A Review of Cetacean Bycatch in Trawl Fisheries

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Literature Review
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Introduction

Incidental capture in fishing activities threatens whales, dolphins, and porpoises worldwide, creating a problem which, if ignored, will cause the extinction of several species and populations in the next few decades (Northridge 1991, Read and Rosenberg 2002). An incidental capture of a marine mammal, also referred to as incidental take or bycatch, occurs when any unwanted, live or dead, marine mammal is caught during fishing operations (Waring et al. 1990, de Haan et al. 1998). Incidental capture of small cetaceans, in particular, presents the greatest threat worldwide to the conservation of cetacean species (House of Commons 2004). The first global bycatch estimate predicts hundreds of thousands of marine mammals are incidentally captured annually (Read et al. 2003). With an increasing global human population and the corresponding need for fish resources, fishing in both coastal and pelagic waters will likely increase, intensifying the interactions between fisheries and marine mammal populations due not only to competition for resources but also to simple spatial overlap (Read 2005).

Bycatch occurs in fisheries ranging from artisanal to industrial in nature throughout the world due to an overlap in distribution and utilization of areas with high prey density by marine mammals and fisheries (Fertl and Leatherwood 1997, Read and Rosenberg 2002). Nearly every fishing gear type, including gillnets, longlines, purse seines, and trawl nets incidentally capture marine mammals throughout the world's oceans (Northridge 1991, Read and Rosenberg 2002). This paper will review bycatch of cetaceans occurring in trawl fisheries.

In a preliminary review of available global bycatch data, Fertl and Leatherwood (1997) indicate that twenty-five species, including twenty-three odonotocete and 2 mysticete species, have been reportedly killed in working trawls or discarded trawl gear. Research on bycaught odontocetes including common dolphins (*Delphinus delphis*) (Waring et al 1990; Couperus 1997; Tregenza and Collet 1998; Morizur et al. 1999; Northridge 2003a,b, Northridge et al. 2003), pilot whales (*Globicephala spp*.) (Waring et al. 1990, Couperus 1997), bottlenose dolphins (*Tursiops spp*.) (Waring et al. 1990, Couperus 1997, Tregenza and Collet 1998, Morizur et al. 1999), Atlantic white-sided dolphins (*Lagenorhynchus acutus*) (Waring et al. 1990, Couperus 1997, Tregenza and Collet 1998, Morizur et al. 1999), harbour porpoise (*Phocoena phocoena*) (Kastelein et al. 1997a,b, de Haan et al. 1998), dusky dolphins (*Lagenorhynchus obscurus*) (Crespo et al. 1997, Dans et al. 1997), white-beaked dolphins (*Lagenorhynchus albirostris*) (Couperus 1997), Commerson's dolphins (*Cephalorhynchus commersonii*) (Crespo et al. 1997), Dall's porpoise (*Phocoenoides dalli*) (Loughlin et al. 1983) and Risso's dolphins (*Grampus griseus*) (Waring et al. 1990); mysticete species including right whales (*Eubalaena glacialis*) (Waring et al. 1990); and pinniped species including grey seals (*Halichoerus grypus*) (Tregenza and Collet 1998, Berrow et al. 1998, Morizur et al. 1999), southern sea lions (*Otaria flavescens*) (Crespo et al. 1997), northern sea lions (*Eumetopias jubatus*) (Loughlin et al. 1983), Hookers sea lions (*Phocarctos hookeri*) (Slooten and Dawson 1995, Gibson and Isakssen 1998), and New Zealand fur seals (*Arctocephalus forsterii*) (Loughlin et al. 1983, Gibson and Isakssen 1998) will be reviewed in this paper.

In the past several decades, the expanded use of trawl nets and the increased rate of marine mammal bycatch may have resulted from improved technology such as the introduction of large freezing and factoring vessels that allow vessels to fish longer and farther from shore (Waring et al. 1990, Crespo et al. 1997). For instance, a distant-water fleet (DWF) from Europe and Japan began fishing off of the east coast of the United States in the early 1960's, harvesting groundfish and pelagic species and utilizing several different off-bottom pelagic trawls. Trawl gear was predominately used by foreign groundfish vessels that once fished in U.S. waters of the North Pacific Ocean and Bering Sea (Bakkala et al. 1979). Since the early 1980's, pelagic trawling has become prevalent in the northeast Atlantic and has displaced other fishing methods (Tregenza and Collet 1998). In a study in north and central Patagonia, trawl gear was used by 80% of all vessels, making it the most common fishing gear type (Crespo et al. 1997). Today, trawl fishing has even become common in African countries. Along the West African coast, large commercial bottom and midwater trawlers come from far away foreign nations including Japan, Korea, Spain, Portugal, Romania, and the Russian Federation (Maigret 1994). Trawl gear is used throughout the western Indian Ocean to catch shrimp by countries including Kenya, Madagascar, Mozambique, South Africa, and Tanzania (Fennessy et al. 2004).

Trawl fishing gear utilizes a funnel-shaped net which is towed through the water by either one or two boats (using two boats is known as pair trawling) to harvest fish, squid, shrimp, and crustaceans (Fertl and Leatherwood 1997, Seagrant 2003) (Figure 1). Water passing over large metal doors attached to the front of the trawl widely opens the mouth of the net, allowing catch to enter; the net slowly tapers in size until the cod end where the catch is collected (Seagrant 2003) (Figure 1). Trawl vessels operate gear differently depending on the fishery, location, and depth (Tregenza and Collet 1998). Trawl fishing gear is generally classified by the type of trawl: surface, bottom, or mid-water (Crespo et al. 1997, Fertl and Leatherwood 1997). Bottom trawls usually operate at 1 to 2 knots while often larger mid-water trawls are pulled at faster speeds to catch fast-swimming, schooling fish (Northridge 1988, Seagrant 2003). Trawl gear can be modified by depth or duration of a set, speed of tow, size of mesh, size of mouth, type of net, and time of operation, either diurnal or nocturnal, in order to target a particular fish species (Crespo et al. 1997). Of particular importance to marine mammal species, the characteristics of trawl gear and location of a set can likely be modified to avoid or reduce cetacean bycatch.

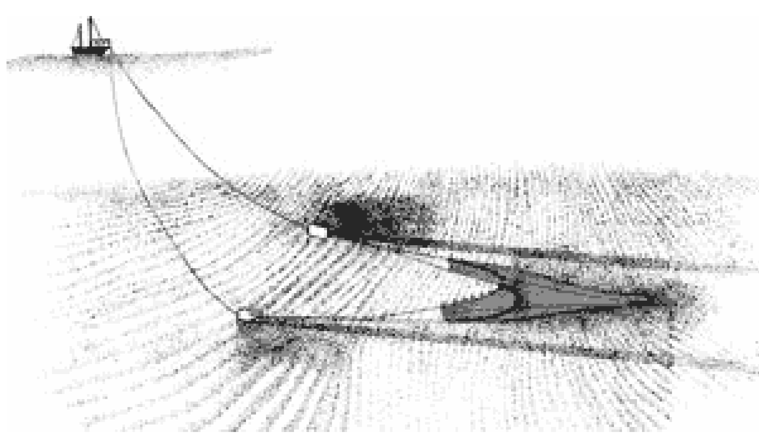

Figure 1. Diagram of a bottom trawl net. A mid-water trawl would be configured similarly, but it would be towed at mid-water depths while a pair trawl net is usually larger and towed by two vessels. (Diagram by Dr. Joe DeAlteris, University of Rhode Island)

Interactions between trawl gear and marine mammals occur throughout the world's oceans, wherever the two overlap in distribution. Estimates of bycatch are usually predicted using data from a sample of the fishery. Morizur et al. (1999) explain that where bycatch is not recorded does not mean that the conflict is not occurring. Fishers often fail to report all incidences of bycatch (Loughlin et al. 1983), and observer coverage differs between fisheries and countries throughout the world. In Portugal, reports of bycatch by fishers decreased when bycatch became illegal even though no action was taken to reduce bycatch (Sequeira and Ferreira 1994). Additionally, many fisheries throughout the world are not observed so it is expected that underreporting of cetacean bycatch occurs. It is also likely that marine mammals fall out of the fishing net or are thrown overboard in some cases and are not included in bycatch estimates. Occasionally, marine mammals wash up on beaches with certain marks or amputations that suggest the animals died as a result of bycatch, but it is often hard to determine which fishery, if any, is responsible (Tregenza and Collet 1998). Some fisheries use a pump to transfer fish catch from the trawl net to the boat (Tregenza and Collet 1998, House of Commons 2004). In these cases, the nets never leave the water, and marine mammals are too large to fit into the pump. The presence of marine mammals in the net may only be detected if part of the animals is amputated, such as the flukes, and brought aboard via the pump.

The interactions between cetaceans and trawl gear can cause injury or death to animals; create negative opinions of, and possibly negative actions to, marine mammals by fishers; and cost fishers time and money to repair and/or replace damaged gear and to disentangle and discard entangled animals. Angry fishers may also take action against marine mammals to protect their gear and catch. For instance, a small number of bottlenose dolphins are caught in shrimp trawls in the Gulf of Mexico, and occasionally, fishers have been known to shoot dolphins to avoid gear damage (Northridge 1991). The presence of trawl gear may also disadvantage marine mammals due to depletion of prey stocks and shifts in available prey in an ecosystem; however, marine mammals may also capitalize on fishing activities by feeding on catch or discards from fishing efforts and thus, reducing their own time spent foraging (Leatherwood 1975, Fertl and Leatherwood 1997, Broadhurst 1998, Pace et al. 2003). By exploiting fisheries, marine mammals may access food usually too deep, fast, or energetically costly to capture themselves (Fertl and Leatherwood 1997).

Characteristics of bycatch

Cetaceans caught in trawl gears may be dying or already dead when picked up by passing trawl nets (Loughlin et al. 1983); however, most evidence suggests that bycaught marine mammals are healthy when entanglement occurs. In Danish fisheries, using unspecified gear types, bycaught harbor porpoises were classified as healthy at the time of death; therefore, researchers believe the animals became entangled in the nets while alive (Larsen and Holm 1996). Reports indicate that eighteen bycaught cetaceans, including common dolphins, Atlantic white-sided dolphins, and one possible bottlenose dolphin, were captured in four of eleven observed fisheries in the northeast Atlantic (Tregenza and Collet 1998, Morizur et al. 1999). Although all animals had died and were found free within the net, with the exception of one entangled individual, all cetaceans appeared to be healthy at the time of capture.

Why cetaceans are caught

Trawling activities can attract healthy animals since they represent an easy-to-access, concentrated food source. As previously mentioned, trawling may open a niche of previously unexploited food resources, such as fish species that are too fast, deep, or energetically costly to capture to cetaceans, or trawling may provide an abundance and diversity of food with a high caloric value (Fertl and Leatherwood 1997). For instance, the importance of Atlantic mackerel (*Scomber scombrus*) is evident in the diet of pilot whales due to the occurrence of this fishery targeted species in the stomachs of these whales and due to the high mortality of pilot whales in the northeastern U. S. mackerel trawl fishery (Waring et al. 1990). However, pilot whales do not normally prey on mackerel, suggesting the whales are opportunistic in exploiting trawlers (Waring et al. 1990).

In all areas of the world, associations between at least 15 cetacean species and trawlers have been documented (Fertl and Leatherwood 1997). Leatherwood (1975) observed three feeding patterns of bottlenose dolphins associated with shrimp trawlers including animals foraging behind working boats, eating organisms stirred-up from trawlers, fish that bypass the net, or fish stuck in the mesh; animals feeding on discarded fish or those that escaped the net; and animals preying on fish attracted to non-working trawlers. For instance, Leatherwood (1975) observed bottlenose dolphins feeding on northern anchovies (*Engraulis mordax*) that were discarded from shrimp trawlers, and he observed groups of four to six dolphins chasing small schools of unidentified bait near anchored fishing vessels. Similarly, Pace et al. (2003) observed bottlenose dolphins associating with trawlers in four phases: following the trawls, feeding on the net, waiting for trash fish, and feeding on discarded, trash fish. Prey associated with trawling gear may be dead, injured, or disoriented, making it easy for cetaceans to capture them with low energy expenditures. Broadhurst (1998) observed groups of up to five bottlenose dolphins, swimming directly behind the cod end of commercial prawn trawl nets and using their rostrums and foreheads to shake the nets, releasing the catch of mostly juvenile whiting (*Sillago* spp.). The dolphins ate the drifting, released catch and those caught in mesh, but the dolphins did not chase or consume escaped, live whiting (Broadhurst 1998).

Whether a cetacean is feeding primarily on the target species of or on species associated with trawling activities may determine the amount of time and energy that is expended on foraging behaviors. For instance, Chilvers and Corkeron (2001) and Chilvers et al. (2003) studied two communities of Indo-Pacific bottlenose dolphins (*Tursiops aduncus*) in Moreton Bay, Australia with overlapping distributions. The two communities, referred to as “trawler” and “nontrawler” dolphins, show complete social segregation and varying behaviors to prawn trawlers. The behavioral budget of the trawler community, which occurred in larger schools than nontrawler dolphins, differed greatly from those normally reported for this species (Chilvers and Corkeron 2001, Chilvers et al. 2003). The trawler community spent a large proportion of time foraging, possibly due to limited resources as a result of trawling or possibly since trawler dolphins rely on stirred-up organisms or on discards (Chilvers et al. 2003). Feeding on discards would require dolphins to follow trawlers for many hours, explaining the foraging time expended by trawler dolphins.

On the other hand, it is also possible that by taking advantage of concentrated fish resources, cetaceans may decrease the time they spend foraging (Fertl and Leatherwood 1997, Pace et al. 2003). Stomach contents of incidentally captured cetaceans suggest that cetaceans may be taking advantage of trawl fisheries; however, cetaceans may be feeding on the same species and utilizing the same high prey density areas targeted by trawl fisheries, making the animals more susceptible to capture. Berrow et al. (1998) found bycaught grey seals were feeding on herring (*Clupea harengus*) targeted by trawl nets at the time of death. Similarly, Waring et al. (1990) found the stomach contents of common dolphins caught in mid-water trawls for Atlantic mackerel and squid (*Illex illecebrosus and Loligo pealei*) to be consistent with the species targeted by the trawlers. Stomach contents also suggested *L. pealei* is also a major component of the diet of pilot whales, also bycaught in trawl operations off the northeast coast of the United States (Waring et al. 1990). White-sided dolphins captured in the Dutch mid-water trawl fishery, southwest of Ireland, contained intact or partly digested fish in their stomachs, most of which was mackerel, the target species of the fishery (Couperus 1997).

Cetaceans may be susceptible to incidental capture in trawl gear for reasons other than feeding on the same species that are targeted by trawlers. For instance, cetaceans may not be feeding on a target species but on an associated non-target species. Crespo et al. (1997) found most of the dusky and Commerson's dolphins caught off of the Patagonian coast could be attributed to shrimp trawling operations although no shrimp were found in the stomachs of the dead animals. Instead, anchovy (*Engraulis spp*.), a shrimp-associated species, was the primary prey of the captured dolphins. Cetaceans may be found in proximity to trawl gear due to an attraction to species that are preying on the caught fish (Fertl and Leatherwood 1997). As previously discussed, marine mammals may also be in the vicinity of trawl gear, feeding on organisms stirred-up from bottom trawls or preying on discarded bycatch (Leatherwood 1975, Fertl and Leatherwood 1997, Broadhurst 1998). Loughlin et al. (1983) found a high incidental capture of northern sea lions since the animals followed fishing vessels while scavenging on discarded fish and interfered with the net during other aspects of the fishing operation.

The behavior of marine mammals while feeding on or in the proximity to trawl nets may lead to their capture. Bottlenose dolphins were observed foraging at night on fish species attracted to the waters illuminated by vessels' lights, placing the cetaceans in close proximity to fishing gear (de Haan et al. 1998). Morizur et al. (1999) observed white-sided dolphins and grey seals feeding around trawl nets during towing, making the animals more vulnerable to capture. Grey seals were seen regularly preying on targeted herring during hauling and were often observed diving between pair trawlers during towing, suggesting the animals can usually avoid capture but occasionally become trapped (Berrow et al. 1998). Waring et al. (1990) observed pilot whales pursuing mackerel and feeding in and around the mouth of active trawl nets during haulback. Northridge et al. (2004) observed bottlenose dolphins facing oncoming water inside trawl nets, feeding on fish. It was apparent that animals entered the net to take advantage of captured fish; the animals entered and left the net at will. One sighting, captured on camera, included animals inside the net for over an hour.

These behaviors of cetaceans in or around trawl nets may be carried on to future generations through cultural transmission of knowledge. Female cetaceans with calves have been observed following trawl boats; therefore, calves may be learning the advantages of an association with trawl vessels (Shane et al. 1986, Pace et al. 2003). Calves or subadult animals may also be more susceptible to bycatch due to curiosity or inexperience around fishing gear. For instance, bycaught harbour porpoises in German gill net fisheries were mainly subadults and weanlings (Siebert et al. 1996).

When and where cetaceans are captured

There is much speculation as to why, when, and where cetaceans become captured in trawl gear. Understanding behavior and foraging patterns of marine mammals may be crucial in explaining the occurrence of bycatch. Many people believe that healthy cetaceans and other marine mammals should be able to avoid capture in trawl nets, particularly when the nets are towed at slow speeds; however, this is apparently not the case. Northridge (2003a) found bycaught common dolphins in bass pair trawl fishing gear were captured at the cod end of the net, many with their beaks poking through the mesh. The positioning of the animals suggested that they were actively swimming prior to capture and were alive when reaching the end of the net. Necropsy results indicated the animals had drowned, and muscle and ligament tears provided evidence that the animals struggled to escape (Northridge 2003a). Similarly, Lipscomb (1996) believes that marine mammals sustain traumatic injuries while struggling to free themselves from underwater entrapment. As the Northridge study indicates, it is likely that cetaceans are alive when caught, but they die due to drowning since the nets are not immediately retrieved after incidental capture occurs (Fertl and Leatherwood 1997).

In a study by Hartmann et al. (1996), researchers noted a dolphin became entangled by its tail at the front of a mid-water trawl net where the mesh size was large enough for a dolphin to swim through safely. The reason the animal became entangled is unknown. However, anecdotal reports suggest that an animal may have survived a similar entrapment at this location, implying the animal became caught during hauling of the net. Therefore, the animal was not underwater long enough for drowning to occur. The information of when the animal was caught may be helpful in explaining why the animal became entrapped. For instance, a change in the configuration of the net may have occurred during hauling.

Marine mammals may be particularly vulnerable to capture during certain phases in the trawl operation. When a trawl net is deployed, cetaceans may be captured due to proximity to a vessel. Cetaceans may enter the mouth of the net during towing but become captured when the boat slows or stops to haul in the catch (Fertl and Leatherwood 1997). Changes in speed or direction of a vessel may contribute to cetacean bycatch since the size and shape of the net and its mouth may become altered, and the space for foraging dolphins to escape the net will become reduced or eliminated (SGFEN 2002). During trawling, the headline of the net creates a U-shape due to friction with surrounding water, creating spaces for marine mammals to become trapped (Northridge 1988). The shape of the headline and net may change significantly during different phases of fishing, including during hauling and during direction changes. Engines on trawl vessels produce characteristic sounds during stages of fishing which may be recognizable to cetaceans and attract the animals to feed during certain periods such as gear deployment or haulback (Leatherwood 1975, Fertl and Leatherwood 1997, Pace et al. 2003). Certain marine mammal behaviors may become associated with certain stages of trawl fishing.

Evidence suggests that species that forage in dense groups, such as common dolphins and pilot whales captured off the northeastern U.S. coast, are also susceptible to capture in fishing gear (Fertl and Leatherwood 1997, Waring et al. 1990). Morizur et al. (1999) found six of eighteen bycaught cetaceans were caught alone whereas the remaining twelve were caught in groups of between two and four individuals.

Where animals are found in the water column determines their likelihood of capture in trawl nets, with those foraging at mid-water depths highly vulnerable to mid-water trawls (Fertl and Leatherwood 1997). Mid-water trawls threaten cetaceans since they often target the same species, are large in size, and travel at relatively high speeds (Northridge 1988). Depths at which cetaceans are found may be closely correlated with the behaviors of prey species. Common dolphins which are caught in the *Loligo* squid fishery may follow the diurnal movement of the squid to the surface at night, causing the capture of common dolphins in the narrow fishing area at the top of the water column (Waring et al. 1990). During the day when fewer common dolphins are bycaught, the cetaceans may be spatially separated from their prey or deeper and more dispersed in the water column (Waring et al. 1990).

As indicated by common dolphins in the *Loligo* squid fishery, time of day may be an important component in understanding when the highest threat of cetacean bycatch occurs in a fishery. However, bycatch occurrence will differ between species and fisheries. For instance, common dolphin bycatch was highest at night for the squid and also the Atlantic mackerel fisheries in the northeastern United States between 1977 and 1988; however, for the Atlantic mackerel fishery, pilot whale bycatch occurred in a contrasting trend (Waring et al. 1990). More pilot whales were caught during the day than at night. Off of the Patagonian coast, the highest incidental takes of dusky dolphins in mid-water shrimp trawlers occurred at night (Dans et al. 1997, Crespo et al. 1997). In an experimental trawl fishery for tuna in the Northwest Atlantic, 22 of 29 takes that included pilot whales, bottlenose dolphins, risso dolphins, and a leatherback turtle occurred at night while the remaining 7 takes occurred in morning tows; however, it should be noted that the fishery, in general, towed at night (Goudey 1995). Similarly, all common dolphins and white-sided dolphins were captured at night or close to dawn in observed fisheries in the Northeast Atlantic, possibly due to an association between cetaceans and trawlers at night (Tregenza and Collet 1998, Morizur et al. 1999). Tregenza and Collet (1998) noted that 95% of the observed hauls occurred at night, with the exception of the hauls of Dutch vessels that occurred both at day and night. Maigret (1994) notes that dolphins may be caught at night since at this time, they are moving slowly near the surface, increasing the threat of capture.

Similar to time of day, seasonality may play an important role in identifying where overlap between cetaceans and trawlers will most likely lead to bycatch. Along the continental slope of southwest Ireland, cetacean catches in Dutch pelagic trawlers occurs in late winter and early spring when Atlantic white-sided dolphins move from offshore to inshore during their southward migration (Couperus 1997). Pilot whales in New England, U.S. were captured in trawl gear when their distribution concentrated along the southern shelf edge primarily between March and July while common dolphins were caught between December and February (Waring et al. 1990). For pinnipeds such as northern sea lions in the north Pacific and Bering Sea, the majority of bycatch occurred between late autumn and early spring when sea lions were not located on rookeries (Loughlin et al. 1983). Understanding the seasonal distribution of marine mammals may lead to identifying spatial and temporal overlaps with fisheries that may be modified to reduce incidental takes of these species.

Distribution may vary daily or seasonally as previously discussed, but it is also possible that males and females may exhibit differential selectivity in the habitat they utilize, making one sex more vulnerable to fishing gear (Crespo et al. 1997). It may be important to understand the sex ratio of bycaught animals to understand the impact of bycatch on cetacean populations. For instance, bycatch of Hooker's sea lions in New Zealand were predominately female (Slooten and Dawson 1995). Additionally, Dans et al. (1997) found 70% of bycaught dusky dolphins caught in the Patagonian shrimp fishery in the 1980's were females; half of these females were mature, and half of those animals were pregnant. Although the study size was small (n=23 animals), Dans et al. (1997) predicted that incidental mortality may have been high, particularly in 1984 through 1986, and the impact of the bycatch may have been severe since many of the bycaught animals were females of highest reproductive value. The shrimp trawl fishery is no longer in use off of Patagonia; however, experimental trawl nets are now used for southern anchovy, possibly continuing the threat of entanglement to the dusky dolphin population. In contrast to the bias towards the capture of female cetaceans observed by Dans et al. (1997), Morizur et al. (1999) noted all dolphins caught in four observed fisheries were adults of both sexes, highlighting the characteristic differences between fisheries and locations.

In summary, cetacean bycatch in trawl fisheries may be associated with the cause of the interaction, whether cetaceans are exploiting the target species of a fishery or an associated species or whether simple overlap in distribution between cetaceans and trawlers leads to bycatch. Incidental takes may also be related to the behavior of the marine mammals, the depth at which foraging and trawling occur, and spatial and temporal use of habitat, possibly even varying between sexes. The differences in these characteristics are essential to understanding the extent of bycatch and to developing strategies to reduce bycatch. Due to the differences between cetacean populations and trawl gear configurations, there will not be one solution to global cetacean bycatch. Solutions in one area may be ineffective elsewhere, or they may be modified to be effective in another area.

Bycatch Mitigation Research

A group of scientific experts on cetacean bycatch convened by the World Wildlife Fund in 2002 noted that "The most appropriate mitigation measures for each situation will depend on the nature and scope of the fishery, the species and behavior of the cetaceans involved and the financial resources available to address the problem (Read and Rosenberg 2002)." The group suggested the further examination of bycatch reduction strategies including fishing gear and practice modification, acoustic alarms, time and area closures, and post-capture release which have exhibited effectiveness in some areas. For instance, bycatch mitigation techniques such as acoustic alarms and time and area closures have proved successful in reducing incidental takes of the most frequently bycaught marine mammal, the harbour porpoise, in gillnets from 2900 individuals in 1990 to 323 animals in 1999 (Read et al. 2003). Even more potential may currently exist to modify trawl gear to reduce interactions with cetaceans since it is actively fished in contrast with passive fishing gears, such as gillnets, which are set, left, and later retrieved (Read 2005).

Gear modification

Gear modification is a promising avenue for cetacean bycatch mitigation. In 2001, delegates to the COPEMED workshop on fishing gear selectivity recommended the investigation of gear selectivity and the development and testing of devices to prevent bycatch as priorities for research and funding (COPEMED 2001). In an experimental trawl fishery for tuna in the Northwest Atlantic, increases in cetacean bycatch between 1994 and 1995 may be attributed to changes in gear configuration (Goudey 1994, 1995), suggesting that subtle differences in gear size and structure may greatly impact bycatch of cetacean species. For this reason, several researchers have conducted research to test the effectiveness of gear modification to deter cetaceans from approaching, entering, or becoming captured in nets, thereby reducing bycatch and gear damage.

The European Commission project CETASEL (CETAcean SELectivity) investigated technical means, including gear modification and acoustic devices, to reduce the bycatch of small cetaceans in pelagic trawl fishing gear between 1994 and 1997 (de Haan et al. 1998). In this section, I will discuss briefly the research included in the CETASEL project that involves modifications to trawl fishing gear or investigations related to these fisheries.

Kastelein et al. (1997a) as part of the CETASEL project conducted an experiment to determine the minimum mesh size that a harbour porpoise would pass through voluntarily. The study was conducted in June 1995 in a Dutch captive environment, using a three year old female harbour porpoise that was being rehabilitated after stranding. Each 20-minute test period was proceeded by a 20-minute baseline session. The harbour porpoise was introduced to 5 net panels that were tested in order of increasing mesh size (1.8 m, 3.6 m, 4.8 m, 7.2 m, 10 m). Each mesh size was large enough for the harbour porpoise to pass through easily.

Results indicated the harbour porpoise would swim through the 4.8 m and 7.2 m meshes hesitantly, would not pass through the 1.8 m or 3.6 m meshes voluntarily, and refused to pass through the 10 m mesh, even though it was the largest mesh size tested. In one trial with the 1.8 m mesh, the animal was observed patrolling the bottom of the net panel, suggesting the animal may have been searching for a way to swim underneath the net. Only one animal was utilized in this experiment; therefore, sex, age, location, experience, and even hunger may have influenced the animal's behavior towards fishing gear; therefore, different results may have been observed if a different animal or species was utilized in the study. Additionally, in this study, the harbour porpoise may have become familiar with net panels in the first sessions and thus behaved differently in subsequent trials. Kastelein et al. (1997a) also used sound to test the effectiveness for acoustic deterrents and to see if sound could force the harbour porpoise to pass through mesh of sizes it would not normally pass through voluntarily. These studies will be discussed in the next section.

The CETASEL project also researched the behavior of cetaceans around an active trawl net. Research was conducted on the *RV Tridens* on the northeast Atlantic shelf edge off of the southern coast of Ireland, in the Bay of Biscay, and along the Spanish shelf edge (de Haan et al. 1998). Researchers used an acoustic tracking system to monitor cetacean movement at longer ranges than an optical based system and to conduct surveys at night when bycatch was mainly reported in the study area. Research was conducted in six trials between March 1995 and April 1997; the trials ranged from 2 to 3 week periods (de Haan et al. 1998), using primarily 4300 meshes and 5600 meshes on occasion. An open trawl, with the cod end removed, was used so that fishing could be continuous, and bycatch would not be a problem. During the study, animals stayed at a distance from the ship and the trawl. However, it is important to note that during the night surveys of at least one of the cruises, bottlenose dolphins, in groups up to fifty animals, were exploiting fish that were attracted to surface waters around the vessel that were illuminated by the vessel's deck lights. This attraction could be an important factor leading to the attraction of cetaceans to trawl vessels and resulting in bycatch.

In a captive facility in Sweden, the behavior of three female bottlenose dolphins was tested between November 1996 and February 1997 towards an excluder panel under two light conditions: bright and low light (de Haan et al. 1998). Previous research has shown that some cetaceans will not pass willingly through gaps delineated by parallel ropes (Silber et al. 1994); therefore, the experiment tested a barrier grid, consisting of sloping parallel ropes (1, 2, and 3 m apart), used to prevent the dolphins from swimming into the trawl and to guide the animals out of the net through an excluder panel with large, stretched diamond-shaped meshes (7.2 and 10 m) in either the top or the bottom of the trawl (de Haan et al. 1998). Sonar reflectors were placed on the parallel ropes. Results of the captive testing of the excluder panel showed that all three animals passed through the net panels without hesitation, even those with rope barriers only one meter apart. All dolphins used sonar during the sessions. The bottlenose dolphins demonstrated a preference for escape at the bottom of the trawl, which would be impossible during bottom trawling.

Tests were also conducted of the excluder panel at sea in April 1997 aboard the *RV Tridens* in waters South of Ireland and in the Bay of Biscay. In the study, ropes were placed in two parallel rows, 2.5 m apart, and seven excluder holes were placed in the top panel with openings of 25 m by 8 m. Field tests of the excluder panel were incomplete and did not demonstrate whether the idea significantly impacts cetacean bycatch; however, the panel appeared technically feasible.

In the CETASEL studies, observed cetaceans stayed near the fishing gear for less than fifteen minutes during field trials (de Haan et al. 1998). It is possible that the animals would have stayed near fishing gear longer if a closed trawl was used, implying the likelihood of catching fish may impact the length of time cetaceans associate with fishing gear. In the captive studies, the cetaceans appeared to acclimate to the net arrangements (de Haan et al. 1998). It is unknown if the same acclimation is true for wild dolphins around full size pelagic trawls; however, if dolphins do become habituated to fishing gear modifications, their success as mitigation measures would decrease. For instance, if cetaceans became acclimated to the excluder panel and began to swim in and out of the large, diamond-shaped meshes, an even higher level of risk may develop for these animals, particularly when the gear shape changes such as during hauling operations (de Haan et al. 1998).

In New Zealand, Gibson and Isakssen (1998) began to experiment with gear modification of trawl fishing gear by creating a full-scale marine mammal exclusion device (MMED) in response to incidental capture of Hookers sea lions, New Zealand fur seals, and an unspecified dolphin species. The MMED was designed to act as a sieve, allowing small objects such as target fish to pass through the tines of the grid while diverting larger objects such as marine mammals towards the top of the net where an escape hatch allows the animals to safely exit the net. The grid was made of metal and fixed inside the net tube at a 45 degree angle to the water flow, preventing marine mammals from entering the cod end of the net. Floats were placed on the grid to make it only slightly negatively buoyant. Three escape hatches were tested to create a visual barrier to deter fish from escaping through the hatch. The hatches were designed with three principal goals in mind: to completely cover the exit, to open freely against the flow of water so as to not hinder the escape of a marine mammal, and to prevent entanglement of the marine mammal.

Gibson and Isakssen (1998) conducted tests of the MMED at 3.1 knots in a flume tank in Launceston, Tasmania. They utilized a dummy seal to determine if a passive object of similar size and shape to a marine mammal would be expelled from the MMED. They found a one hundred percent success rate of excluding the dummy seals from the cod end of the net and a fifty percent rate of success at ejecting dummy seals from the net. In five of eight trials, the dummy successfully escaped the net, but during the other three trials, the flippers of the seal became entangled in the device. Gibson and Isakssen (1998) predict that entanglement of this sort would not occur in real seals since the flippers are a continuation of the body rather than a connection point which allowed sticking in the trials. Furthermore, the movement of real animals would assist in the animals' escape through the hatch, and fur of real animals will slide more easily than the neoprene of the dummy seals. Increased water flow of more than 3.1 knots will also assist in ejecting animals from the MMED.

All of the hatch designs worked well; however, the wire frame worked most effectively at covering the exit. Testing with live fish is still required (Gibson and Isakssen 1998). The device is believed to be easy to use by fishers as it lies flat on the deck, takes up little storage space, and can be stored on a net drum. Therefore, it is likely that the device would be adopted by fishers if additional testing proves that the target species will not escape as a result of use of the MMED.

Northridge (2003a,b) and Northridge et al. (2003, 2004) also experimented with gear modification including an exclusion grid in response to common dolphin and harbor porpoise strandings on beaches in the Southwest of England three times their normal levels since the early 1990s. Evidence suggested that the cause of these strandings related to fishing operations. In the mid-1990's, bass pair trawl fishing increased in this region by a factor of ten, prompting attention to be drawn to this fishery as the likely cause of the cetacean strandings (Northridge et al. 2004). However, the majority of bass fishing occurs in March while most cetacean strandings in this area occur in January. During observations of 116 tows in the bass pair trawl fishery in January, February, and March of 2001, Northridge (2003a,b) found that 52 of 53 bycaught dolphins were caught during the month of March, as predicted by the fishers themselves. The animals were often taken in small groups of between one and ten animals and an average of 4.4 animals per bycaught group (Northridge 2003b, Northridge et al. 2003).

Additionally, studies of this fishery show no incidental take of harbor porpoise occurs, but based on 32% observer coverage from 2000 to 2002, the bass fishery took an average of 90 common dolphins per year (Northridge et al. 2003, 2004). Based on the frequency of captures of common dolphins in the UK bass pair trawl fishery in 2001, Northridge (2003a) designed a study to build an exclusion grid system, test a model in a flume tank, construct a full scale prototype, and test the prototype in the fishery for handling ease, target species capture and loss, and dolphin escape. As mentioned earlier in this paper, initial observations found that common dolphins became entangled in the cod end of trawl nets, with their beaks through the mesh, suggesting the dolphins were alive at the time of entanglement. Therefore, an exclusion grid at the entrance to the sleeve, which is usually 20-30 m long and about 1.8 m wide, should prevent animals from swimming to the rear of the net (Northridge 2003a,b, Northridge et al. 2003) (Figure 2).

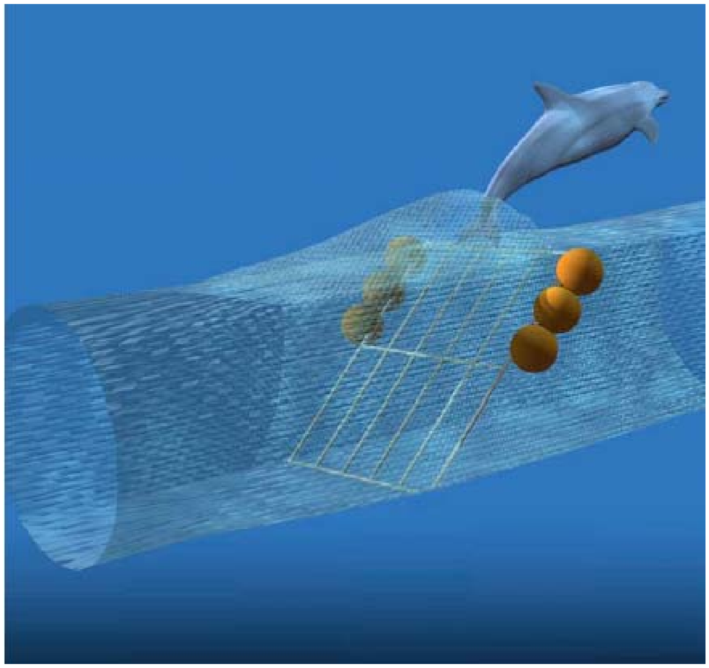

Figure 2. Diagram of the dolphin exclusion device tested by Northridge 2003a,b, and Northridge et al. 2003, drawn approximately to scale (dolphin = 2m in length). (Figure from Northridge 2003b)

Northridge (2003a) began by using grids of various materials including plastic so that the device would be wound on a net drum and stainless steel because of strength. Similar to the Gibson and Isakssen (1998) study, buoyancy aids were used to make the grid close to neutrally buoyant. The spacing of the grid tines was chose to ensure the passage of fish to the cod end of the net but would be small enough to prevent cetaceans from passing through; therefore, a grid spacing of 22 cm was chosen. The outlet size and placement was chose to enable a 2.5 m long and 70 cm wide animal to pass through. The escape hatch was placed immediately in front of the grid. The outlet cover was designed to limit fish loss. Sea trials were conducted on two four-day trips in March 2002, in which 16-20 tows were observed.

Results of the 2002 field season suggest that the grid was effective as no dolphins were captured while the grid was deployed, and a shark escaped successfully through the hatch. Skippers involved in the study reported that the grid presented no handling difficulties. Additionally, video coverage demonstrates that bass are unlikely to be affected by the grid, although several fish escaped by pushing through the escape hatch net. During the trials, the grid slightly changed orientation, becoming shallower than planned and allowing more bass to escape.

In response to changes in the grid angle after several tows, Northridge (2003b) tested adjustments to the net section where the grid was placed, including changes to the grid angle, cover net, and number and orientation of floats surrounding the grid during March 2003 on 31 tows. Additional monitoring continued until May 8, 2003; a total of 82 were observed through the entire 8 week-long fishing season. A Scanmar Grid Sensor monitored the angle of the grid and the rate of water flow around it. A camera monitored the grid and escape hole from the inside of the net while a second camera monitored the escape hole and cover outside of the net, which enabled scientists to determine if target fish were escaping through the hatch.

During the 2003 season, only two common dolphins were recovered after hauling (Northridge 2003b). It appeared that one animal had become caught in the mesh (40mm) of the cover net to the escape hatch, blocking the escape hatch for the second animal. Both animals had drowned, and scientists concluded the mesh size of the cover net needed to be reduced. Despite these two deaths, a great reduction in cetacean bycatch had been observed since preliminary observations in 2001 found 53 cetacean deaths due to bycatch in this fishery. Although the mechanism for why bycatch was reduced is unclear, it is clear that the grid prevented cetaceans from entering and becoming trapped in the cod end of the net. In fact, the animals did not enter the grid section of the net, possibly since they could detect the stainless steel grid by sight during daylight or through echolocation and swim out the mouth of the net. It is unlikely that the grid, which traveled at speeds of 1.8 to 2.4 knots, could seriously injure an animal as robust as a dolphin (Northridge 2003b).

Northridge et al. (2004) continued monitoring the grid system in late 2003-2004, resulting in an unprecedented amount of observed bycatch in the bass pair trawl fishery. Over four hundred animals were captured during this study season, compared to an annual average of ninety animals captured in preceding years (Northridge et al. 2003, 2004). In total, twenty-seven cetacean groups became caught in the nets. The escape hatch captured half of these groups while the other half was captured further forward in the nets. Larger groups were caught close to the grid. Northridge et al. (2004) also observed an earlier peak in bycatch, occurring in December, and bycatch occurred closer to shore (12-18 nm) compared to 24-30 nm as in previous years.

Nets made of thinner twine may have contributed to the higher bycatch rates as animals may have tried to swim through the net rather than out of the net's mouth. Subsequent research may move the grid and escape hatch forward in the net as a result of animals becoming caught in large meshes close to the mouth of the net.

Additional research is necessary to determine the level of effectiveness that grids or excluder devices can achieve. Excluder devices or separator grids are currently used worldwide to exclude unwanted fish species from catch. However, some criticize the use of these devices for marine mammals since it is possible for these animals to become injured or killed while using the escape hatch, as suggested by the entangled dummy seals in the MMED (Gibson and Isakssen 1998) and the common dolphin caught in the escape hatch mesh (Northridge 2003b). Others suggest that if the noise created by the device is scaring cetaceans from the trawl net, leading to the effectiveness of the device, then habituation to the sound may occur, and high levels of bycatch may return (House of Commons 2004). Therefore, additional research is needed to determine the effectiveness of marine mammal excluder devices such as those previously discussed.

Gear modification may never be a solution to cetacean bycatch but may provide a means to reduce mortality rates until more far-reaching solutions can be found (Silber et al. 1994). As in gillnet gear modification, modification of trawl gear is constrained by a number of factors, as described by Dawson (1994). These constraints to gillnet modification can be adapted to trawl net modification and need to be addressed in bycatch mitigation research. The following conditions apply to both gillnets and trawl nets (adapted from Dawson 1994):

- Any modifications to fishing gear must have longevity under commercial fishing conditions.
- Modified fishing gear must be safe to handle; it must not add any level of threat to fishers.
- Gear modifications must be relatively inexpensive.
- Catch rates of target species must not be compromised as a result of gear modifications.

Any gear modification will only be effective if it is willingly adopted and used by fishers. Therefore, gear modifications must be practical, affordable, and easily used to be adopted by commercial fishers (Dawson 1994). For trawl gear, it is important that the nets and any gear modifications be stored easily on deck, and any escape hatch or exclusion device must maintain catch of target species. It is recommended that fishers be involved in the development of a gear modification for two reasons. Firstly, fishers will be more likely to adopt a device or modification they were involved in creating. Secondly, due to fishers' detailed knowledge of fishing gear and years of experience, modifications will more likely be successful with the involvement of fisher knowledge. Implementation of gear modification into any fishery should, of course, be subject to ongoing monitoring. If a gear modification proves successful, particularly in the long term, it should be tested, and if successful, implemented in other fisheries using similar fishing gear.

Acoustic devices

It is known that cetaceans rely heavily on sound to navigate in their marine environment. It is also known that the use of acoustic devices has successfully reduced bycatch of cetacean species in some fisheries such as harbour porpoises caught in gillnets (Lien et al. 1995, Read et al. 2003). Bycatch in gillnets is likely a result of the low visibility and low acoustic reflectivity of the fishing gear. In contrast, trawl nets are more visible and relatively loud which suggests cetaceans should be able to detect and avoid the fishing gear (de Haan et al. 1998). It is possible that the noise from the fishing gear acts as an attractant, indicating the availability of prey and leading to, instead of preventing, bycatch. On the other hand, some cetaceans may be unfamiliar with the noises, and thus, the dangers, associated with trawling (Northridge 1988).

The CETASEL project investigated the use of sound, in addition to the gear modifications previously discussed, for its effectiveness in deterring marine mammals from fishing gear (Kastelein et al. 1997, de Haan et al. 1998). For instance, Kastelein et al. (1997) tested five sound sources, which created nine sounds, to determine if a sound would force a captive harbour porpoise to pass through a net with a mesh size that it would not normally swim through voluntarily. The animal was observed during a fifteen minute baseline period without sound, a fifteen minute test period with sound, and a fifteen minute recovery period without sound. In each baseline study, the animal did not swim through the nets (3.6 and 10 m mesh sizes) that were present without deterring sounds. However, after the sound was activated, the animal swam through the net panel within ten seconds.

Researchers found that the sweep sounds (bandwidth octave, center frequency 7.5 kHz to 140 kHz, SL 99-117 dB re 1 μPa at 1 m) were most effective at altering the behavior of the harbour porpoise (Kastelein et al. 1997, de Haan et al. 1998). The observed behaviors during sound activation included increased swimming speed, respiration and surfacing rates, and decreased swimming depth. It remains unknown how marine mammals will respond to these sounds if placed on actively fishing gear or if the observed behaviors would benefit cetaceans near fishing gear in the wild. It is possible that the response observed in the harbour porpoise occurred as a startle response to the onset of the sounds which may not occur if the device was used on fishing gear and which cetaceans may become acclimated to. Although habituation did not appear to occur for the harbour porpoise during the study, the test periods lasted only fifteen minutes. In the wild, cetaceans will experience acoustic deterrents repeatedly in their habitat; therefore, habituation to sounds may occur despite the results of this study.

Northridge (2003a) and Northridge et al. (2003) also experimented with acoustic deterrence devices in attempt to mitigate cetacean bycatch. Acoustic deterrence devices, or pingers, contributed to the successful reduction of harbour porpoise bycatch in gillnet fisheries (Kraus et al. 1997, Read et al. 2003). In March 2001, to deter common dolphins from entering a trawl net, Northridge (2003a) deployed up to twelve Dukane Aquamark 1000 pingers around the mouth of a trawl net. The fifteen tows with the pingers did not result in fewer bycatches; therefore, Northridge (2003 a,b) concluded that pingers were not a promising avenue for bycatch mitigation research. However, Northridge et al. (2003) also experimented with pingers in the rear of a trawl near where meshes changed from large to small sizes. Once again, no obvious reduction in the bycatch rate of cetaceans was observed. Northridge et al. (2004) noted that the pingers may have been ineffective due to the loud noises associated with trawlers which masked the pinger sounds and allowed the cetaceans to continue to enter the trawl net.

Although acoustic deterrents may be effective in preventing bycatch in gillnets (Lien et al. 1995, Kraus et al. 1997), there are many arguments against the use of sound to prevent cetacean bycatch in trawl nets. The fishing gear associated with trawling produces considerable sound from the chains and ropes used; therefore, any sound device used would need to produce sounds greater than the noise created by the ship and the fishing gear. The noises associated with trawling and the sounds used to act as a deterrent may actually act as a beacon to attract cetaceans to the low-cost foraging strategy. Furthermore, the loud sounds may actually cause ear damage to cetaceans or may prevent the animals from using sound in their environment, which could be detrimental for animals that rely on sound for communication, navigation, and foraging. Another argument against the use of acoustic devices on fishing gear is that not only will they deter cetaceans from fishing gear, thus reducing bycatch, but they may also deter cetaceans from entering an area, used by numerous fishing vessels, that may be a significant feeding habitat for the animals. Therefore, the impact on cetacean populations may be significant, but the impact may actually be negative. Furthermore, acoustic devices may elicit varying, unpredictable responses in different cetacean species (Cox et al. 2003). As previously discussed, habituation may also be a problem for the effectiveness of acoustic devices (Cox et al. 2003). Future studies into the use of acoustic deterrents on fishing gear must take these factors into consideration.

Time and Area Closures

As previously discussed, cetacean bycatch differs between species, fisheries, and areas. For instance, between 1996 and 2000, a Basque observer program observed 661 hauls of a pelagic and large vertical opening (VHVO) pair trawl fishery in ICES areas VIII a, b, c, and d (SGFEN 2002). Bycatch was reported in all areas except VIII c, demonstrating the variance of bycatch by fishing area (SGFEN 2002). Additionally, observers in the U.K. have monitored fisheries in ICES area VII, including the mackerel, bass, pilchard, blue whiting, and anchovy fisheries, and they found cetacean bycatch occurred only in the bass fishery (SGFEN 2002). Bycatch varies depending on a number of factors including target and bycatch species, fishing gear configurations, and fishing areas. Time and area closures may be an effective tool for reducing bycatch in areas with relatively high bycatch; however, the utility of closures will be fishery specific.

Time and area closures have been used to protect fish and protected species populations. For instance, the Banks Peninsula Marine Mammal Sanctuary was created in 1988 to protect Hector's dolphins (*Cephalorhynchus hectori*) from gillnets in New Zealand (Dawson and Slooten 1993, Dawson and Slooten 2005). A second Marine Mammal Sanctuary was established in New Zealand to protect Hooker sea lions from all fishing gear, including trawls, within 12 nautical miles of the Auckland Islands (Slooten and Dawson 1995). In a study on the spatial overlap between sea turtles and shrimp trawling efforts, McDaniel et al. (2000) located areas where interactions are likely to occur and where area closures present a potential strategy for protecting endangered marine animals.

For time and area closures to be effective, they should be targeted at areas or times with relatively high bycatch and where long term monitoring has determined that the high bycatch rate has been consistent and is not just a transient or random occurrence (SGFEN 2002). Candidate closure areas are those that are highly productive and utilized by both marine mammals and fishers; however, due to the dependence on these areas by many fisheries, closures of these areas are likely to be resisted by fishers (SGFEN 2002). In order to address this concern, McDaniel et al. (2000) suggest fishery closures in areas where trawling efforts are low but sea turtle abundance is high, thus, protecting the endangered species while minimizing impact to shrimpers.

Time and area closures should target a specified level of bycatch reduction. In order to accomplish this target, a management plan utilizing closures must take into consideration that when an area becomes closed, either permanently or temporarily, to a particular type of fishing gear, fishers using that gear may chose to fish elsewhere or to switch to a permitted fishing technique (SGFEN 2002). For instance, in response to cetacean bycatch in the Liguarian Sea Sanctuary, the Italian government banned driftnet fishing in the area in1992 (SGFEN 2002). Monitoring of the area indicated that over twenty boats switched from driftnet fishing gear to longline gear, which is a gear type associated with high rates of sea turtle bycatch (SGFEN 2002). Other vessels chose to fish outside of the Liguarian Sea Sanctuary, simply displacing their fishing effort elsewhere instead of removing their fishing efforts (SGFEN 2002). The environmental consequences of time and area closures must be taken into consideration since fishing effort will rarely be removed. Displaced fishing effort or gear switches may have equal or higher bycatch rates on cetacean species the closure is meant to protect, or the closures may impact other cetacean populations or protected species.

For instance, higher bycatch rates of harbour porpoise resulted in 1994 in the New England multispecies sink gillnet fishery from a poorly designed time and area closure network by the National Marine Fisheries Service. The network was designed to protect harbour porpoise, but due to temporal and spatial variation in patterns of bycatch rate and displacement of fishing effort to fishing areas surrounding the closed areas, the bycatch rate of harbour porpoises actually increased to levels higher than in 1993 (Murray et al. 2000). Areas adjacent to closed areas remained open solely to minimize disruption to fishery practices. Furthermore, the closure period was too short to adequately protect the harbour porpoises. Murray et al. (2000) concluded in a study of the gillnet fishery closure that “Closures may be effective when: (1) the area where bycatch occurs is a small subset of the area where fishing effort occurs; (2) patterns of bycatch are predictable in time and space; (3) displacement of fishing effort does not result in bycatch rates as high or higher than in the closure area; (4) fishermen support and cooperate with the regulations; and (5) an adequate information base exists on which to design closures." The 1994 closures failed to meet these conditions (Murray et al. 2000).

In this example of the New England sink gillnet fishery, we learn that prior to establishing area or time closures, assessments of the consequences of displaced fishing and of switches in fishing gear used are recommended to determine if the intended level of bycatch reduction can be achieved. Furthermore, research into the distribution and habitat utilization of cetaceans is necessary to determine if the candidate closure areas will be sufficient to reduce bycatch of the threatened population or species (SGFEN 2002). Both Marine Mammal Sanctuaries in New Zealand would have been more effective at protecting endangered marine mammal populations had they closed larger areas to fisheries (Slooten and Dawson 1995, Dawson and Slooten 2005). Monitoring of closed areas and surrounding regions is necessary to ensure the desired level of bycatch reduction is met and to verify that the closed areas are necessary to protecting cetacean species.

Due to resistance from fishers to time and area closures, some would argue they should be explored as a last resort to cetacean bycatch reduction when and where other reduction techniques are unsuccessful at achieving the desired level of bycatch reduction. Alternatively, time and area closures might be most effective in combination with other mitigation strategies such as with pingers, a strategy which successfully reduced harbour porpoise bycatch in gillnets (Read et al. 2003). As seen in the Banks Peninsula Marine Mammal Sanctuary, time and area closures may become socially acceptable and financially beneficial in time, due to increased tourism and business such as dolphin-watching programs (Dawson and Slooten 2005).

Conclusion

Bycatch, or incidental capture in fishing gear, threatens populations of marine mammals throughout the world's oceans (Northridge 1991, Read and Rosenberg 2002, House of Commons 2004). While the estimated number of marine mammals taken annually already numbers into the hundreds of thousands (Read et al. 2003), the situation is likely to worsen with an increasing human population depending of fisheries (Read 2005). In order to address the problem of marine mammal bycatch, managers and fishers must work cooperatively to develop successful mitigation strategies.

Solutions to cetacean bycatch, whether they are acoustic devices, gear modifications, fishery closures, or a combination of strategies, may vary by fishery, target species, and location; however, several factors must be true for a bycatch reduction plan to be effective. First of all, a bycatch mitigation strategy must reduce or prevent cetacean bycatch and/or allow marine mammals to safely escape capture by fishing gears, while preventing the loss of targeted fish species (Gibson and Isakssen 1998, Northridge 2003 a,b). As with the other mitigation strategies discussed, fishers are most likely to cooperate with a management scheme if they are involved in its creation, if they find it fairly implemented, if it is easy to use and/or follow, and if it is safe and affordable (Dawson 1994, Murray et al. 2000). Effective management techniques must also be enforceable and monitored for direct and indirect effects.

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