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Behavioral responses of bottlenose dolphins, *Tursiops truncatus,* to gillnets and acoustic alarms

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Abstract

Along the east coast of the United States, by-catches of bottlenose dolphins, *Tursiops truncatus*, in gillnet fisheries exceed removal levels set under the US Marine Mammal Protection Act. One measure proposed to reduce this mortality is the use of acoustic alarms, or pingers, which have proven effective in reducing by-catches of other small cetaceans, but have not been tested with bottlenose dolphins. We examined the responses of bottlenose dolphins to a commercial gillnet equipped with functional (active) and non-functional (control) Dukane NetMark® 1000 alarms near Fort Macon, NC. Between 5 April and 10 May 2001 we used a theodolite to track 59 groups of dolphins around the net. Choice of treatment was random each day and the two shore-based observers were unaware of whether alarms were active (13 days) or controls (9 days). There were no significant differences in the number of groups observed ($P = 0.315$; $1-\beta = 0.835$) or in the closest observed approach to the net ($P = 0.307$; $1-\beta = 0.828$) between treatments. However, dolphins entered a circular buffer approximately 100 m around the net more frequently with control than active alarms ($P = 0.015$). We conclude that some dolphins responded to the alarms by avoiding the net, but caution that the potential efficacy of alarms is confounded by dolphin behavior. Most dolphins were aware of the net, regardless of the status of alarms, and some dolphins fed on fish in the net or discarded by the fishing vessel. We believe that it would be unwise to use pingers in these fisheries because of the limited behavioral responses we observed in our experiment. Furthermore, the responses we observed are likely to diminish or change over time as dolphins habituate or sensitize to these alarms. Further research is required to understand the behavior responsible for entanglement.

Keywords: Behaviour; Bottlenose dolphins; By-catch; Fisheries; Noise

1. Introduction

By-catch, the unintended catch of non-target species in fishing gear, is one of the primary conservation challenges facing fishery managers today. By-catch can have severe impacts on marine populations, species, communities and ecosystems (Alverson et al., 1994). By-catches can be especially problematic for species that are long-lived, have slow growth rates and low fecundity, such as marine mammals, seabirds, and elasmobranchs. These long-lived species are at an even higher risk if caught in a fishery targeted at and managed for short-lived species with high fecundity (Alverson et al., 1994; Dayton et al., 1995). For example, the common skate, *Raja batis*, is locally extinct in the Irish Sea (Brander, 1981), and the barndoor skate, *Raja laevis*, is severely depleted in the northwest Atlantic (Casey and Myers, 1998), due to high by-catch rates in groundfish trawl fisheries. Declines in the abundance of such large predators due to by-catches can have severe impacts on the trophic structure of marine communities (Crowder and Murawski, 1998; Fogarty and Murawski, 1998; Dayton et al., 1995; Alverson et al., 1994). In addition, by-catch can have catastrophic effects on small populations or populations already under pressure from other environmental stressors, such as the vaquita, *Phocoena sinus*, in the Gulf of California (Rojas-Bracho and Taylor, 1999)

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and the baiji, *Lipotes vexillifer*, in the Yangtze River (Kaiya and Yuemin, 1989).

Large numbers of dolphins and porpoises are taken as by-catch world-wide, primarily in gillnet fisheries, endangering several populations and species (Jefferson and Curry, 1994; Perrin et al., 1994). A variety of measures have been used to address this problem in different areas (IWC, 2000, 2001), including time-area fishery closures (Murray et al., 2000), permanent marine protected areas in which the use of gillnets is banned (Dawson and Slooten, 1993) and modification of fishing gear or practices (IWC, 2001).

Another mitigation measure designed to reduce the by-catch of small cetaceans in gillnets is the use of acoustic alarms, also known as pingers (IWC, 2000). Pingers are small devices attached to gillnets that emit a high frequency sound. The devices are intended to either deter dolphins and porpoise from the nets or to warn animals of the presence of a potentially dangerous barrier (see Dawson et al., 1998). In a controlled experiment, Kraus et al. (1997) demonstrated that pingers caused a significant reduction in by-catch of harbour porpoises, *Phocoena phocoena,* in a gillnet fishery in the Gulf of Maine. Since that study was conducted, pingers have been shown to be effective in reducing by-catches of harbour porpoises in other gillnet fisheries (Gearin et al., 2000; Trippel et al., 1999) and in reducing by-catches of common dolphins, *Delphinus delphis,* in the California drift gillnet fishery (Barlow and Cameron, 2003). The use of pingers is currently required in both the Gulf of Maine and California fisheries (IWC, 2000).

In response to a high by-catch of bottlenose dolphins, *Tursiops truncatus*, in gillnet fisheries along the US east coast, the US National Marine Fisheries Service convened a Take Reduction Team (TRT) in November 2001. The TRT is comprised of stakeholder representatives and is charged with negotiating a plan to reduce the by-catch of dolphins to below the allowable mortality limits set under the US Marine Mammal Protection Act (Young, 2001). One of the management options available to the team is the use of pingers. However, to date there have been no tests of the efficacy of pingers in reducing by-catch of bottlenose dolphins in gillnet fisheries in the USA or elsewhere. It is not appropriate to generalize from the results of previous field tests on other species (IWC, 2000), particularly when there are inter-specific differences in behavior, such as those that exist between relatively shy harbor porpoises and the more inquisitive bottlenose dolphins. It is entirely possible that dolphins might not react to the sound of a pinger or, even worse, that animals might learn to associate pingers with food (fish gilled in the nets), the so-called “dinner bell” effect (Richardson et al., 1995).

Predicting the reaction of bottlenose dolphins to pingers is further complicated because we do not understand the mechanism by which dolphins are caught in gillnets, nor do we know much of the behavior of dolphins around nets. Fishermen in North Carolina have noted that dolphins interact frequently with their nets without becoming entangled (Hagedorn, 2002). Thus, it is likely that entanglement of bottlenose dolphins is a rare occurrence, compared to the amount of time that dolphins spend around gillnets.

We were interested in determining whether the use of pingers would reduce the by-catch of bottlenose dolphins in gillnet fisheries along the US east coast. It was not possible for us to conduct a full-scale field test, such as the experiment of Kraus et al. (1997), to determine whether or not pingers would be effective because the by-catch *rate* of dolphins in these gillnet fisheries is too low to allow for a statistically meaningful experiment (see Palka and Rossman, 2001). A very large, and prohibitively expensive, number of fishing trips would have to be observed to determine whether or not pingers were effective. Thus, we used an observational approach to determine the behavioral response of dolphins to gillnets and pingers. We designed a field experiment to accomplish two objectives: (1) investigate the reactions of bottlenose dolphins to a gillnet equipped with pingers and (2) determine how bottlenose dolphins interact with gillnets.

2. Methods

2.1. Study area and experimental design

Between 5 April and 10 May 2001, we monitored dolphin movements around a bottom-set gillnet near Ft. Macon State Park, Atlantic Beach, NC, USA (Fig. 1). This is an area where by-catches of bottlenose dolphins have been recorded in nets like the one used in our experiment (Waring et al., 2001). We set a commercial gillnet each morning approximately 300 m from the beach, perpendicular to shore, in 3–6 m of water, and hauled it at the end of the observation period each day. The net was 200 m long, with a stretched mesh of 7.6 cm, anchored on the bottom and demarcated at the surface with orange buoys at each end. Our fishing protocol was similar to that used by commercial fishermen in this area, except that we set the net in the same location each day to facilitate observation from our shore station.

Our fishing vessel or photo-id vessel stood by at all times while the net was set in case of entanglement. We equipped the net with three Dukane NetMark® 1000 pingers: one on each end and the third on the middle of the cork line. Dukane NetMark® pingers emit a regular interval pulsed, broadband signal with a fundamental frequency of 10 kHz and a minimum sound pressure level of 132 dB re 1 μPa at 1 m, which meets the current regulatory specifications for pingers in the Gulf of

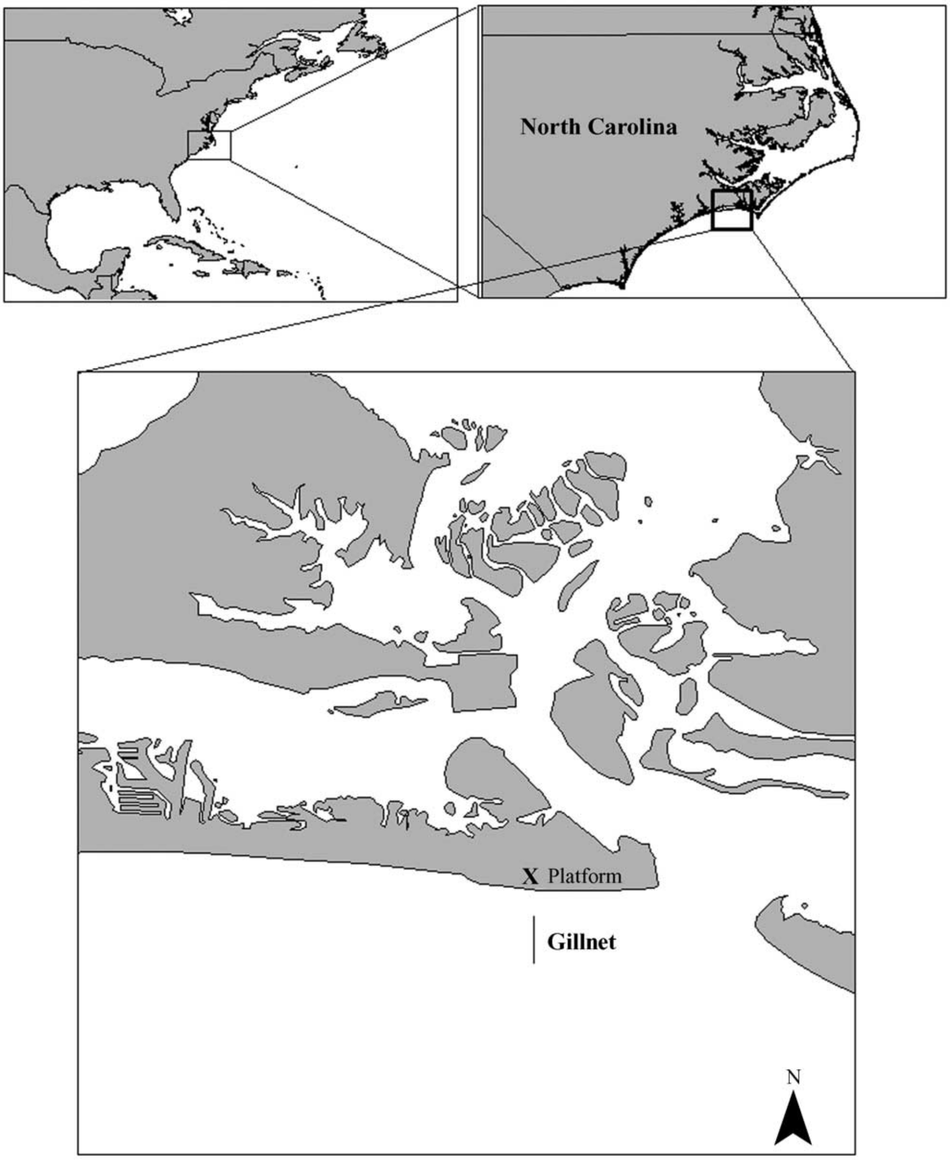

Fig. 1. Study area. Fort Macon State Park, Atlantic Beach, North Carolina, USA.

Maine (Federal Register, 1998) and is well within the hearing range of bottlenose dolphins (Johnson, 1967). Each day the pingers were either on (active) or off (control—batteries placed in backwards); we chose the treatment randomly each day. Sound pressure level and frequency decrease with decay in battery voltage (Trippel et al., 1999), so we changed the batteries on 21 April 2001 after 46 h of use and tested the voltage of the batteries after they were removed and at the end of the study.

2.2. Tracking

Two researchers tracked the movements of dolphins using a TopCon® total station from a 3.8 m raised platform approximately 300 m from the net. The total station, also referred to as a theodolite, allowed us to measure relative horizontal and vertical angles to the position of dolphin surfacings and to the buoys demarcating the ends of the net. From these angles and the known height of the platform, we used trigonometry to calculate the relative positions of the net and dolphins. We measured the positions of the buoys on the net every 15 min, as they moved slightly with the tides and currents. The observational area encompassed a 300 m radius around the net, delimited by a rock jetty to the East, a pier to the West, the shoreline to the North, and sighting distance to the South. One researcher, the *surveyor*, used Fujinon® 7×50 binoculars to scan the observational area for dolphins. The surveyor looked in concentric circles around the net, extending out to 300 m. This individual reported sightings of dolphins to the *tracker*, the researcher stationed at the theodolite. The tracker used the theodolite to track each surfacing of the lead dolphin in a group until (1) the animals left the study area or (2) the tracker lost sight of the group or could not confirm that it was the same group. We also terminated tracking and field effort if the Beaufort Sea State exceeded 3. The tracker and surveyor were not aware of the status of the alarms, i.e. control or active.

2.3. Photo-identification

After the dolphins exited the study area, the surveyors contacted researchers on a 7 m outboard-powered research vessel via VHF radio. Researchers aboard this boat approached the group to obtain photos of the dorsal fins of each dolphin using a Nikon N-90, 300-mm lens, and color slide film. We attempted to photograph every dolphin in each encounter. We used standard photo-identification techniques (Würsig and Würsig, 1977) to identify all distinguishable dolphins and determine if individual animals encountered the net on multiple occasions.

2.4. Sound field

We measured the sound field radiated by the pingers on 10 May 2001. The day was clear and the Beaufort Sea State was 2. Researchers in the boat drifted past the net parallel to shore while the tracker recorded the position of the boat at 1-min intervals using the theodolite. Observers in the boat monitored the sound produced by the pinger with a High Tech, Inc. HTI 96-MIN calibrated hydrophone connected to a TCD-D8 DAT recorder. We conducted eight drift transects through the study area from west to east, with the weighted hydrophone 3 m below the surface. Using Syntrillium Software Corporation's Cool Edit 96, we uploaded the recordings using 44,100 Hz sampling rate, 16-bit, and single-track settings. We then created a power spectrum (FFT 1024 points, Hanning window) to estimate the relative sound pressure level. We converted the relative decibel levels to absolute decibel levels, using the following equation:

$$Y = 0.8625x + 158.04 \text{ dB}$$

We derived this equation using known source level sounds of 250 Hz, 1 kHz, and 2 kHz ranging from 120 dB re 1 μPa at 1 m to 170 dB re 1 μPa at 1 m and an oscilloscope to calibrate the Cool Edit readings with absolute decibel levels. At each tracking position we assigned the greatest absolute dB level obtained within 8s of recording that position. We then interpolated (spherical semivariogram model, lag size: 0.5 m, search radius: 50 points) in ArcGIS 8.1 to map the sound field.

2.5. Analysis

For each experimental treatment, we standardized the number of dolphin sightings by the duration of observation (h), using each day as a replicate and tested for differences between the two treatments with a two-tailed *t*-test. We also examined *point of closest approach*, defined as the minimum distance between the net and a surfacing dolphin. In this analysis we only used tracks with more than three points and tested for differences between treatments with a two-tailed *t*-test. In ArcView 3.2, we constructed a *zone of vulnerability*, a 100 m buffer around the center of the net, and tested for differences in the frequency with which dolphins entered this zone with a Chi-squared test.

Kraus et al. (1997) demonstrated that pingers reduced catches of Atlantic herring (*Clupea harengus*) in the Gulf of Maine. Therefore, we tested for differences in fish catch between the two treatments. We estimated weight of the fish catch by eye as the net was hauled, standardized it by soak time, and tested for differences between treatments using a Kruskal–Wallis test. We conducted all statistical tests in SPSS; means are reported with their associated standard deviations.

3. Results

We tracked 59 groups of dolphins through the study area on 22 days (Table 1). However, for the point of closest approach and zone of vulnerability analyses, we only considered tracks that contained 3 or more points ($N=40$). No dolphins were entangled in the net during the course of this study.

Number of dolphin groups observed per hour ($t=1.030$, df=20, $P=0.315$, $1-\beta=0.835$) and closest observed approach to the net ($t=-1.035$, df=38, $P=0.307$, $1-\beta=0.828$) did not differ significantly between the two treatments (Table 1). However, dolphins entered the zone of vulnerability significantly more frequently when the pingers were off than when they were on ($P=0.015$); 7 out of 15 groups entered the zone during the control treatment, while only 2 out of 25 groups entered the zone while the pinger was active

Table 1
Summary of results

	Control	Active	P	$1-\beta$
Days	9	13		
Hours	56	78		
Groups	26	33		
Groups/h	0.56±0.53	0.38±0.36	0.315	0.828
Tracks	15	25		
COA (m)	38±33.8	47.4±23.6	0.307	0.835

Means are shown with their associated standard deviations. "Tracks" refers to those tracks for which we recorded three or more positions. $1-\beta$ represents the power of the statistical test. A power of greater than 0.8 is considered sufficient to accept the null hypothesis of no difference (Peterman, 1990).

(Fig. 2). Fish catch did not vary with treatment (Table 2).

We were unable to take photographs of every group due to weather and other factors. We obtained photographs of 15 groups of dolphins that were tracked and identified 29 individual dolphins in these groups. We tracked at least 16 dolphins on multiple occasions (Fig. 3). The maximum number of encounters we documented between an individual dolphin and our experimental net was five (mean 2.34) and individuals were exposed to active alarms on up to 4 days. From these

Table 2
Average fish catches (with associated standard deviations) in kg/h

	Kingfish	Bluefish	Dogfish	Menhaden
Control	0.32±.43	2.7±4.8	2.1±4.5	1.3±2.2
Active	3.5±9.9	3.3±5.0	3.8±4.9	3.4±5.4
P	0.51	0.47	0.13	0.11
$1-\beta$	0.84	0.94	0.87	0.80

$1-\beta$ represents the power of the statistical test. A power of greater than 0.8 is considered sufficient to accept the null hypothesis of no difference in fish catch (Peterman, 1990).

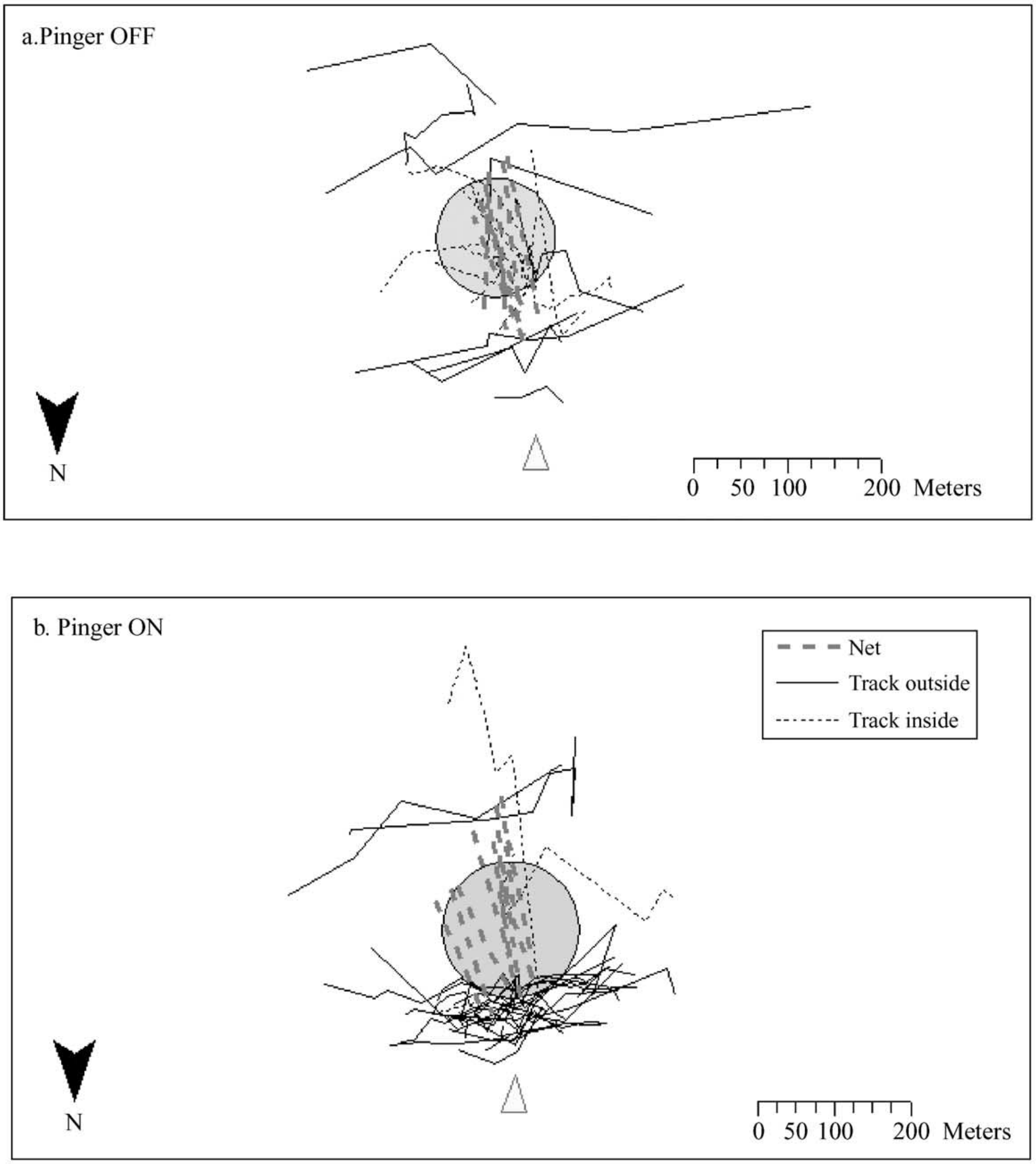

Fig. 2. Tracks (solid and dotted lines) and net positions (dashed lines) when the pingers were off (a) and on (b). Triangle denotes position of theodolite. Tracks within the zone of vulnerability are denoted by dotted lines. Filled circle represents approximate zone of vulnerability (exact location of zone of vulnerability changed each day with each net set).

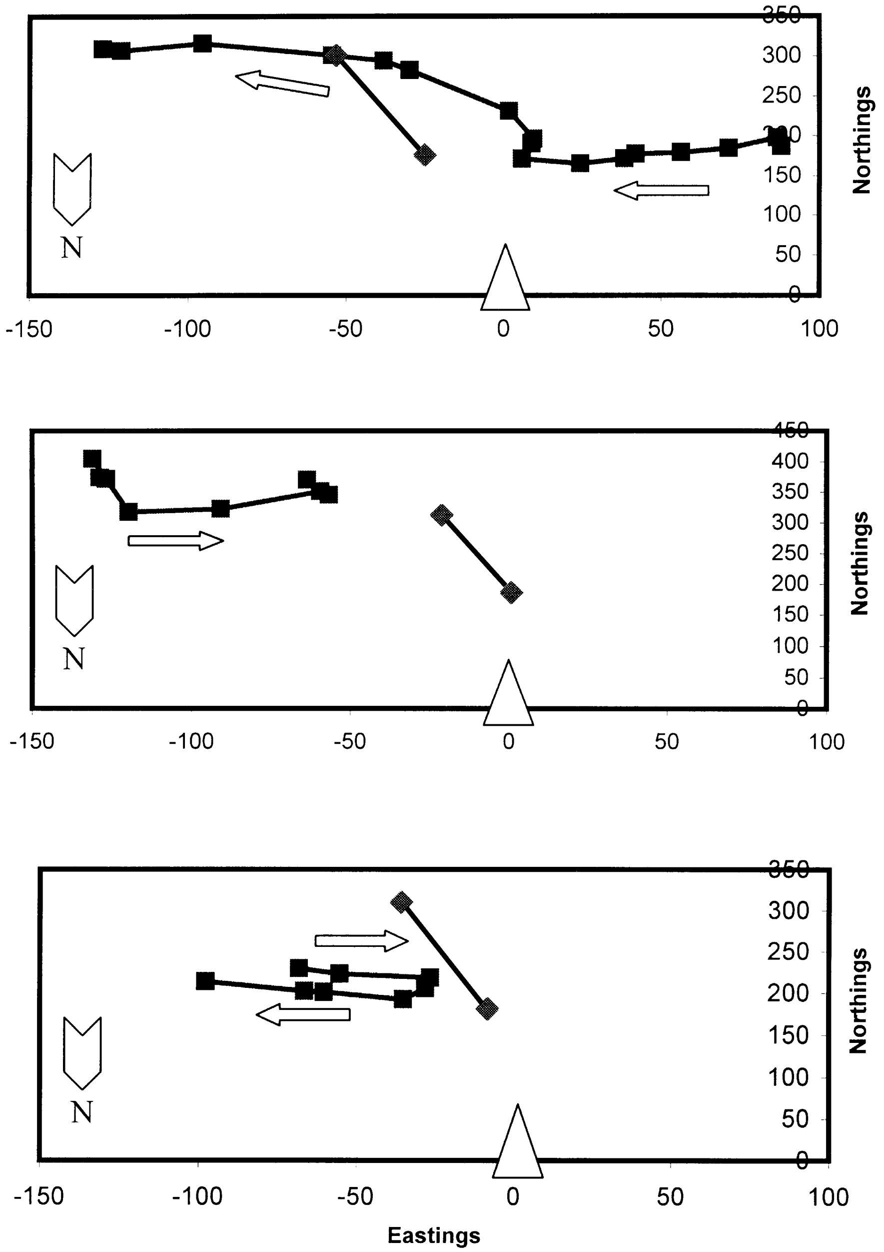

Fig. 3. Multiple encounters with the net of the same mother/calf pair, as identified by photo-id. All encounters took place on 6 April 2001. Triangle represents position of theodolite. Squares represent dolphin positions. Diamonds represent buoys demarcating approximate ends of net. Arrows represent direction of dolphin movement.

results, it is clear that many individual dolphins were exposed to our net on multiple days within our month-long study. However, there were insufficient multiple encounters to examine the responses of these dolphins to the net or pingers in a quantitative fashion.

The sound pressure level decreased to 120 dB re 1 μPa approximately 100 m from the net (Fig. 4). Ambient noise was broadband, but at 10 kHz ranged from 79 to 105 dB re 1 μPa. Thus, dolphins would have been able to hear the pingers within 100 m of the net and probably at considerably greater distances.

Battery voltages averaged 6.06±0.2 V on 21 April and 6.10±0.2 V on 10 May when removed from the pingers. Two pingers emitted a fundamental frequency of 10.8 kHz and the other a fundamental frequency of 11.2 kHz.

4. Discussion

Pingers displaced bottlenose dolphins from the gillnet in a subtle manner, but not to the extent that they displace

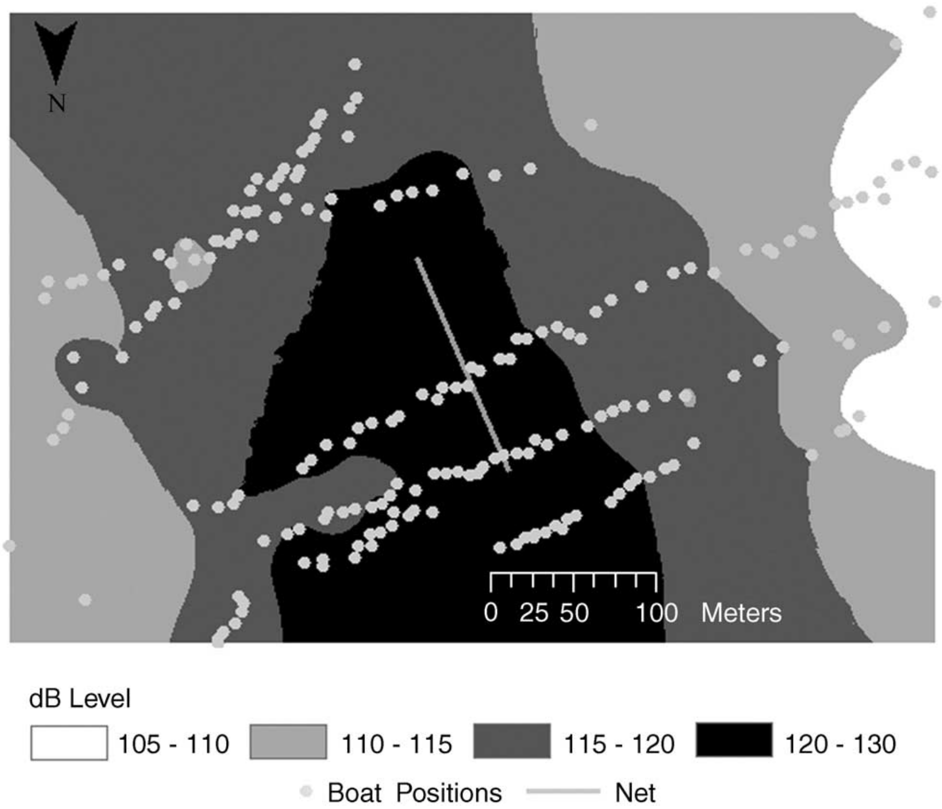

Fig. 4. Sound field radiated by three pingers attached to the gillnet. Ambient noise ranged from 79 to 105 dB. Boat position was recorded with theodolite.

harbour porpoises (Laake et al., 1998, Culik et al., 2001). Laake et al. (1998) demonstrated that harbour porpoises were excluded from an area of 125 m radius around a net equipped with pingers. Culik et al. (2001) displayed a similar exclusion of 130 m (see Fig. 1 in Culik et al., 2001). In captive settings, harbour porpoises move as far away as possible from pingers and surface more frequently (Kastelein et al., 2000b). These results have been interpreted as evidence that harbour porpoises find the sound produced by pingers to be aversive and, therefore, stay well away from the nets to which the alarms are attached (IWC, 2000). Thus, the reductions in by-catches of harbour porpoises observed in controlled experiments with pingers on commercial fishing gear (Kraus et al., 1997; Gearin et al., 2000) are likely due to displacement of porpoises away from the nets where entanglement could occur. This displacement is so pronounced in harbour porpoises that some researchers have voiced concern over the potentially adverse effects of habitat exclusion caused by pinger usage in widely dispersed fisheries (see IWC, 2000).

In the present study, however, bottlenose dolphins diverted their travel around the net only slightly when the pingers were active, often traveling just inshore or offshore of the buoys demarcating the ends of the net. This result is markedly different from that exhibited by harbour porpoises. The different responses of the two species may reflect fundamental differences in their reactions to novel stimuli. In comparison to bottlenose dolphins, harbour porpoises are relatively shy animals and are perhaps less likely to tolerate or even investigate a new sound in their environment. The lack of reaction we observed from the bottlenose dolphins was not caused by past habituation; dolphins in this area have not been previously exposed to pingers, so we believe the responses we observed were naïve.

Despite their initial displacement from acoustic alarms, harbour porpoises have been shown to habituate rapidly to the presence of a pinger (Cox et al., 2001). Bottlenose dolphins may exhibit a similar response, although the magnitude of the initial response is small. Individual dolphins were exposed to active pingers on at least four occasions during our short study, thus setting the potential for habituation. Given our experience fishing a single net for a relatively short period along our coast, it is likely that individual dolphins would be exposed to pingers on a very frequent basis if these devices were adopted by the North Carolina fishing community.

Even though porpoises habituate to pingers, it is possible that bottlenose dolphins might become sensitized to pingers. Habituation is defined as “the relatively permanent waning of a response as a result of repeated stimulation which is not followed by any kind of reinforcement" (Thorpe, 1966). In contrast, sensitization is the increase in a response over time due to a positive reinforcement, or the "dinner bell" effect (Richardson et al., 1995). For example, dolphins may learn to associate the pinger with the presence of a gillnet that contains fish. This is supported by the behavior of the dolphins around the fishing boat and net in this experiment. On several occasions when we started hauling the net, dolphins moved very rapidly towards the boat from over 300 m away. The dolphins also consumed discarded fish as we hauled the net. As dolphins moved along the net as it was being hauled, we observed half-eaten fish in the net, leading us to speculate that dolphins were consuming fish from the net. In addition, on multiple days over the course of the study, we photographed one individual dolphin begging alongside our vessel. Depredation, and other similar interactions between bottlenose dolphins and gillnets, occur in North Carolina (Hagedorn, 2002) and elsewhere in parts of the range of this species (Reeves et al., 2001). Thus, it is possible that dolphins would eventually associate pingers with a source of food, possibly leading to higher by-catch rates.

Predicting the dolphins' response to pingers would be more straightforward if we understood more about the fine-scale behavior of dolphins around gillnets. We gained some insight over the course of this study into how dolphins interact with gillnets. We can identify four types of interactions: (1) dolphins taking fish from the net, (2) dolphins begging fish from fishing vessels, (3) dolphins using the net as a barrier to herd fish as a foraging tactic, and (4) dolphins transiting around the net without interacting with it. On 6 April, when the pingers were not active, the first group of dolphins we tracked swam directly to the net and made a series of fluke-up dives around the net (Fig. 5). This group remained in the area of the net for 20 min and then continued moving to the east. We speculate that the dolphins were either taking fish from the net or foraging along the net. Regardless of their motivation, the dolphins seemed to be clearly aware of the net's presence.

Unfortunately, we were unable to observe individual dolphins on a sufficient number of occasions to examine the responses of individual dolphins to the net or to the pingers. However, on 6 April we observed a mother/calf pair transit the study area while the pinger was off (Fig. 3). The dolphins approached the net from the west, stopped approximately 200m from the net and logged at the surface, and then traveled offshore. They passed the offshore buoy, and continued traveling east. Approximately 90 min later, the pair approached from the east, offshore of the net. As they approached the offshore buoy, a boat approached and we lost sight of the animals. One hour later, they approached the net from the east, dove in the vicinity of the net and then turned back and headed east. Thus, these dolphins were aware of the net and interacted with it multiple times, yet did not become entangled. We witnessed at least 10 close interactions (dolphins diverting their track around the net, making fluke-up dives, or logging at the surface near the net) between dolphins and the gillnet, but no dolphins were entangled. This leads us to conclude that entanglement is a rare event compared to the number of interactions between dolphins and gillnets.

Current levels of by-catches of bottlenose dolphins in gillnet fisheries exceed allowable removal levels along the eastern coast of the USA (Waring et al., 2001). Pingers are but one of many potential mitigation measures being considered to address this problem. Our limited understanding of the nature of interactions between dolphins and gillnets is a hindrance to evaluating which of these measures will be most effective, while minimizing adverse impacts on the fishing industry. We believe that an improved understanding of these interactions is

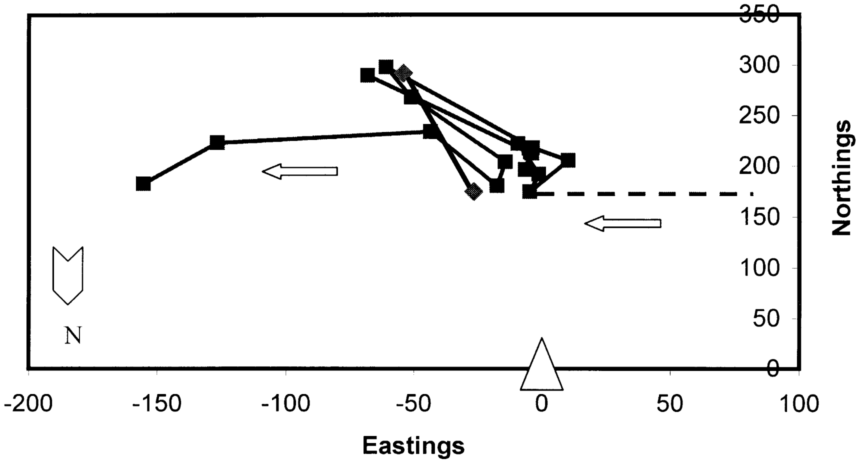

Fig. 5. Track #1, 6 April 01. The dotted line represents the estimated track; the solid line represents the actual track of the group of dolphins. The diamonds represent the buoys demarcating the approximate ends of the net. The triangle denotes position of theodolite. The squares represent dolphin positions.

critical to the development of effective conservation strategies.

With excellent visual acuity and a sophisticated echolocation system (Kastelein et al., 2000a), why do dolphins become entangled in gillnets? We hypothesize that entanglement stems from one or more of three scenarios: (1) while traveling, dolphins do not detect the net or do not recognize it as a barrier, (2) dolphins may become entangled while feeding on fish caught in the net, or (3) dolphins may be feeding on fish in the vicinity of the net (perhaps using the net as a barrier). At the present time, we do not have enough information to determine which, if any, of these hypotheses is correct. During this study we were able to observe behavior of dolphins only at the surface and therefore can only speculate as to their behavior at the depth of the net. Future studies need to be conducted to determine what behavior leads to entanglement, including observation of the fine-scale underwater behavior of dolphins around gillnets. Observations of the reactions of captive dolphins to gillnets would also enhance our understanding of this problem (e.g. Kastelein et al., 2000a). Such an approach has been very effective with other species (Nachtigall et al., 1995).

Pingers did not adversely affect fish catch in our experiment. However, we did not set the net to maximize the catch of a specific target species. Rather, we set the net in a location that was easily observed from our shore platform. Pingers emit a sound within the hearing range of some commercially important fish species (Mann et al., 1997). Therefore, before pingers are implemented in this or any other fishery, researchers should test for effects on the catch of target species, under realistic fishing situations.

We conclude that pingers are unlikely to reduce bycatch of bottlenose dolphins in gillnet fisheries along the US east coast because of the limited behavioral responses we observed in our experiment. Furthermore, the responses we observed are likely to diminish or change over time as dolphins habituate to these alarms. Other measures, such as the modification of fishing gear and practices hold more promise to reduce the magnitude of these by-catches. The major challenge currently facing researchers is to determine the ultimate and proximate causes of by-catches and the specific behavioral sequences that lead to entanglement. Until we understand why dolphins become entangled in fishing nets, it will be difficult to devise effective mitigation measures.

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