

## CETACEAN DETECTION AND RESPONSES TO FISHING GEAR

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### INTRODUCTION

Cetaceans interact with fisheries throughout the world (see reviews in Northridge, 1984, 1991; Currey et al., 1990, 1991; Bjørge et al., 1991). These interactions can be divided into operational and predatory types (Beddington et al., 1985). Predatory interactions include effects of prey competition between fisheries and cetacean stocks. Operational interactions refer to gear damage by cetaceans and incidental catch of cetaceans in fisheries. This paper will only deal with operational interactions, and will focus on problems of incidental catch. Directed fisheries for cetaceans will not be discussed in this paper.

The incidental entrapment and entanglement of non-target cetacean species in fishing gear is a problem of increasing concern and has recently received much attention (see Brownell et al., 1989; Perrin, 1989; International Whaling Commission, in press). However, little is known about the factors which result in cetacean catches in fishing gear or the animals' ability to detect gear. Operational interactions depend on the type of fishing gear being used, the ecology and behavior of the marine mammals involved, the fishes being caught, and various temporal factors. In many cases, attempts to reduce incidental catch have proceeded without proper information on cetacean responses to fishing gear and on reasons for entanglement. This paper attempts to bring together what is known about how cetaceans interact behaviorally with nets and equipment used in commercial fishing.

## TYPES OF FISHERIES KNOWN TO HAVE INTERACTIONS WITH CETACEANS

Commercial fisheries of the world are highly diverse, although most fisheries can be classified into one of 11 types (Nedelec and Prado, 1990). Cetaceans are known to interact with six of these fishery types. Surrounding nets catch fish by encircling and surrounding it from the sides and below. The most common type of surrounding net is the purse seine, which is closed at the bottom with a purse line after encirclement. Purse seines tend to be used to catch schooling fish, such as tuna and herring. Cetaceans, primarily dolphins, are taken both directly and incidentally in purse seine fisheries; the major case is the well-documented large kill of dolphins by tuna purse seiners in the eastern tropical Pacific (ETP) (see Perrin, 1968, 1969a,b).

Seine nets (purse seines are not in this category) are long nets that are pulled from a boat or from shore to entrap fish by herding them. Small cetaceans are taken in beach seines, although the numbers taken do not appear to be high (see Jones, 1975; Thomas, 1983).

Trawl nets are towed nets consisting of a cone-shaped net with a cod-end or bag for collecting the fish or other target species. These can be bottom, midwater, or surface trawls, and are operated from one, or occasionally two, boats. Target species caught by the three trawl types include hake, pollock, and other groundfish, shrimp, prawn, and a variety of squids. Some cetaceans feed in association with trawling activities, and several species of cetaceans are known to become incidentally caught in the nets (see below).

Gillnets and entangling nets (including driftnets) are most often used passively to entangle fish or invertebrates that blunder into the webbing. They may be used singly or in fleets, be set on the bottom or left to drift, and used passively or actively to herd fish and other marine animals. They tend to be used to catch non-schooling or loosely-schooling target species such as salmon and various species of groundfish. Apparently, more cetaceans are taken in gillnets than in any other fishery type (see International Whaling Commission, in press for a review). Some catches are deliberate, but most are accidental.

Traps, such as pound nets, weirs, and pots are used to catch a variety of species of fish and invertebrates. They are fished passively and are most often set or anchored on the bottom. Cetaceans are taken in weirs and pound nets in some areas (Smith et al., 1983; Lien et al., 1990).

Hook and line methods include poles, handlines, longlines, and trolling gear. These are common fishing techniques used for many target species. Some cetaceans are known to interact with longline fisheries, both by damaging gear and stealing catches, and by becoming caught on hooks (Sivasubramanian, 1964; Mitchell, 1975; Dahlheim, 1988; Zhou and Li, 1989).

Grappling and wounding gears (harpoons, arrows, and spears) are used to catch specific target individuals. Cetaceans would not be caught accidentally, but are taken directly by harpoon in many areas.

Dredges are dragged along the bottom to catch shellfish. Liftnets are used to catch fish attracted to the boat, which are then collected by hauling the submerged net from beneath. Falling gears (cast nets) are thrown or dropped over the target species. Harvesting machines are new advancements used to catch fish through direct pumping or sifting. As far as we know, none of these four types catch cetaceans.

We consider purse seines, gillnets, and trawls to be the most common types of fisheries with cetacean interactions, so we discuss them separately below. Evidence of cetacean interactions with longline fisheries is increasing, but at present, we know little of this type of interaction.

## DETECTION AND RESPONSES TO FISHING GEAR

### Purse Seines

Dolphins are often found in multispecies aggregations, with other dolphin species, marine birds, and fishes (Au and Pitman, 1986; Au, 1991). A particularly strong affiliation exists between yellowfin tuna (Thunnus albacares) and pantropical spotted (Stenella attenuata), spinner (S. longirostris), and common (Delphinus delphis) dolphins in the eastern tropical Pacific (ETP), roughly between 20° N and 20° S, and as far west as the Hawaiian Islands (Perrin 1968, 1969 a,b). Dolphin associations with skipjack (Katsuwonus pelamis) and other tuna are not as common. Other species of dolphin, most notably striped dolphins (S. coeruleoalba) in the ETP and Mediterranean and common dolphins off west Africa, are known to school with tuna at times and are taken in purse seines (Simmons, 1968; Best and Ross, 1977; Magnaghi and Podesta, 1987).

The reasons for the association are unclear (see Stuntz, 1981). It is possible that tuna are schooling with dolphins, generally below them, for safety or enhanced prey-finding capabilities, due to the echolocation ability of the dolphins. It is also possible, and not mutually exclusive of the previous hypothesis, that dolphins are using tuna as an early warning signal of sharks attacking from below (see Pryor and Norris, 1978; Coe and Stuntz, 1980). The association is strong, and during daytime especially, spotted dolphins can be chased by vessels while generally retaining the tuna below. It is unclear what happens to the association at night; there is some evidence that it breaks down, and tuna and dolphin schools find each other again during early daylight (Norris et al., 1978).

Although dolphins and tuna feed on a variety of food items, a major prey for each in the ETP is the epipelagic squid, Dosidicus gigas, with stomach contents of skipjack and spotted dolphins overlapping most strongly (Perrin et al., 1973). Spinner dolphins generally feed on smaller squid than do either spotted dolphins or tuna, and spinners tend to feed more on mesopelagic squid and fish at night. Spotted and common dolphins appear to feed mainly during the day, and it is unclear how much foraging overlap there is between these two species. Regardless,

considerable prey overlap is apparently possible because of feeding on variable prey sizes and at different times of day.

Because dolphins are more easily seen from a vessel than tuna, it is not surprising that tuna fishermen learned to hunt for schools of dolphins, with high-powered binoculars, a watchman on a high 'tuna tower' on the vessel, and more recently, even with helicopters. Flocking seabirds are also used as cues to the presence of tuna/dolphin schools. Once tuna fishermen changed from hook and line fishing to the more efficient purse-seining (see McNeely, 1961), they began to set purse seine nets around dolphin schools in the hope of netting the tuna as well. Unfortunately, dolphins often become entangled in the purse-seine, and suffocate, drown, or get crushed in the power block that is used to haul the heavy net aboard. In the late 1960s and early 1970s, when the problem first became well-known, as many as 500,000 dolphins were dying annually in ETP tuna nets (Perrin, 1969b). In the late 1980s, despite many modifications in fishing gear and procedures, the annual kill was still close to 100,000 (Hall and Boyer, 1989, 1990). For a more detailed description of the recent situation, see Steiner et al. (1988).

The problem of dolphin entanglement in tuna nets is fundamentally different from entanglement in passive set and drift gillnets described below. While dolphins and porpoises tend generally to blunder into the latter, they are well-aware of the tuna seine, and become entangled in it, in large part due to finding no way out of the ever-tightening enclosure, and then panicking. To analyze the fishing-dolphin interaction, a brief description of the fishing procedure is necessary.

A spotter on the tuna vessel generally sees a dolphin school from a distance of 5 to 7 km, often sighting the accompanying birds first. The dolphins, experienced at having been caught earlier, begin rapidly swimming and leaping from the vessel at about 5 km distance (Norris et al., 1978). It is presumed that they hear the underwater engine noise of the tuna seiner, and they may even be able to distinguish purse seiners from other much larger or smaller vessels, such as transport vessels and pleasure cruisers, respectively (R.L. Pitman, NMFS-SWFSC, pers. comm., 1991). This "leaping flight" (Norris et al., 1978) is a very energetic activity, which must be especially draining for pregnant females and young calves. Leaping flight at times abruptly turns into a quiet dive by all members of the school in an apparent (and occasionally successful) attempt to evade an approaching tuna vessel by hiding below the surface. There is, undoubtedly, learning involved after repeated captures, for some dolphins react to vessels at great distances, and nearshore spinners off central America alternate leaping flight and hiding so efficiently that they have been dubbed the "untouchables."

As the tuna vessel approaches, circling speedboats and the seiner itself combine to stop the tuna/dolphin school's forward motion, and to herd the animals into a tight ball (Mendes et al., 1986). Both the noise of the engines and the substantial underwater bubble trails left by the seiner and speedboats as they churn through the sea are thought to be responsible for the herding. Bubbles form acoustic barriers to the dolphins' echolocation signals and dolphins do not cross through them (Awbrey et al., undated). Interestingly, dolphins usually will

not dive deep and out of the net to evade the surface barrier. Their social tendency is to bunch during flight, and they do not often scatter in all directions, a response which would make herding and capture ineffective.

With the help of a net skiff, the circling seiner lays a net about 1000 m long and 100 m deep around the dolphins and tuna. Once the net is attached to the seiner by both ends, the bottom is shut or "pursed" by pulling on a cable which runs through metal rings on the net, reducing the working depth of the net to about 50 m. The top of the net is held at the surface by a floatline (Figure 1). A successful net set has enclosed dolphins above and tuna below without any animals escaping (except that in mixed schools, spinner dolphins, which are considered by most fishermen to "not carry fish," are sometimes deliberately cut-out). Dolphins do not leap over the surface corkline, although they are physically capable of doing so; the crossing-over of a surface barrier without extensive training is a "psychological impossibility" for these animals (Pryor, 1987).

Once enclosed in the net, dolphins show a variety of behavioral responses. Much echolocation and whistling, apparently in distress, takes place (Coe and Vergne, 1977). Aggression, another sign of distress, also appears to be substantially higher than in unenclosed animals (Norris et al., 1978, 1985). Aggressive interchanges, usually by adult males, but also by subadult males, females, and even, at times, by mothers towards their calves, consist of mouth gaping, snapping, striking sideways with jaws or flukes, threat sounds and gestures, chasing and ramming (Pryor and Kang, 1980; Pryor and Shallenberger, 1991). In multispecies aggregations, spotted dolphins appear to be "dominant" to spinner dolphins, with spotters in the center of the group and spinners at the periphery. Dolphins generally stay near the surface in the net, as far from the seiner as possible, while maintaining some distance from the sides of the net as well. As the net is pulled-in and the enclosure becomes tighter, dolphins often raft near the surface, hanging with the top of the head out of the water and the tail down at an angle, in a quiet, listless fashion. A more extreme form of rafting, most often seen in spotters, consists of listlessly sinking to the bottom or sides of the webbing, with only occasional and feeble muscle movements (Norris et al. 1978; Coe and Stuntz, 1980). Other spotted dolphins sporadically leap and tail slap at the surface, possibly due to fear or aggression. As the net crowds the dolphins more, the danger of entanglement becomes greater; dolphins are prone to dive into netting in apparent attempts to escape, only to be enveloped in the netting, which has bunched-up around or above them (McNeely and Holts, 1977). Pelagic dolphins of the genera Stenella and Delphinus do not back-up; once their snouts or flippers have been entangled in the webbing, it is unlikely that they can free themselves and they suffocate or drown. Suffocation can happen remarkably rapidly, probably due to high oxygen usage during the previous intensive chase and the extreme fright of being captured.

Dolphins are released from the net during a procedure called "backdown," which occurs when a majority of the net is aboard the ship. Net retrieval is stopped, the net is tied down to the

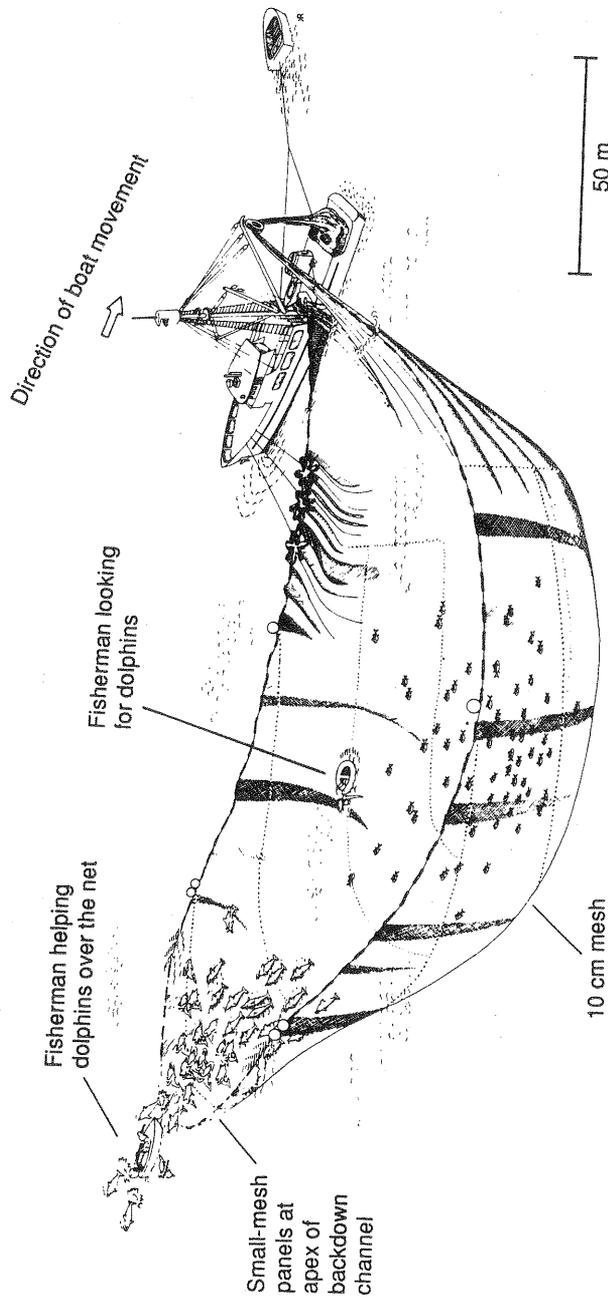


Fig. 1. "Ideal" tuna-dolphin set, with tuna below and dolphins escaping at the backdown area of the net. Unfortunately, this ideal situation is not always achieved, and dolphins can die during any portion of net setting or retrieval. Especially dangerous are net portions folding on themselves, or forming a canopy, to entrap dolphins. Figure courtesy National Marine Fisheries Service, Southwest Fisheries Science Center.

vessel, and the engine is put into reverse. The result is that the section of net in the water forms a long narrow channel (Figure 1). Dolphins are moved to the apex of the backdown channel by the resulting water current, or swim there on their own. The current also causes the end of the backdown channel to be pulled below the surface, so that dolphins can swim out. This is the most critical part of the set; on a good set, the dolphins are released unharmed at this point. This is also the point at which an operation can turn into a "disaster set," where many dolphins are killed.

Dolphins that escape the net leap rapidly away from the scene, in horizontal leaps which cover 2.3 body lengths forward, for at least 1.5 km. They then leap lower, but usually do not stop swimming rapidly until about 7 km from the vessel (Norris et al., 1978). These splashy "escape leaps" are different from the original leaping flight and appear to indicate that the dolphins know they are free (Norris et al., 1978). The energetic activity outside of the net is in marked contrast to the often listless activity inside.

There are several important sensory and behavioral features related to fishing on dolphins. Dolphins detect the sound of approaching tuna vessels from a distance and initiate evasive action. They have learned that such vessels mean trouble. Dolphins can be enclosed by sound and air bubble "walls" around them. They have not learned that they can dive deeply or scatter to avoid the acoustically confusing stimuli. Once enclosed by netting, they could still dive down and out before the net bottom is pursed, but again they appear confused and disoriented and such escape usually does not take place. As the net is pursed and hauled-in, dolphins could jump over the corkline to freedom, but this is not in their behavioral repertoire. They definitely sense the net, both by their excellent vision (Dawson, 1980) and by echolocation (Awbrey et al., undated; Leatherwood et al., 1977; Wood and Evans, 1980). They attempt to stay away from the net until desperate dashes take them into it if an opening, such as the backdown channel, does not appear. Free dolphins may know that they are no longer in direct danger because of their exuberant-seeming leaps (Norris et al., 1978). However, the fact that they rapidly move far away from the site may argue against this hypothesis.

Rafting and sinking behaviors result in very quiescent animals which generally do not become entangled, and under which the net may often be pulled during backdown. However, the interpretation that rafting is a learned behavior to decrease the chance of entanglement is unlikely. Instead, the observed listlessness may be due to fear and exercise overload of nerves and muscles (myopathy, Harthorn, 1973; Colgrove, 1978; Coe and Stuntz, 1980). It could also be a form of de-arousal in which an overloaded sensory system uncouples stimuli at the level of the brain (Delius, 1970; Norris et al., 1978). Dolphins appear to have "given-up" and allow anything to happen to them, including humans handling them while physically shunting them over the net. The discovery that they can still be saved resulted in significant reductions of dolphin deaths, because previously these animals were considered dead by the fishermen, and backdown was ended prematurely.

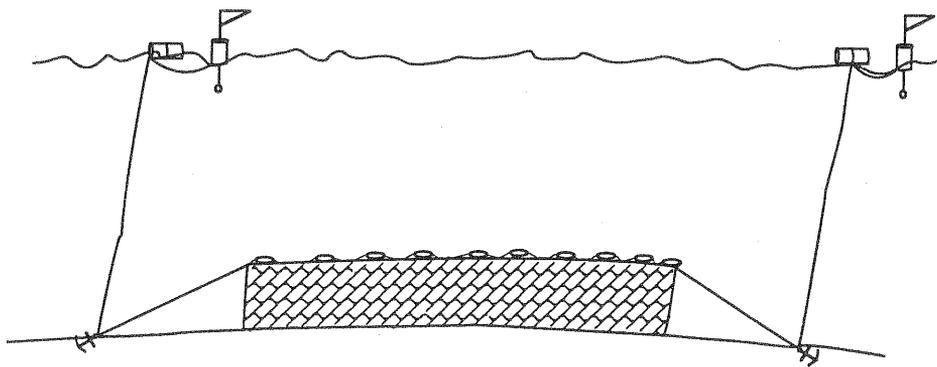
The two major behavioral studies to investigate dolphin behavior in and around tuna nets disagree somewhat on level of fear and abnormal behaviors. Pryor and Kang (1980) and Pryor and Shallenberger (1991) described nursing, sexual solicitation, copulation, and some other normal-seeming social interactions inside the nets. They deduced that dolphins of the ETP are so used to purse seining that being enclosed is, at times, almost "business as usual" and not at all that disruptive. Norris et al. (1978), on the other hand, pointed to what they describe as excessive aggression, huddling, and rafting/sinking to argue that the animals are in mortal fear, and that their behaviors and social interactions must be understood in that vein. The issue is far from settled, and some experienced dolphins may react calmly and know what to do, as reported by Wells (1989), for repeatedly-caught bottlenose dolphins (*Tursiops truncatus*). However, we believe that because of the unnatural confinement of pelagic dolphins, totally unused to barriers in their environment, and the occasional catastrophic deaths of schoolmates during seining, dolphins are in great psychological stress before, during, and after netting.

### Gillnets

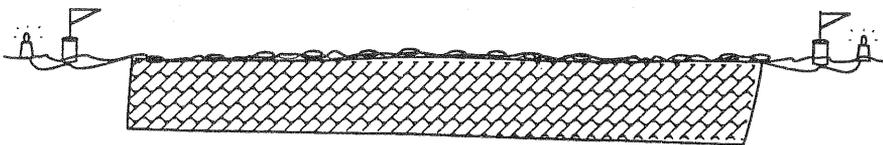
Dolphins and porpoises (and occasionally large whales) become incidentally entangled in gillnets each year in alarming numbers (see International Whaling Commission, in press). Unlike the case of purse seine nets, where dolphins are surrounded by the net with no apparent escape, small cetaceans swim into gillnets and become entangled, despite the fact that they could easily dive under or go around the net in almost all cases (Figure 2). Thus, the early assumption was made that the animals can not detect the nets, or at least the monofilament nets now used in many fisheries, either visually or with echolocation (Awbrey et al., 1979). The problem of non-detection would be potentially solvable by increasing the acoustic reflectivity of the nets or adding sound generators to alert the porpoises.

The non-detection theory seemed plausible at first. Certainly the low-visibility of monofilament nylon gillnets (see Brandt, 1984) would make them nearly invisible even to the excellent visual capabilities of dolphins and porpoises (Herman et al., 1975; Dawson, 1980; Mass and Supin, 1990). In fact, invisibility is the primary principle on which gillnets work, especially at night when most fisheries operate.

With vision ruled-out, this left hearing as the only primary sense likely to alert the animals to the presence of a net in enough time to avoid entanglement. The work of Awbrey et al. (1979) on the Dall's porpoise (*Phocoenoides dalli*) interaction with the salmon driftnet fishery of the North Pacific indicated that the target strength of the monofilament webbing was too low for the porpoises to detect. However, knots in the webbing and floats and leadlines have higher target strengths than the filaments themselves. Research on reduction of entanglement therefore focused on increasing acoustic reflectivity of nets and adding sound generators to alert porpoises (see Dawson, 1991).



a.



b.

Fig. 2. Schematic diagrams of types of gillnets: typical set gillnet (a), and typical driftnet (b). Gillnets are generally used passively as vertical walls of webbing. Since they are designed to be invisible, marine vertebrates, including cetaceans apparently swim into them by accident and drown or suffocate.

Early indications that small cetaceans are capable of detecting gillnets (Walker, 1979; Jefferson, 1985) seemed at odds with the non-detection theory. Recently, much evidence has been gathered that strongly suggests that small cetaceans do have the acoustic capabilities to detect gillnets (Evans et al., 1988; Peddemors, 1989; Hatakeyama et al., 1990; Hatakeyama and Soeda, 1990; Au and Jones, 1991; International Whaling Commission, in press).

The International Whaling Commission gillnet workshop (International Whaling Commission, in press) gathered evidence that the nets are probably detectable visually (under some conditions), acoustically (under most conditions), and by a variety of other sensory cues (occasionally). If dolphins and porpoises can detect gillnets, then why do they become entangled? This dilemma is at the heart of the problem, and the difficulty in answering it seems to be the major stumbling block to finding methods of eliminating or reducing take. Among the possible reasons are: (i) the animals may not be echolocating all the time; (ii) nets may be detected, but not perceived as dangerous barriers (for instance, foraging porpoises may disregard net echoes as "acoustic clutter," as proposed by Evans and Awbrey, 1988; Evans et al., 1988); (iii) dolphins may fail to detect the nets through inattention during resting, feeding, or socializing; and (iv) nets may be detected, but navigational errors may result in entanglement (porpoises may even be attracted to areas of nets by prey, thus increasing their chances of becoming entangled through navigational errors).

The absence of echolocation may present a major problem, for many species of dolphins and porpoises do not echolocate all the time. Hector's dolphin (*Cephalorhynchus hectori*), a frequently caught species, has been documented to be silent much of the time (Dawson, 1991). Small cetaceans that live in the open ocean, which is normally free of obstacles, and those coastal species that have some site fidelity and know their physical environment well, may be expected to be quiet when not actively engaged in food searching or some other activity that might require echolocation. It is not of advantage to advertise oneself to potential predators such as killer whales (*Orcinus orca*). If it is true that small cetaceans spend much time not echolocating, then a large part of the incidental catch problem will be explainable, and gillnet modifications that attempt to increase reflectivity will be of little use in reducing bycatch.

Various physical conditions, such as light levels, turbidity, ambient noise, currents, and sea state may be important in the ability of small cetaceans to detect and avoid gillnets. Also, behavioral factors may be important. The behavioral state of the animals will affect their susceptibility, as will their social environment. For instance, the sensory integration function of large herds of delphinids may help them avoid entanglement (K.S. Norris, University of California, Santa Cruz, pers. comm., 1991). However, despite previous assumptions that gillnet entanglement was largely a problem for phocoenids, recent expansions of driftnet fisheries into the ranges of some pelagic delphinids, such as Pacific white-sided dolphins (*Lagenorhynchus obliquidens*) and northern right whale dolphins (*Lissodelphis borealis*) have resulted in large kills of these

species (see Northridge, 1990 for review). Even when small cetaceans swim into a gillnet, they can sometimes avoid entanglement by breaking through the net, at least if they approach perpendicularly at high speed (Hatakeyama et al., 1990).

Ultimately, we do not know how different species of small cetaceans detect gillnets in various circumstances. We know that they have the ability to detect them in certain cases, but the specific conditions that result in entanglement are unknown. Attempts to modify nets without such information will not likely meet with a high degree of success.

#### Trawl Nets

While the problems of purse seines and monofilament gillnets have been widely publicized, interactions of cetaceans with trawl nets also occur, but to an undetermined, yet potentially damaging, magnitude. Animals can be affected by trawls in three different ways: (i) nets may provide an easy food source; (ii) animals may become entangled in operating nets, causing harm to the animal or damaging the gear; and (iii) they may become entangled in discarded gear. Several cues may be used by the animals to detect the nets. Engines on trawlers produce a characteristic sound, particularly when changing stages of operation. It has been suggested that some odontocetes are able to acoustically distinguish between stages of trawl operation. Bottlenose dolphins are attracted when nets are deployed (Gunter, 1954) and have been seen approaching shrimp boats to wait for bycatch to be culled (Norris and Prescott, 1961; Leatherwood, 1975). Killer whales have been observed to do the same with trawlers in the Bering Sea (J.R. Heimlich-Boran, Cambridge University, pers. comm., 1991). Gruber (1981) documented various reactions of bottlenose dolphins to operational stages, including following the net as it was being hauled in, and at other other times, switching to boats trawling in the vicinity.

Gear characteristics can be important variables in the detectability of nets. Knots between meshes, floats, and ropes have been shown to be readily apparent to cetaceans in captive environments (Hatakeyama et al., 1990). Nets produce sounds as water moves through them. Fish, held by the nets, may also produce sounds (Lien et al., 1990). It has been postulated that bottlenose dolphins and killer whales may detect prey by passive listening (Barros and Myrberg, 1987; Ford and Fisher, 1983). An echosounder operating at 38 kHz was implicated in the incidental take of four Atlantic spotted dolphins (*Stenella frontalis*) and two bottlenose dolphins by a National Marine Fisheries Service (NMFS) research trawl (R. Ford, NMFS-SEFSC, pers. comm., 1991).

Eight odontocete species have been documented to feed in association with trawls; bottlenose dolphins are the most common (Fertl, in prep.). Cetaceans are probably attracted to trawls because they represent a concentrated food source that it easy to exploit. Dolphins appear to be interested in all stages of shrimp and prawn boat operation: trawling, raising nets, and discarding of bycatch.

Feeding around shrimp boats has been suggested to be a learned behavior (Shane, 1991). Females with calves have been

seen following shrimp boats (Gruber, 1981; Corkeron et al., 1990), and it is likely that the calves are learning this foraging behavior by observation and participation. Such observations may also indicate that lactating females are taking advantage of this concentrated food source to meet increased energetic needs (Fertl, 1991).

There has been some speculation as to how cetaceans become caught in trawls. It appears that many of the cases of entanglements in trawl nets may be a result of cetaceans attempting to capitalize on human activities. There are many factors that influence an animal's chances of becoming entangled; behavior around the nets and species distribution are two of the most important. For instance, the sociality of some species may be a factor in multiple entanglements, and this has been suggested to be the case for pilot whales (*Globicephala* spp.) in the Northeast Atlantic (G. Waring, NMFS-NEFSC, pers. comm., 1991). Young animals may fall victim more than adults, because of lack of experience around nets or other related behavioral traits. Distribution will be an important factor where the species' range overlaps areas of heavy fishing.

Entanglement in discarded gear is fundamentally different from entanglement during an active trawl. During trawling, marine mammals are probably aware of the net and the boat's activity, but they become entangled due to navigational mistakes or unexpected folding or jerking of nets or related fishing gear. Entanglement in trawl-web fragments, however, is more akin to entanglement in gill nets, and is probably usually caused by blundering into the discarded netting.

#### Other Fisheries

Some cetacean entrapment in traps and weirs occurs, especially on the east coast of Canada. Humpback whales (*Megaptera novaeangliae*) are not thought to detect cod traps visually in Newfoundland and Labrador, even though entanglement in nets occurs primarily at night. The acoustics of the nets have been investigated, and it has been suggested that cod traps are less acoustically detectable than capelin traps, in which the whales rarely become entrapped (Lien et al., 1990).

Cetaceans also interact with longline fisheries. Gear damage, fish loss (both as a result of predation on hooked fish by cetaceans), and incidental catch have been reported. Killer whales, at least, appear capable of detecting the lines and hooks, although there is much less information available on this type of interaction than there is for purse seines and gillnets (see Dahlheim, 1988).

#### ATTEMPTS TO REDUCE OR ELIMINATE ENTANGLEMENT

##### Purse Seines

Since the beginning of setting purse seines on dolphins to catch tuna, in the late 1950s, suites of gear and procedural modifications have lowered the average dolphin kill per set. For

example, while about 50 dolphins were killed per set, on average in 1973, this figure was reduced to about 5 by 1977, by the U.S. tuna fleet (Coe et al., 1985). Nevertheless, disaster sets of over 25 dolphins killed still occur. The major modifications are two-fold: (i) Fishermen have initiated the backdown procedure which consists of pulling the outer portion of the net underwater and under the rafting dolphins, freeing them while not allowing the tuna below to escape. A tender is stationed at the backdown area to physically help dolphins that are passively milling over the slightly submerged net. Backdown is a tricky procedure requiring some skill in appropriately handling the net relative to wind, current, placement of dolphins and tuna, and amount of bunching and folding of the net (Mendes et al., 1986). Disaster sets usually occur when the net collapses upon itself, enclosing the dolphins and making backdown impossible or ineffective. Disaster sets are especially common when nets are set in the evening and last into the night (Coan et al., 1988). Danger in sundown sets comes from reduced gear handling and dolphin detection capabilities, partly solved by large floodlights to illuminate the area, but is probably also due to decreased sensory capabilities of the dolphins. (ii) A smaller-mesh panel, of variable size and with mesh size of about 3 to 5 cm (often called the Porpoise Safety Panel or Medina Panel), has been sewn into the top, outer (away from the vessel) portion of the net in the area that forms the apex of the channel during backdown (normal mesh is about 11 cm). The smaller mesh panel entangles dolphins less easily than the wide mesh, even if they rush at the smaller webbing (Barham et al., 1977). Unfortunately, not all of the net can be made of this safer mesh size because the net would be much too heavy to deploy efficiently, and it would sink too easily.

Over the years, many devices and techniques have been proposed to reduce the kill of dolphins in tuna nets (see review by Coe et al., 1985). The two main ones, small-mesh panels and backdown, have already been described. Other gear modifications and procedures have also been useful. Of direct and measurable help has been the physical aid of distressed or entangled animals, moving them over the net by hand (Coe and Sousa, 1972). Divers or simply people viewing underwater from rafts have been stationed in the backdown area and can signal the skipper when backdown can proceed safely, and what the dolphin status is during different stages of net hauling (Coe et al., 1984). Other techniques have been less useful. A proposed method of crowding the dolphins to one side of the net by movement of a curtain net, or hukilau (Östman et al., 1990) is unlikely to be successful, since crowding increases dolphin agitation and entanglement (Perrin and Hunter, 1972). Playbacks of killer whale sounds have also been tried, with similar confusing effects, and have been discontinued. Artificial bubble nets (created by dry ice) and high intensity strobe lights to herd the dolphins, have had equivocal success and are also not being used anymore (Coe et al., 1985).

### Gillnets

Despite a lack of knowledge on why and how small cetaceans become entangled, fairly extensive research on reduction of take in gillnets has been conducted. Attempts to reduce or eliminate

cetacean entanglement in gillnets have been of three types: (i) increasing acoustic reflectivity of nets; (ii) adding sound generators to nets; and (iii) hanging nets from lines, so that the top of the net is below the surface.

Studies of Dall's porpoise entanglement in the North Pacific Japanese salmon gillnet fishery have attempted to increase the reflectivity of the nets by incorporating several meshes of hollow threads and multifilament line into the nets. The philosophy is that the hollow threads and multifilaments trap air and should thus increase the target strength of the nets. Japanese researchers reported some significant reductions in cetacean catch rate (Hatakeyama et al., 1990), but on the whole the results are considered weak and inconsistent (see Dawson, 1991). This is not surprising, since target strength studies of hollow tube nets have shown weak and inconsistent differences from unmodified nets (Pence, 1986; Au and Jones, 1991).

Another approach to increasing acoustic reflectivity of the nets is to add reflective materials, such as rope, blister packaging, surgical tubing, bead chain, or aluminum discs. Despite greater target strengths of some of the objects (Au and Jones, 1991), results of attempts to decrease catch rates with nets incorporating them have also been inconclusive or unsuccessful (Hembree and Harwood, 1987; Hatakeyama et al., 1990; Peddemors and Cockcroft, 1990; Peddemors et al., 1991). In the only observational study so far conducted on small cetacean behavioral responses to gillnets, Silber et al. (1989) found that harbor porpoises in Monterey Bay, California changed their course in response to various objects hung on hukilaus (Hawaiian fish capture devices consisting of a corkline with only hanging lines), which were used as gillnet substitutes. However, sample sizes were small and no object was totally effective in diverting porpoises from the hukilaus.

Sound emitters have also been tried. In the Japanese salmon mothership gillnet fishery, where Dall's porpoise entanglement was a problem, four types of active sound generators were tried, with minor success (Hatakeyama et al., 1990). Passive and active sound emitters tried on South African shark gillnets to reduce dolphin incidental catch also turned-out not to be effective due to inconclusive results and various technical difficulties (Peddemors and Cockcroft, 1990; Peddemors et al., 1991).

Recently, some fisheries have tried a simple modification of nets, in which the top of the net (usually at the surface) is suspended from floats and lines. Such subsurface gillnets used in Australia (Hembree and Harwood, 1987) and in the South and North Pacific (Hayase and Watanabe, 1990) have shown some promise in reducing cetacean catch rates; however, results are preliminary and such modifications will not be appropriate for coastal set gillnets which already fish several meters below the surface or on the bottom.

#### Trawl Nets

Attempts to reduce entrapment in trawls have been biased toward pinnipeds, due to the alarming number of animals that are caught in this manner and the damage they incur to the nets.

Shaughnessy et al. (1981) reported on attempts to develop acoustic methods of keeping Cape fur seals (Arctocephalus pusillus) from fishing nets. Seals moved away from firecrackers that exploded underwater, and from 0.303-inch caliber rifle bullets fired into the water near the cod-end of a trawl net, but did not respond to bullets fired over their heads. An arc-discharge transducer was developed to produce underwater compression and sound levels similar to those resulting from firecrackers and bullets. The transducer was effective when played at the cod-end of a trawl net lying at the surface.

For bottlenose dolphins, as in the case of fur seals, firecrackers detonated near the animals, and bullets fired in the water nearby do cause the animals to flee from the nets (Reynolds, 1985). A Texas bay shrimper was prosecuted for shooting at dolphins (U.S. vs. Mossier). Cadenat (1957) reported that bottlenose dolphins attack nets in West African waters, and that explosives were used to scare animals away. Transducers have not been used as cetacean deterrents. Shrimpers in Mississippi have also tried methods less harmful to the animals. Long, colored plastic strips tied to the net's mesh seem to deter some bottlenose dolphins. Other shrimpers are resorting to an extra mesh skirt attached near the cod-end to scare animals from the nets. In areas where dolphins harrass nets, some shrimpers believe that the dolphins are reacting to low fish productivity brought on by human activities.

Attempts have been made to reduce pilot whale entanglement in the Northeast Atlantic. Foreign fishing vessel captains have been instructed to avoid haulback operations in the vicinity of animals, and to monitor cetacean activity during these operations (G. Waring, pers. comm., 1991). These procedures are thought to have helped reduce cetacean bycatch; however, field experiments have not been conducted.

#### Other Fisheries

As far as we know, there have been no attempts to reduce cetacean takes in other fisheries, except for some work on reducing large whale entrapment in cod traps off Newfoundland and Labrador (Lien et al., 1990). The motive for this work is as much to reduce gear damage by the whales as it is to reduce whale injury or death resulting from entrapment. Several sound emitters were tested; low-frequency "beepers" significantly reduced catch rates and have been in use now since the early 1980s (Lien et al., 1990).

#### CONCLUSIONS AND RECOMMENDATIONS

Extensive research has been conducted on dolphin behavior relative to tuna purse seines, and this has contributed significantly to past reductions in catch rates. The innate reactions of dolphins that have not learned to deal effectively with barriers are going to continue to cause death to at least some of them in tuna nets. They do not know that they can swim through acoustically opaque bubble screens, jump over nets at the surface, or back-up once their snouts become entangled in netting. If the goal is to reduce dolphin deaths to zero in the

tuna purse seine fishing industry, tuna boats should no longer set on dolphins. Instead, they can set on logs and other oceanic debris, which often harbor tuna underneath, as is being done successfully in many parts of the world, including the ETP.

In contrast, we know almost nothing about how cetaceans detect and respond to gillnets. Due to the so-far unimpressive and inconclusive results of attempts to reduce catch rates by modification of gear, we concur with Dawson (1991) that management action must proceed, in cases of serious kills, along the lines of time and area closures of fisheries. Any further attempts to reduce catch rates by modifications of gear must address the need to understand why dolphins and porpoises become entangled in gillnets. All aspects (not just acoustic ones) of the small cetacean/gillnet interaction must be examined. Until workable modifications are found that will bring about major reductions in cetacean catch rates, fisheries with known serious kills should be shut down, and those with suspected serious kills must be investigated immediately.

Based on the fact that a few cetacean species have been seen feeding in association with trawl nets, many of the entanglements may be a result of animals attempting to capitalize on human activities. Almost the only reliable information comes directly from fishermen involved. Although useful corroborating information may be obtained, even fishermen in the same port may know little about incidental catches of other fishermen. Now that the link between reporting entanglements and stricter fishing regulations has been made clear, interviews with fishermen are unlikely to give reliable information. Fishermen seldom provide unsolicited reports of entanglements to government agencies.

Although we now have reasonably accurate estimates of incidental catch of cetaceans in the ETP purse seine and in some gillnet fisheries, we know very little about behavioral responses and interactions with nets. We can not wait for incontrovertible evidence of serious problems to take action. Proper systematic documentation of all cetacean entanglements and entrapments should be encouraged. Where possible, independent observer programs should be used to obtain such information, as well as better data on numbers of animals taken.

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