential to influence seafood consumer practices and to reduce demand and value of seafood caught in fisheries with relatively high rates of interaction with cetaceans (Wessells *et al.*, 1999).

Ecological

Potential effects on the status of cetaceans

While bycatch of cetaceans is a much larger problem in fishing gear such as gillnets and trawls (Perrin *et al.*, 1994), cetacean-longline interactions occasionally result in their entanglement and hooking, causing injury and sometimes mortality (e.g. Northridge, 1984; Ashford *et al.*, 1996; Waring *et al.*, 1999; Baird *et al.*, 2002; Forney, 2004; Baird and Gorgone, 2005). For instance, Forney (2004) estimates that from 1994-2002, the Hawaiian pelagic longline fleet resulted in the mortality and serious injury of about 48 whales and dolphins per year, which equates to one in every 250 sets.

In addition, in some areas the actual or perceived economic costs sustained by fishermen may incite them to harass and kill cetaceans by shooting them, using explosives or employing other harmful methods to try to prevent depredation and gear damage (e.g. Yano and Dahlheim, 1995; Hucke-Gaete *et al.*, 2002; Dalla Rosa and Secchi, 2002; Wang and Yang, 2002). It is possible that such mortality and injury may have important population-level consequences in terms of numbers and/or distribution, especially for small isolated populations of cetaceans, e.g. those associated with islands. For example, there is concern over the ecological effects of longline interactions with false killer whales around the Hawaiian Islands and Palmyra Atoll, which interact with several international pelagic longline fisheries including the Hawaii based fleet (Carretta *et al.*, 2005).

As also discussed below, the use of deterrent devices has the potential to alter the distribution of cetaceans by causing them to avoid their preferred feeding grounds; this may result in less than optimal feeding with the possibility of affecting the 'fitness' of the population (e.g. by lowering successful reproduction or increasing susceptibility to disease).

Altered cetacean foraging strategies

There are a number of possible ecological effects of the adapted foraging behaviour on cetaceans but their precise nature and level of effects are unclear. For example, in some cases cetaceans may feed on species of fish taken from longline gear that are not a normal component of their diet; this may result in their consuming a smaller number of their usual prey species. Depredation may also lead to a change in distribution if the longline fishing grounds are not in their usual feeding grounds.

Unexpected effects from avoidance strategies

Use of acoustic deterrents and acoustic masking devices to deter cetacean interactions with fishing gear will result in the addition of noise to the marine environment; it is not clear what ecological effects this could have on cetaceans and other species. For instance, clupeoid fishes, including herring (*Clupea harengus*), can hear the frequencies emitted by currently used 'pingers' (Nestler *et al.*, 1992, cited in Dawson *et al.*, 1998). Kraus *et al.* (1997) found that active pingers placed on gillnets to reduce porpoise bycatch resulted in a 6.5× lower catch of Atlantic herring. One possible explanation for this is that the herring moved away from the vicinity of the pingers (Dawson *et al.*, 1998). Despite recent advances, our knowledge of the short- and long-term responses of cetaceans to artificial sounds in the marine environment is limited (Reeves *et al.*, 1996). However, possible responses may range from hearing damage and ultimately strandings, (e.g. from close range exposure to intense noises such as Acoustic Harassment

Devices designed to scare pinnipeds away from mariculture facilities (Morton and Symonds, 2002) and military sonar (e.g. IWC, In press)) to temporary (e.g. Australian Fisheries Management Authority, 2005) or even perhaps long-term abandonment of some feeding grounds.

Ecological effects of depredation

The loss of fish due to depredation by cetaceans is generally not taken account of in fish stock assessments and the provision of management advice (e.g. total allowable catches). The degree to which this is important will clearly vary on a case-by-case basis, depending *inter alia* on whether the prey taken from the longlines are the same species, age/size and quantity that the cetacean would normally feed on. Similarly, any increased effort by fishermen to account for lost catches due to cetaceans may potentially confound fish assessments and place increased pressure on target fish species; it may also result in increased bycatches of other species such as seabirds, turtles and fish.

STRATEGIES TO REDUCE CETACEAN INTERACTIONS

There are a range of strategies that can or at least have the potential to reduce cetacean interactions with longline gear. Below we review a number of categories of approaches.

Fleet communication and coordination

The distribution of cetaceans (and other incidentally caught species groups such as seabirds and sea turtles), is often unpredictable and may be spatially contagious or aggregated. Consequently, fleet communication systems may be employed by the fishing industry to report near real-time observations of hotspots to enable a fishery to operate as a coordinated 'One Fleet' in order to reduce fleet-wide depredation by and bycatch of cetaceans (Gilman *et al.*, 2006). Gilman *et al.* (2006) describe case studies of industry fleet communication programmes of the US North Atlantic longline swordfish fishery, US North Pacific and Alaska trawl fisheries and US Alaska demersal longline fisheries, designed to reduce bycatch of seabirds, sea turtles and fish. Evidence suggests that these programmes substantially reduced fisheries bycatch and provided economic benefits that greatly outweighed operational costs. Fleet communication may be appropriate in fisheries where there are strong economic incentives to reduce depredation and bycatch and where such efforts can be monitored adequately via onboard observer coverage. Such an approach will be facilitated where vessels are coordinated by a fishery association. It is possible that fleet coordination of daily fishing positions and times (already a current practice in many fleets) may minimise per vessel depredation levels relative to vessels that fish in isolation, providing fishermen with an economic incentive to follow such a strategy.

Changes in fishing gear and methods

General approaches to altering fishing gear and fishing methods to reduce cetacean interactions fall into the following five categories. These are adapted from Gilman *et al.* (2005) who describe strategies to reduce seabird bycatch in longline fisheries. Methods need to be assessed for their efficacy in reducing cetacean bycatch and depredation, as well as their commercial viability (Gilman *et al.*, 2005); carrying out the appropriate testing is not simple and the question of habituation can not be ignored (IWC, 2000, pp.235-43; IWC, 2001).

Avoid areas and periods with peak cetacean abundance

At the simplest level, individual fishing vessels can avoid setting (or cut a set short) when problematic species of cetaceans are observed in the vicinity. It would be valuable for fishermen to learn to differentiate cetacean species in order to determine an appropriate response. Alternatively, when cetaceans are observed during a set, vessels could break a set and re-commence parallel and adjacent to the previously set line to attempt to lose cetaceans that might follow the first line to the end and not find the second line. In addition to visual detections, it is also possible to use sonobuoys and hydrophones to detect the presence and movement of some cetaceans (McPherson *et al.*, 2002) and in some cases identify the presence, species and even location and identification of specific pods of cetaceans. In theory this information can be used to avoid fishing in areas where depredation will probably be high (Donoghue *et al.*, 2002). Although suggested by some as a possible approach, telemetry is expensive, not sufficiently reliable and may give rise to objections with respect to attachment methods (Donoghue *et al.*, 2002). Better knowledge of the behaviour of cetaceans around gear may suggest other appropriate avoidance strategies. For example, if cetacean interactions are more common during daytime hours, then night hauling may be effective. Area and seasonal closures can also be used to help avoid known areas and periods of high concentrations of cetaceans, where these are predictable and this is discussed further in a following section.

Reduce cetacean detection of fishing gear and vessels

Vessels with lower cetacean bycatch and depredation rates than the rest of the fleet should be examined for their specific design and operational characteristics; this may suggest relatively simple solutions to reduce cetacean-longline interactions. For example, vessels that are observed to seldom experience depredation may have different acoustic signatures due to different hull shapes, materials (timber, fibreglass or steel) and electronic equipment.

If it is the sound of the vessel/operation that attracts the cetaceans, then underwater acoustic masking devices, quieter fishing vessels and/or equipment that disrupts cetacean echolocation may reduce cetacean detection of fishing gear. Creating a muffler for the hauler or isolating the hauler, transmission and gear hydraulics from the vessel hull with vibration isolating mounts may reduce vessel noise and reduce cetacean detection of fishing operations (Donoghue *et al.*, 2002; Australian Fisheries Management Authority, 2005). The introduction of a new relatively quieter vessel engine, with rubber mounts and Teflon coupling for sound insulation, to an Australian demersal longline vessel initially resulted in lower cetacean depredation compared to noisier vessels in the fleet. However, over time this vessel has come to experience the same depredation rates as the rest of the fleet, indicating that the resident killer whales learned to identify this new quieter vessel (Australian Fisheries Management Authority, 2005). Although it has been suggested that acoustic devices that masks returning echolocation signals may be an effective strategy to reduce cetacean-longline interactions, even if true, many design aspects remain unresolved (McPherson, 2003). McPherson (2003) suggested that an effective acoustic device for toothed whales will need to be: (a) impulsive (activated when toothed whale sounds are detected, versus continuously emitting sound) and broadband rather than tonal; (b) ultrasonic 20-100kHz; (c) loud enough to be aversive but not too loud that it causes permanent damage to cetaceans; and (d) varied sufficiently to avoid habituation. Development of such a prototype acoustic deterrent device was initiated for testing in the Australian longline fisheries, but development was discontinued due to concerns over cost effectiveness (McPherson *et al.*, 2002; McPherson, 2003).

Refraining from chumming during the set and not discarding offal and spent bait during the haul may also reduce cetacean detection of fishing vessels. Use of ‘decoy’ tactics (e.g. setting lines in a sinusoidal or wavy pattern rather than in a straight line and setting parts of the line without hooks) has also been suggested as a possible way to reduce cetacean interactions with longline gear (Donoghue *et al.*, 2002; Australian Fisheries Management Authority, 2005). Similarly, playing pre-recorded longline fishing vessel sounds from stations throughout a fleet’s fishing grounds may serve as a decoy to distract cetaceans from actual fishing vessels. Using a decoy fishing vessel to distract cetaceans away from fishing grounds with other fishing vessels has also been suggested as being effective, although even if it works, it might not be necessarily cost effective and the animals might quickly adapt to the strategy. There have been reports of vessels motoring over a competing vessel’s gear in an attempt to leave following whales behind (Straley *et al.*, 2002).

Limit cetacean access to catch and bait

It has been suggested that setting fishing gear at depths greater than 400m may reduce cetacean interactions, for those species where the maximum normal dive depths might be less than this (Donoghue *et al.*, 2002). However, this tactic would be commercially viable only in those fisheries targeting fish foraging predominantly at these depths. Even then, because cetaceans are known to wait for hauling in order to take fish at shallow depths, it is likely to be ineffective.

Some odontocete species have been observed to be less likely to depredate tuna entangled in fishing gear compared to tuna caught on a hook and not entangled (McPherson, 2003). This suggests that the development of gear that entangles or encapsulates caught fish could reduce depredation. It is unclear what mechanism causes this reduction in depredation but it is thought that it is either due to (1) a reduction in access to the fish or (2) a reduction in the desirability of the fish by making them appear dead. It should be remembered that while such an approach may decrease depredation it may result in entanglement of cetaceans.

Reduce the likelihood of hooking and entangling cetaceans

If lack of perception of the gear is the reason for the injury or death of cetaceans in longlines, making longlines more detectable by cetaceans could potentially reduce damage to them. Technology developed to reduce cetacean bycatch in other fisheries might be effectively modified for use with longline gear. However, making longline gear more detectable may also increase the incidence of depredation by odontocetes by drawing attention to the gear.

Some acoustic devices (small, low-intensity sound-generators called ‘pingers’), intended to provide a warning to alert cetaceans of the presence of fishing gear, have been demonstrated to significantly reduce entanglement bycatch of harbour porpoises (*Phocoena phocoena*) and short-beaked common dolphins (*Delphinus delphis*) in gillnets (e.g. Reeves *et al.*, 1996; Kraus *et al.*, 1997; Dawson *et al.*, 1998; Baldwin *et al.*, 2002; Barlow and Cameron, 2003; McPherson, 2003). The question as to whether porpoises habituate to the acoustic alarms over time (Dawson *et al.*, 1998; Gearin *et al.*, 2000; Cox *et al.*, 2001) requires further investigation. However, even if the animals do become accustomed to the pingers, the noise may still enable the animals to identify the presence of the fishing gear and avoid becoming entangled in it (McPherson, 2003). Methods to improve the detectability of gillnets to echolocating odontocetes have been tried to reduce bycatch (Read, 2002) e.g. by adding dense material such as barium sulphate to the nylon used to manufacture monofilament to increase reflectivity. The same technology could theoretically be applied to longline gear monofilament. Increasing the acoustical reflectivity of fishing gear will only reduce odontocete bycatch if these animals echolocate in the vicinity of the fishing gear and entanglement is occurring because the animals are not detecting the fishing gear in time to avoid it (Read, 2002). Acoustic warning devices and acoustically reflective fishing gear have not been tested in longline fisheries for any cetacean species.

Deter cetaceans from taking catch and bait

As noted above, in certain situations, pingers have been shown to reduce bycatch of some small cetacean species. Louder acoustic deterrents (e.g. Acoustic Harassment Devices used to scare and cause pain to primarily pinnipeds to prevent them coming close to aquaculture cages), are large, expensive in part due to battery maintenance, and may permanently damage cetaceans’ hearing. Acoustic deterrents may be impractical and cost prohibitive for use in longline gear, because a large number of units would be required to cover the entire length of gear. A towed device that broadcasts noise designed to mask the sounds of fishing vessels and imitate killer whale vocalizations when hunting has been suggested as a possible solution (Bakharev, No date), although cetacean habituation to this strategy is probable.

The use of bait or gear with an unpleasant smell or taste could help reduce the attractiveness of gear, bait and catch to cetaceans and could result in cetaceans developing a learned aversion to depredation behaviour. However, in addition to the need to test the effectiveness of this approach for cetaceans, it must also be assessed for any adverse effects on fish catches. There are several records of fishermen using devices , such as rifles, harpoons, and explosives, to intentionally injure or kill cetaceans (e.g. Yano and Dahlheim, 1995; Dalla Rosa and Secchi, 2002; Hucke-Gaete *et al.*, 2002; Wang and Yang, 2002). This raises ecological, ethical, social and legal concerns.

Formal constraints

National-level legal, regulatory and policy-derived formal constraints, combined with an effective surveillance and enforcement programme, can promote fishing industry compliance with laws, rules and policies to minimise cetacean bycatch. Seasonal or area closures and mandatory use of avoidance techniques, are examples of regulatory tools that might be used to manage cetacean bycatch (Hall *et al.*, 2000; Gilman *et al.*, 2005). Fishery management authorities could create a compensatory mitigation fee and exemption structure for cetacean bycatch, applicable to individual vessels or to an entire fleet, similar to a ‘polluter pays’ system (Gilman *et al.*, 2002). Alternatively, the fee structure could provide a positive reward-based incentive, where a higher subsidy, lower permit or license fee, earlier start to the fishing season, or lower taxes apply and a positive image is portrayed when a vessel or fleet meets standards for cetacean bycatch. This, combined with the threat of a fishery closure if performance standards are not met would provide a strong incentive for industry compliance to minimise cetacean interactions.

For example, the US Marine Mammal Protection Act (MMPA) is the primary legislation for the management of marine mammals in the USA. A maximum allowable level of anthropogenic mortality is determined for each stock of marine mammal, referred to as the Potential Biological Removal (Wade, 1998). If anthropogenic mortality levels from bycatch and other human sources of mortality exceed this level, then a take reduction plan is prepared, identifying measures to reduce mortality and serious injury from anthropogenic sources to below the threshold level.

Regional and international accords, regulations and policies

Multilateral treaties and accords that address cetacean interactions can obligate national governments to adopt enabling legislation to manage such interactions. Regional Fishery Management Organisations can adopt regulations and policies to manage interactions between fisheries and sensitive species to be implemented by member nations. Multilateral bodies can adopt advisory policies to encourage fishing nations to sustainably manage icetacean-longline interactions. However, determining what are sustainable levels requires good information on stock structure, anthropogenic removals and abundance; information that is often lacking.

Marine protected areas, area and seasonal closures

Area and seasonal closures are management tools that can complement employment of other strategies to reduce cetacean-longline interactions (e.g. Reeves *et al.*, 1996; Murray *et al.*, 2000; Read, 2002; Donoghue *et al.*, 2002). Closed areas can have substantial adverse economic effects, but remain a tool available to fishery managers in the absence of alternative effective methods. It may also be a more desirable option than a closed fishery.

Marine protected areas (MPAs) can be effective at reducing cetacean-fisheries interactions provided that the locations and times of occurrence of cetacean hotspots are known and predictable (Murray *et al.*, 2000). Furthermore, the hotspots must be a small component of the fleet's fishing grounds in order for temporal and area avoidance to be commercially viable.

The consequences of establishing MPAs need to be carefully considered, as resource use restrictions may displace effort to adjacent and potentially more sensitive and valuable areas, where weaker management frameworks may be in place. For instance, time and area closures for the Gulf of Maine gillnet fishery, designed to reduce bycatch of harbour porpoises, were ineffective due to displacement of fishing effort to areas with high harbour porpoise bycatch, as well as unpredicted inter-annual variability in timing and distribution of porpoise bycatch hotspots (Murray *et al.*, 2000). Closures implemented in the Northwest Atlantic for the US pelagic longline swordfish fleet to address sea turtle bycatch displaced longline effort to alternative grounds such as the South Atlantic, where bycatch rates of other sea turtle populations may have been problematic (Kotas *et al.*, 2004). One of the consequences of displacing longline fishing effort from an area closed off Newfoundland, due to concerns with bycatch of sea turtles, was an increase in the catch of 11 shark species and 10 depleted fish species (Baum *et al.*, 2003).

Similarly, closing of a fishery by one nation may also result in an increased effort by another nation's fleet with fewer controls to manage bycatch. For example, during a two-year closure of the Hawaii longline swordfish fishery due to concerns over bycatch of sea turtles, swordfish supply traditionally met by the Hawaii fleet to the US marketplace was replaced by imports from foreign longline fleets, including those from Mexico, Panama, Costa Rica and South Africa, which have substantially higher ratios of sea turtle captures to unit weight of swordfish catch than Hawaii and less stringent or no measures to manage seabird bycatch (Gilman and Freifeld, 2003; Bartram and Kaneko, 2004; Sarmiento, 2004).

Establishing MPAs within a nation's Exclusive Economic Zone to protect high-density areas for resident or migratory cetaceans is potentially an expedient method to reduce cetacean-longline interactions. However, establishing high seas MPAs to restrict fishing in cetacean foraging areas and migration routes, which would require extensive and dynamic boundaries and extensive buffers, may not be a viable short-term solution. This is due in part to the extensive time anticipated to resolve legal complications with international treaties, to achieve international consensus and political will and to acquire the requisite extensive resources for surveillance and enforcement to implement high-seas marine protected areas (Thiel and Gilman, 2001).

Some international bodies have succeeded in creating MPAs on the high seas. For example, the International Whaling Commission (IWC) has declared the Indian and large parts of the Southern Ocean as 'Sanctuaries' within which commercial whaling cannot occur; this covers around 30% of the world's oceans, mostly on the high seas. Conventions governing international shipping have designated large areas of the ocean that include high seas as Special Areas where stringent restrictions apply regarding discharges from ships. Furthermore, under the United Nations Convention on the Law of the Sea, the International Seabed Authority could protect areas from mineral extractions beyond national jurisdiction, where there is a risk of harm to the marine environment (Kelleher, 1999). Recent developments within the framework of the United Nations Convention on the Law of the Sea and associated conventions may make it possible to restrict future fisheries activities on the high seas that are shown to undermine marine conservation (Kelleher, 1999).

Improved practices for handling and release of cetaceans

Reducing injury and incidence of post-release mortality for cetaceans caught in longline gear may contribute to reducing the adverse ecological affects of cetacean-longline interactions, provided it is on a sufficient scale. For instance, there are prescribed best practices for disentangling whales caught in fishing gear (Lyman *et al.*, 1999) and formal networks to respond to entangled marine mammals (Bowman *et al.*, 1999).

Eco-labelling

Consumer demand can alter industry behaviour. A longline fishing industry can pursue certification or accreditation from an eco-labelling certification programme, in part, to demonstrate the employment of best practices to reduce cetacean interactions, assuming such best practices exist. The incentives to industry are a market-based incentive to increase demand for and value of their products and a social incentive to receive recognition from the public for complying with accepted norms (Wessells *et al.*, 1999). Eco-labelling can serve as an effective marketing tool for a fishing industry, when properly managed. For instance, certification under an eco-labelling scheme can be used as a marketing tool to develop and market an image and product differentiation, through advertising, sales promotion, public relations, direct marketing and media coverage. A company can differentiate their products from other seafood as originating from a fishery that follows internationally accepted practices to ensure environmental sustainability. This is a form of cause-related marketing and is a proven means to promote recognition and develop a positive company image and reputation.

For example, the Marine Stewardship Council is an international organisation that has a certification programme for seafood and uses a product label to distinguish environmentally responsible fishery management and practices. Principles and criteria adopted by the Marine Stewardship Council, used to assess the suitability of fisheries for certification, are intended to ensure that certified fisheries are sustainable and well managed (Marine Stewardship Council, 1998).

Industry self-policing

A longline industry can create a programme that makes information on individual vessel-cetacean interaction levels and compliance with relevant regulations available to the entire industry. This method is especially effective where regulations contain industry-wide penalties, such as a reduction in the length of a fishing season, closed areas, or complete fishery closure, should the fleet exceed cetacean bycatch rates. This self-policing programme uses peer pressure within the industry to criticise 'bad actors' and publicly acknowledge those who are operating in a responsible manner. For example, the North Pacific Longline Association initiated a seabird bycatch report card system among its members in 2000 (Fitzgerald *et al.*, 2004).

CONCLUSIONS AND NEXT STEPS

There is limited understanding of the mechanisms responsible for cetacean-longline interactions and the extent of ecological and economic repercussions from these interactions. Fishery-specific assessments are needed to determine reliable depredation levels and rates of cetacean injury and mortality. There is a need for reliable assessments of cetacean-longline interactions, derived from independent observer programmes where possible, which will benefit from training of observers and fishermen to correctly identify cetacean species and identify fish damaged by cetaceans versus other animals (e.g. sharks, squid, bony fish). A better understanding of the degree to which cetacean depredation is occurring during the set, soak and haul should help identify effective solutions.

Whilst there are several potential methods to reduce cetacean-longline interactions, there has been little research to test their efficacy and/or economic viability. To pursue these possibilities, we suggest that it is a priority to examine and compare vessels with relatively low cetacean depredation and bycatch rates with vessels with relatively high rates to identify design and operational differences. There may not be an effective way to reduce cetacean interactions with longline gear other than currently practiced strategies, such as avoiding fishing at times and locations when and where interactions are known to be frequent and shifting fishing position. However, several additional ideas to reduce cetacean-longline interactions warrant assessment.

The most appropriate avoidance measures for individual longline fleets may depend, in part, on the characteristics of the fishery, species and behaviour of cetaceans that interact with the fleet and available financial resources. There is a need for experimentation in individual longline fisheries over several seasons to assess fishery-specific efficacy and commercial viability of strategies to reduce cetacean interactions. This is necessary as different cetacean species likely respond differently to alternative avoidance methods (e.g. a single acoustic device is unlikely to be an effective deterrent for multiple cetacean species (McPherson, 2003)) and to address the question of possible cetacean habituation to the avoidance strategy (e.g. Dawson *et al.*, 1998), especially in fisheries that operate in grounds that overlap with resident cetaceans. Such evaluation must precede widespread advocacy for longline fleets to adopt specific avoidance methods.

Longline fishermen are some of the most qualified people to develop and improve methods to reduce cetacean-longline interactions. Longline fishermen have a large repository of knowledge and information related to this problem, which can be tapped into to contribute to finding effective and practical solutions (Gilman *et al.*, 2005). This has been demonstrated by successful collaborative research by the US Alaskan demersal longline fisheries (Melvin *et al.*, 2001), US Hawaii pelagic longliners (Gilman *et al.*, 2003, Gilman *et al.*, In press) and various industry-lead voluntary fleet communication protocols, to reduce fisheries bycatch (Gilman *et al.*, 2005; Gilman *et al.*, 2006). Incentive instruments should be instituted to encourage longline fishers to participate in developing and testing new mitigation methods (Gilman *et al.*, 2002). Fishermen and longline fishery associations are encouraged to become active participants in research and commercial demonstrations, implementing best practices and supporting adoption of regulations based on best available science.

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