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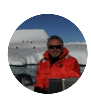
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A field test of acoustic deterrent devices used to reduce interactions between bottlenose dolphins and a coastal gillnet fishery

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ABSTRACT

Bottlenose dolphins (*Tursiops truncatus*) interact frequently with gillnet fisheries throughout their range. These interactions, which include the depredation of captured fish, can have deleterious impacts on both dolphins and fishermen. Acoustic deterrent devices have been proposed as one means of reducing the frequency and severity of these interactions. We studied interactions between bottlenose dolphins and a gillnet fishery for Spanish mackerel (*Scomberomorus maculatus*) in North Carolina, USA and investigated the effect of SaveWave® acoustic deterrent devices on target fish catch and the frequency and nature of interactions with bottlenose dolphins. We made observations from commercial vessels and conducted focal visual and acoustic follows of dolphins from a research vessel. We examined the effects of SaveWave® devices on fish catches and dolphin behavior by comparing sets with functioning (active) devices and non-functioning (control) devices. In 2003, we collected baseline data on catch and dolphin behavior from 136 gillnet sets; during 2004 and 2005 we monitored 151 gillnet sets (83 with active devices, 68 with control devices). Fish catches were significantly lower when dolphins were observed interacting with gillnets. SaveWave® status (active versus control) did not affect fish catch, but dolphins were less likely to interact with and more likely to echolocate around gillnets equipped with active SaveWaves® than gillnets with control SaveWaves®. Despite these encouraging findings, SaveWave® devices were not sufficiently durable to be deployed effectively in this fishery.

1. Introduction

Bottlenose dolphins (*Tursiops truncatus*) interact with fisheries throughout their range (Brotons et al., 2008a; Chilvers and Corkeron, 2001; Lauriano et al., 2004; Lopez, 2006; Powell and Wells, 2011; Rocklin et al., 2009; Zollett and Read, 2006). The behavioral flexibility of this species has allowed bottlenose dolphins to exploit fisheries in a number of ways, including herding fish along nets, consuming discarded catches, and removing captured fish from gear (depredation). These behavioral adaptations have likely increased the consumption rates and perhaps dietary breadth of some individual dolphins, but at a cost of increased risk of entanglement and the threat of retaliatory measures from fishermen. For fishermen, these interactions incur costs due to a reduction in the quantity and value of catches and from damage to gear during depredation attempts (Brotons et al., 2008a). There are significant incentives, therefore, to reduce the frequency and severity of such interactions from both economic and conservation perspectives.

Simple acoustic alarms, or pingers, have been used successfully to reduce the bycatch of a number of other odontocete species in gillnet fisheries, including harbor porpoises (*Phocoena phocoena*) (Kraus et al., 1997), Franciscana dolphins (*Pontoporia blainvillei*) (Bordino et al., 2002), common dolphins (*Delphinus delphis*) (Barlow and Cameron, 2003) and beaked whales (Caretta et al., 2008). These sound emitters are intended to reduce the frequency of entanglement of small cetaceans by acting as acoustic beacons. Unlike the accidental entanglement of these species, however, bottlenose dolphins interact intentionally with gillnets as a foraging strategy. Thus, simple acoustic alarms that function primarily as an alerting device are unlikely to decrease interactions between bottlenose dolphins and fisheries (IWC, 2000).

Past experiments to determine whether acoustic alarms could be used to prevent or deter bottlenose dolphins from interacting with fishing gear have provided mixed results. For example, Cox et al. (2003) found no significant difference in the closest approach distance to a gillnet equipped with active or control pingers,

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although bottlenose dolphins were less likely to approach within 100 m of the net when active pingers were used. In addition, the pingers used in this experiment did not prevent occasional incidences of depredation. Leeney et al. (2007) found decreased bottlenose dolphin echolocation around moored pingers, perhaps as an avoidance response or merely due to decreased vocalization rates. Gazo et al. (2008) tested pingers in a trammel net fishery and, although the alarms did not stop bottlenose dolphins from approaching the nets, there was decreased damage to both nets and fish when active pingers were used. Finally, Busciano et al. (2009) evaluated pingers in a bottom gillnet fishery and found that although bottlenose dolphins interacted with both active and control nets, there was significantly higher fish catch and less damage to nets in active sets than in control sets.

In contrast to simple acoustic alarms, acoustic deterrent devices (ADDs), which produce an aversive stimulus, rather than function as a simple sound beacon, have been suggested as a more promising strategy to reduce interactions between bottlenose dolphins and fixed fishing gear. Various types of ADDs have been developed that differ in peak frequency, signal length, interval and source level, but all are intended to function as an aversive stimulus. A particularly popular ADD was developed by SaveWave® to deter dolphins from engaging in depredation with stationary fishing gear. The devices include a randomized transmission interval and a randomized pulse length in an effort to reduce the possibility of habituation, which has occurred with single-signal pingers and harbor porpoises (Cox et al., 2001). Each of these devices incorporates one of two sound-producing cores: white (5–90 kHz) and black (30–160 kHz). Each core emits a signal every 4–16 s, with a pulse length between 0.2 and 0.9 s and a maximum signal energy of 155 dB re 1 μPa at 1 m. The SaveWave® devices are equipped with a saltwater switch and are thus only activated when immersed. Brotons et al. (2008b) tested SaveWaves® in a gillnet fishery around the Balearic Islands and reported an overall decrease in interactions between bottlenose dolphins and nets equipped with active SaveWaves®, although these differences were not statistically significant. Ours is the first study in an Atlantic fishery to simultaneously examine the effects of SaveWave® ADDs on both fish catches and the behavioral response of bottlenose dolphins.

The objectives of our research were to: (1) describe, in quantitative terms, the impact of bottlenose dolphin interactions on a gillnet fishery for Spanish mackerel (*Scomberomorus maculatus*) in North Carolina, USA; (2) investigate the effect of SaveWave® acoustic deterrent devices on catches in this fishery; and (3) determine whether these devices reduced the frequency of interactions between bottlenose dolphins and this fishery. We used both visual and acoustic observations of bottlenose dolphins to evaluate the effects of acoustic deterrents. We employed a multivariate modeling approach to assess the importance of SaveWaves® and dolphin presence relative to other relevant habitat factors. We selected the study site and fishery due to frequent interactions between dolphins and Spanish mackerel gillnets in this area (Hagedorn, 2002).

2. Methods

2.1. Observations from a commercial gillnet vessel

We conducted observations aboard a 13 m commercial fishing vessel from May to September 2003 and June to October 2004 near Hatteras, North Carolina and during June 2005 near Cape Lookout, North Carolina (Fig. 1). Most Spanish mackerel gillnets are 300 m in length; the stretched mesh size typically ranges from 7.6 to 10.2 cm. The gillnets are set perpendicular to the shoreline with the inshore end of the net as close to the beach as possible. Each commercial vessel sets multiple nets, which are often separated by only a few hundred meters and are in close proximity to the nets of other vessels. As a result, the nets form a series of barriers to the along-shore movement of dolphins. The nets are set during daylight hours for relatively short periods (see below). The fishery typically operates from May through October.

An observer aboard the vessel recorded the location and soak time of each set, the environmental characteristics (water temperature and depth at the inshore and offshore ends of the net, from the vessel's echo sounder) and the physical characteristics of the gear (twine size, mesh size, net length and net height). The observer also collected detailed information on fish catch for each set, including the composition and weight of retained catch (as estimated by the captain), the composition and counts of discarded species and incidences of depredation (damaged or partially consumed fish). When possible, the observer determined which predator species was responsible for depredation of individual fish by noting distinct bite pattern characteristics on damaged fish, noting the presence of predator species gilled next to the depredated fish and recording observations made by the vessel captains. Finally, the observer recorded the presence and behavior of dolphins around the net using the terms defined by Read et al. (2003):

Encounter – dolphins approaching within 500 m of the net. When an encounter occurred, dolphin behavior was scored into the following categories:

With net – dolphins approaching within one body length of the net;
Depredate – dolphins removing fish from the net;
Beg – dolphins surfacing repeatedly around the boat and/or consuming discarded fish;
Divert – dolphins changing direction to travel around the end of the net; and
Travel – dolphins swimming past the net without changing direction.

We considered "With Net", "Depredate", "Beg" and "Divert" to be forms of interactions with the gear and/or the fishing boat. We did not consider "Travel" to be an interaction because the dolphins did not change their behavior in the presence of the net.

During 2003, we collected baseline data on fishing activities and dolphin behavior around gillnets, but we did not deploy acoustic deterrent devices. During 2004 and 2005 the observer deployed and retrieved the acoustic deterrent devices and collected data on fishing activities and dolphin presence (as described above). We attached SaveWave® devices to the float line at the bridle between each 100 m segment of net. Each net was approximately 300 m long, comprised of three net sections attached together with two bridles (Fig. 2). The observer flipped a coin each morning to determine whether active or control alarms would be used that day. We refer to nets equipped with functional SaveWave® devices as *active* sets, whereas *control* sets were those equipped with non-functional but otherwise identical devices. Each active set was equipped with two SaveWaves®: one white core (5–90 kHz) and one black core (30–160 kHz). The type of core (white or black) placed on the inshore end of the net was alternated to account for any effect of the sound produced by the two core types. The fishermen were not informed whether active or control alarms were to be used, but once the devices were deployed on the first set and the saltwater switches were activated, the devices with white cores were audible.

2.2. Observations of dolphins around gillnets

In addition to the observations made aboard the gillnet vessel, we observed the behavior of dolphins around gillnets independently from a 7 m center-console research vessel. A three-person

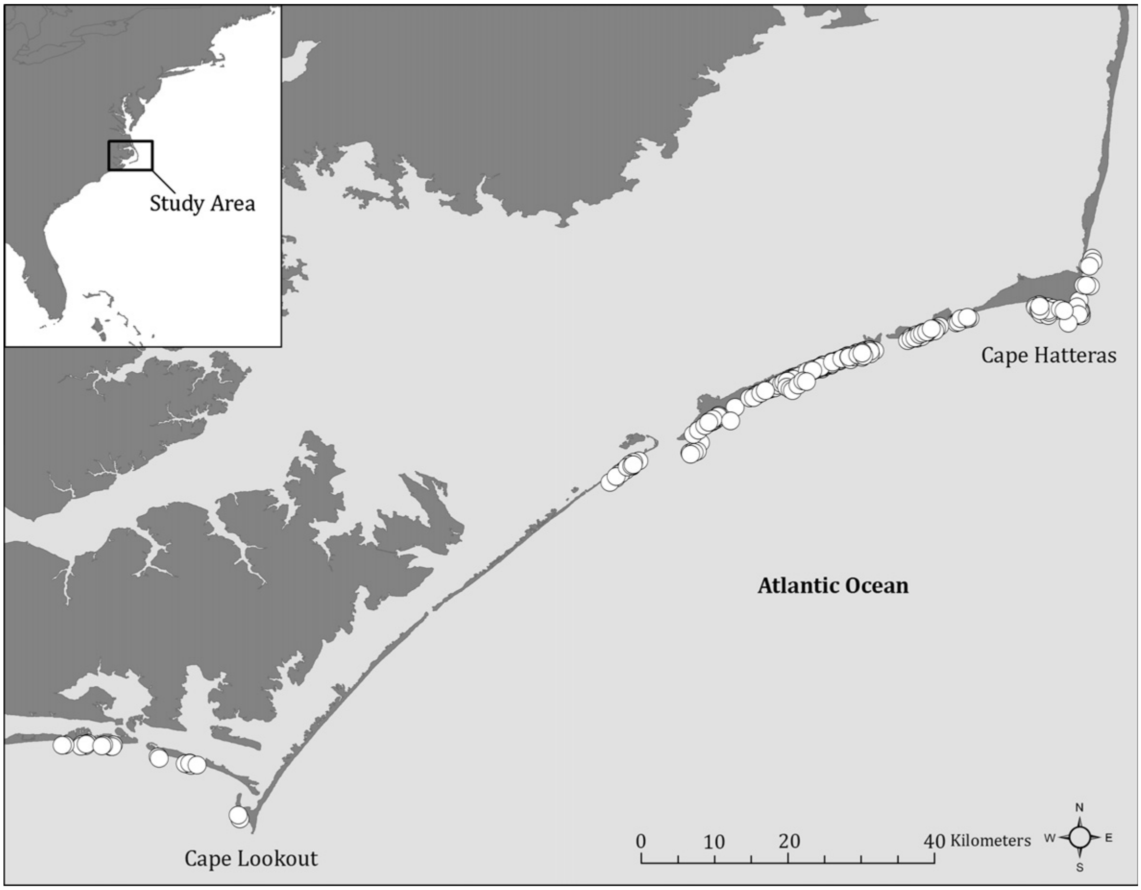

Fig. 1. Study area for the Spanish mackerel gillnet observations near Cape Hatteras and Cape Lookout during 2003–2005. The inset shows the location of the study area in relation to the US east coast. Locations of observed Spanish mackerel gillnet sets are indicated by circles.

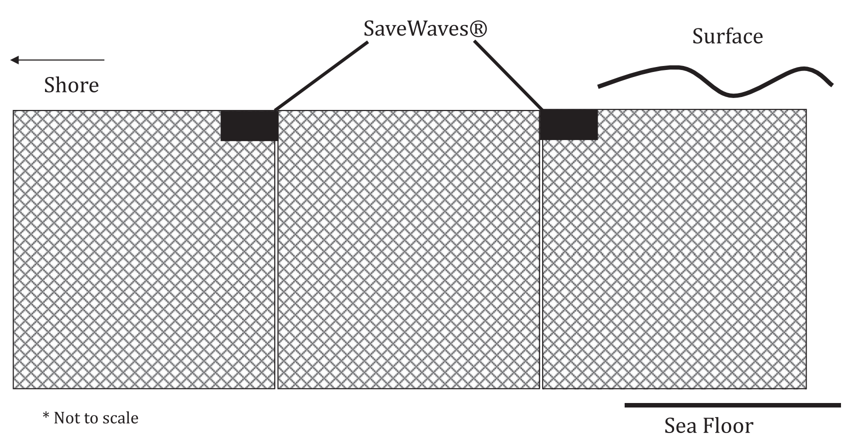

Fig. 2. Schematic of a gillnet used in this study: SaveWave® devices are attached to the floatline at 100 m intervals.

team searched for dolphins while moving along the shoreline in the vicinity of the fishing vessels and nets. At each encounter with dolphins we recorded position (using an onboard GPS unit), depth, the number of dolphins and group composition (e.g. the number of adults, calves and neonates). We then photographed the dorsal fins of all dolphins in the group, selected a distinctive dolphin and conducted observations of that individual, using focal animal sampling techniques (Altmann, 1974). During these focal follows we recorded the following information each time the dolphin surfaced: the location and heading of the research vessel, the distance from the vessel to the dolphin, the behavioral state of the dolphin and any specific details regarding its interactions with nets.

While following the focal dolphin and its group, we used a towed hydrophone to record dolphin echolocation signals (Whitehead et al., 2000). We made recordings using an HTI-96 hydrophone and a Sony model TCD-D8 digital audio tape (DAT) recorder with a sampling rate of 44.1 kHz, yielding a frequency response of 20 Hz–22 kHz. The hydrophone was filtered with a 4 kHz high-pass filter to reduce noise from the outboard engine. During the follows, a dedicated acoustic recorder made additional notes on the activity of the focal animal, general activity of the group and estimated distances to any gillnets. We attempted to remain in close proximity to the focal dolphin and its group; typically during follows and acoustic recordings our research vessel was less than 40 m from the focal animal.

2.3. Model construction

We calculated catch-per-unit-effort (CPUE) as the weight (kg) of retained catch per 100 m of net per hour of soak time. We calculated CPUE for total commercial catch, which included Spanish mackerel (the target species) and other species, such as bluefish (*Pomatomus saltatrix*), butterfish (*Peprilus triacanthus*), harvestfish (*Peprilus alepidotus*) and cobia (*Rachycentron canadum*), and also for Spanish mackerel catch alone.

We did not deploy SaveWaves® in 2003 and there were significant differences in fish catch by year for both Spanish mackerel and total commercial catches (Kruskal–Wallis tests; $p = 1.17 \times 10^{-5}$ and 5.35×10^{-4}, respectively), so we used observations from 2003 only to examine the effect of the presence of dolphins on fish catch. Using data from 2004 and 2005 we developed a multivariate framework to examine the effect of SaveWaves® on fish catches and dolphin behavior relative to other relevant habitat variables. Temperature is thought to be an important habitat variable influencing the distribution of Spanish mackerel (Chittenden et al., 1993), and the spawning activity of the species results in seasonal trends in inshore abundance in the southern United States (Collins and Stender, 1987). We incorporated sea surface temperature, depth and day of year into generalized additive models (GAMs) (Hastie and Tibshirani, 1990) to account for the effects of these variables when evaluating the influence of SaveWaves® on fish catch and dolphin behavior. The GAMs allowed us to estimate relationships between predictor and response variables using nonparametric functions, without making assumptions regarding the nature of these relationships.

We constructed separate GAMs for: (1) Spanish mackerel and commercial catches and (2) occurrences of dolphin encounters, interactions and dolphins "with net". We did not observe any instances of dolphin depredation from the commercial vessel during 2004 and 2005, so we used "with net" as a proxy for depredation in our models. We constructed GAMs using the following predictor variables for each set: SaveWave® status (active or control), depth, sea surface temperature (SST) and day of year (DOY) for all models; Spanish mackerel and commercial catches (kg fish/100 m/hr) for dolphin models; and dolphin encounters, interactions and dolphins "with net" for fish catch models (included as binary variables).

Exploratory data analyses showed that catch data were overdispersed, so GAM models of fish catch specified a quasi-Poisson distribution with a log link (Ver Hoef and Boveng, 2007). For the dolphin models, we employed a binomial distribution with a logit link (e.g., Hastie et al., 2005). We used depth measured at the inshore end of the set in all models. As noted above, we constructed GAMs using only data from 2004 and 2005, when both active and control devices were deployed. We modeled the relationship between response and predictor variables using cubic splines for all continuous variables. The number of knots in GAM models controls the flexibility of the spline curve; large numbers of knots can result in over-fitting of the model (Wood and Augustin, 2002). We limited the number of knots to four to allow for a biologically realistic response curve while preventing the model from being over-fit (e.g., Vilchis et al., 2006; Weber and McClatchie, 2010). We used backwards model selection and selected final models using Generalized Cross-Validation (GCV) or Unbiased Risk Estimator (UBRE) scores for continuous and binary response variables, respectively (i.e., the model with the lowest GCV or UBRE score was selected as in Wood and Augustin, 2002). All variables with a *p*-value less than 0.10 were retained in the final model.

Before evaluating fish catch and dolphin models, we plotted and visually examined correlations between all variables and assessed them with Pearson's correlation coefficients. No pairs of variables were significantly correlated and had a correlation coefficient greater than 0.5 ($r < 0.25$ for all pairs of variables). Therefore, we included all relevant variables initially in the GAMs. We conducted all analyses in the R statistical package (Version 2.12) using the "stats" and "mgcv" packages.

2.4. Analysis of acoustic recordings

We analyzed acoustic recordings using the sound analysis programs Signal/RTSD version 3.0 and Syntrillium Software Corporation's Cool Edit 2000. For each focal follow we determined the total number of seconds during which echolocation clicks occurred in each 1-min interval. We used this metric because it was often impossible to discern individual clicks or click trains when more than one dolphin was vocalizing. At each sampling point the distance from the focal animal to the nearest gillnet in the area was estimated by an observer aboard the research vessel. In 2003 we compared echolocation occurrence inside and outside of a 500 m buffer around the gillnets. During the SaveWave® trials in 2004 we only considered echolocation clicks made during portions of the follows when dolphins were within 500 m of gillnets. In addition, we excluded echolocation data collected during 2005 because these observations were made near Cape Lookout, rather than Cape Hatteras and we know that geographic variation in echolocation rate exists in this population (Jones and Sayigh, 2002). We assumed that almost all click events we recorded were from the focal animal and its group as we rarely encountered other groups of dolphins during these follows.

The resulting data were not normally distributed, so we performed Wilcoxon rank-sum tests to examine the differences in echolocation rates between active and control sets. All of these statistical tests were performed using JMP® 8.0 software.

3. Results

3.1. Observations aboard commercial gillnet vessels

We monitored 136 gillnets sets without SaveWave® devices near Cape Hatteras in 2003, 118 gillnet sets near Cape Hatteras in 2004 (63 with active devices, 55 sets with control devices) and an additional 33 sets near Cape Lookout in 2005 (20 sets with active devices, 13 sets with control devices; Fig. 1). Soak times ranged from 0.1 to 7.6 h, with a mean soak time of 1.8 h (±1.4). Nets were typically set perpendicular to shore and close to the beach, with a mean inshore depth of 4.5 m (±1.9) and a mean offshore depth of 6.4 m (±1.8). Water temperatures ranged from 20° to 28 °C with a mean of 25 °C.

In 2003 mean total commercial CPUE was 14.9 (±43.4) kg/100 m/hr and mean Spanish mackerel CPUE was 6.8 (±9.7) kg/100 m/hr. During 2004 and 2005 mean total commercial CPUE was 8.2 (±17.0) kg/100 m/hr during active sets ($n = 83$) and 4.3 (±4.6) kg/100 m/hr during control sets ($n = 68$). Mean Spanish mackerel CPUE was 3.2 (±6.3) kg/100 m/hr during active sets and 2.3 (±2.7) kg/100 m/hr during control sets.

The GAM evaluating commercial catch performed relatively well, with an R^2 value of 17.5 and an explained deviance value of 28.3%, but models for Spanish mackerel were not as robust (R^2 values ranging from 4.93 to 6.44 and explained deviance values ranging from 7.10% to 10.2%; Table 1). Model results indicated that commercial catch was highest in shallow water and lowest at intermediate depths and peaked during the middle of the Spanish mackerel fishing season in early August. The status of SaveWave® devices was not an important predictor of fish catches. We do not discuss models for Spanish mackerel catch further due to their low predictive power. However, dolphin behavioral parameters (interaction and "with net") were important predictors in the models of Spanish mackerel catch, and dolphin behavior was influenced

Table 1
Results for GAMs modeling fish catch in the Spanish mackerel gillnet fishery. Predictors for Spanish mackerel and total commercial catch are shown here, as evaluated using GCV. Dolphin behavior (i.e., encounter, interact and "with net") was not important predictors of commercial catch, and consequently only one model is presented for commercial catch. Depth and DOY were treated as continuous predictor variables.

Dependent variable	Category	Predictors	N	*p* Value	R^2	Explained deviance	GCV score
Spanish mackerel catch	Encounter	Intercept Depth	147	2.0×10^{-16} 1.2×10^{-2}	4.93	7.10	2.24
Spanish mackerel catch	Interact	Intercept Interact Depth	147	2.0×10^{-16} 5.0×10^{-2} 2.3×10^{-2}	6.44	10.00	2.20
Spanish mackerel catch	"With net"	Intercept "With net" Depth	147	2.0×10^{-16} 5.8×10^{-2} 1.7×10^{-2}	6.3	10.20	3.87
Commercial catch	n/a	Intercept Depth DOY	147	2.0×10^{-16} 1.0×10^{-5} 4.86×10^{-3}	17.6	28.30	7.48

Table 2
Results of Wilcoxon tests for differences in Spanish mackerel and total commercial catch in 2003 for sets when dolphins were observed encountering nets, interacting with nets, or "with net" in comparison to sets when dolphins were not observed engaging in these behaviors. SaveWaves® were not deployed on nets in 2003.

Dependent variable	Category	*p* Value	Catch with dolphins present (kg/100 m/hr)	Catch without dolphins (kg/100 m/hr)
Spanish mackerel catch	Encounter	0.16	5.80	7.10
Spanish mackerel catch	Interact	0.0026	3.97	7.30
Spanish mackerel catch	"With net"	0.00091	3.52	7.36
Commercial catch	Encounter	0.072	8.23	10.51
Commercial catch	Interact	0.0057	6.35	10.62
Commercial catch	"With net"	0.0025	5.94	10.65

by SaveWave® devices (see below). Consequently, we evaluated the effect of dolphin presence on fish catch using Wilcoxon tests using data from 2003 to evaluate the effect of dolphin behavior on fish catch independent of SaveWave® devices. Mean values of fish catch were lower when dolphins were observed encountering, interacting, or "with net", and the differences in these means were significant for dolphins interacting or "with net" for both Spanish mackerel and commercial catch values (Table 2).

Over 3 years of observations aboard commercial vessels, we observed evidence of depredation during 146 sets (51% of all observed sets) and many sets had more than one fish damaged. In total, we observed 334 fish of 13 species that had been partially consumed by various predators (note that this does not include fish that were completely removed and consumed). From bite patterns on depredated fish and the presence of predators captured next to damaged fish, we determined the predator responsible for 236 individual depredation events (70%). Depredation was caused by a variety of predators including: bottlenose dolphins; loggerhead turtles (*Caretta caretta*); cobia; bluefish; and several species of sharks, rays and crabs. Dolphins engaging in depredation typically left fish without heads, fish with only their heads remaining, fish with distinct tooth marks and holes in the gillnet, while shark depredation was typified by a curved bite with smooth edges (Fig. 3).

The species depredated most frequently was Spanish mackerel (65% of observations); sharks were responsible for 34% of this damage. Bottlenose dolphins were responsible for 23% of depredation in 2003, but only 1% of the Spanish mackerel depredation in 2004 and 2005. During these two latter years we observed only one Spanish mackerel with wounds that suggested that a dolphin was responsible for the depredation, although dolphins were not observed during this set.

During observations from the commercial vessel, we documented dolphins encountering gillnets on 36 of 136 sets when no acoustic deterrent devices were employed (26%), four of 83 sets with active deterrents (5%), and 21 of 68 sets with control deterrents (31%). GAMs performed well in predicting dolphin-fishery interactions, with R^2 values ranging from 38.7 to 65.7, and explained deviance values from 34.5% to 56.6% (Table 3). SaveWave® status and year were significant predictors of the dolphin behaviors we modeled (encounter, interact and "with net"). Dolphin encounters were more likely to occur at lower temperatures and at the peak of the Spanish mackerel fishing season (from July through early August). For all dolphin models, relationships between dolphin-fishery interactions and SaveWaves® were significant and negative (z values of −2.74, −2.47 and −3.79 for encounter, interaction and "with net", respectively), indicating that dolphins were less likely to encounter, interact with and engage in "with net" behavior when SaveWave® devices were active.

3.2. Observations of dolphins around gillnets

Our understanding of how dolphins reacted to the SaveWave® devices was enhanced greatly by observations of dolphin behavior from the research vessel. We conducted focal follows of 11 individually identified dolphins in the vicinity of Spanish mackerel gillnets in 2003. During these baseline follows we recorded 18 encounters between dolphins and gillnets. In most (14) of these encounters, the focal dolphin did not interact with the net, but transited past either the inshore or offshore buoy as it traveled along shore. We recorded interactions between focal dolphins and nets on the remaining four occasions, with focal dolphins diverting around three nets and a single instance of apparent depredation. One focal follow deserves special mention. On June 30th we followed a female dolphin for three hours and 22 min as she traveled through an area where many nets were set. The dolphin, accompanied by a calf, was part of a group of approximately 15 individuals. During this follow, the focal dolphin and her group encountered 10 nets as they traveled west towards Ocracoke Inlet (Fig. 4). The focal female passed inshore of three nets and offshore

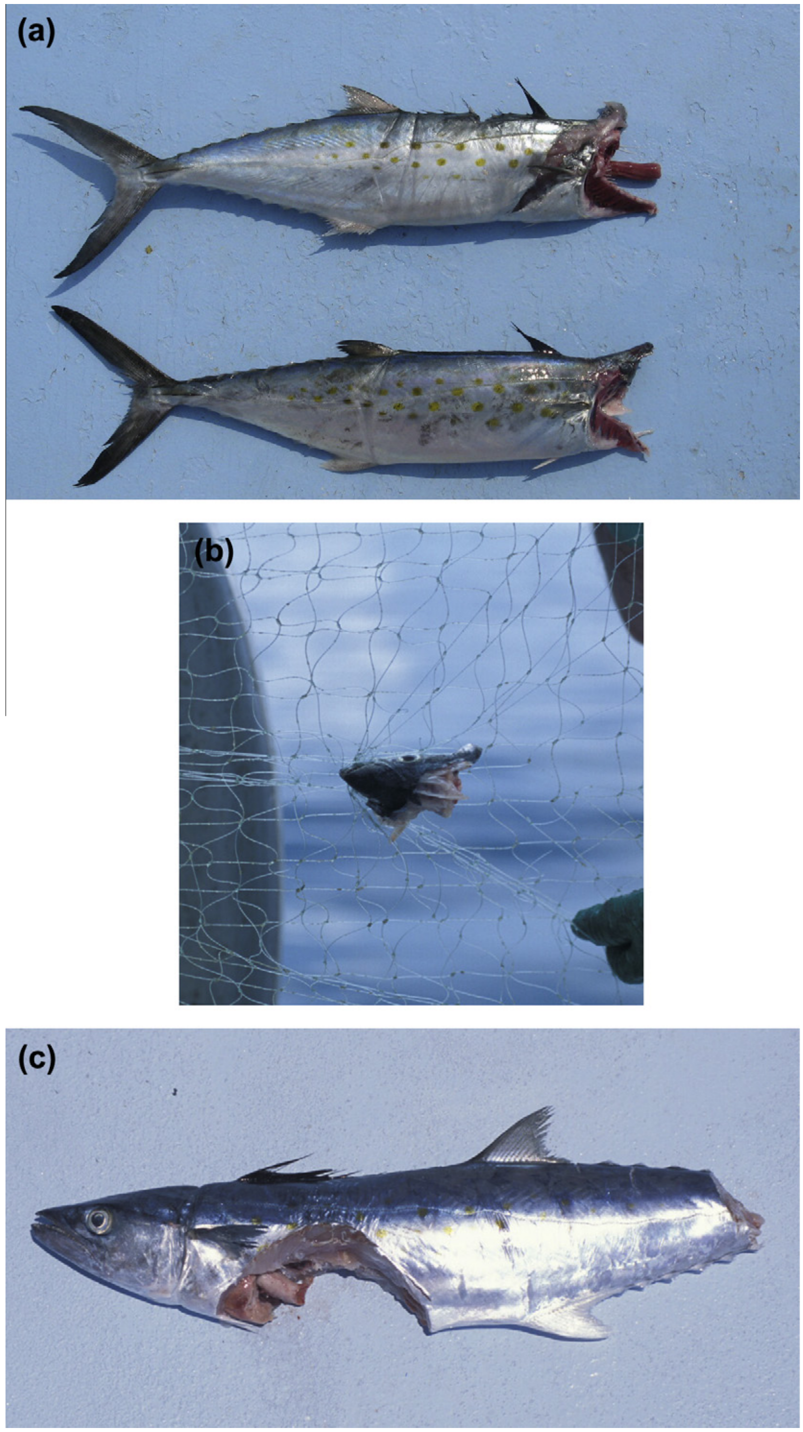

Fig. 3. Dolphin and shark depredation on Spanish mackerel. Dolphin depredation is characterized by fish with distinct tooth marks and missing heads (a) or fish with only the head remaining (b). Shark depredation is characterized by a curved bite pattern with smooth edges (c).

of four others without any appreciable change in direction. The dolphin also diverted around nets on three occasions, once by changing course around the inshore buoy and twice by changing course around the offshore buoy. The focal dolphin never engaged in depredation, but several other dolphins in this group were observed to approach nine of the ten nets very closely. Depredation was confirmed after the fisherman retrieved one of these nets.

In 2004 and 2005 we conducted focal follows of six individually identified dolphins around gillnets equipped with active SaveWaves®, two follows around gillnets with control SaveWaves® and four follows around gillnets of other commercial vessels that were not equipped with SaveWaves®. Dolphins interacted with the gear on five of six focal follows around nets with active devices: these dolphins were found to be "with net" on two separate occasions, begging from the commercial vessel during another set, and diverting around two of the nets. During the remaining focal follow, the dolphin traveled inshore of the net with no discernible change in direction but the follow ended due to logistical problems before the dolphin completely passed the net.

During one of the follows of dolphins around control nets the dolphin diverted around the offshore end of the net. During the other follow around control nets the focal dolphin encountered

Table 3
Results for GAMs modeling dolphin-fishery interactions in the Spanish mackerel gillnet fishery. Predictors in the best models for dolphin encounters, interactions and dolphins observed to be "with net" are shown here, as evaluated using UBRE scores. Temperature and DOY were treated as continuous predictor variables.

Category	Predictors	N	*p* Value	R^2	Explained deviance	UBRE score
Encounter	Intercept	151	5.15×10^{-4}	38.70	40.40	−0.39
	SaveWave®		2.44×10^{-4}			
	Year		0.008			
	Temperature		0.050			
	DOY		0.083			
Interaction	Intercept	151	3.81×10^{-7}	43.20	34.50	−0.54
	Year		8.16×10^{-6}			
	SaveWave®		1.64×10^{-3}			
"With net"	Intercept	151	6.93×10^{-5}	65.70	56.60	−0.73
	Year		3.39×10^{-5}			
	SaveWave®		1.31×10^{-3}			

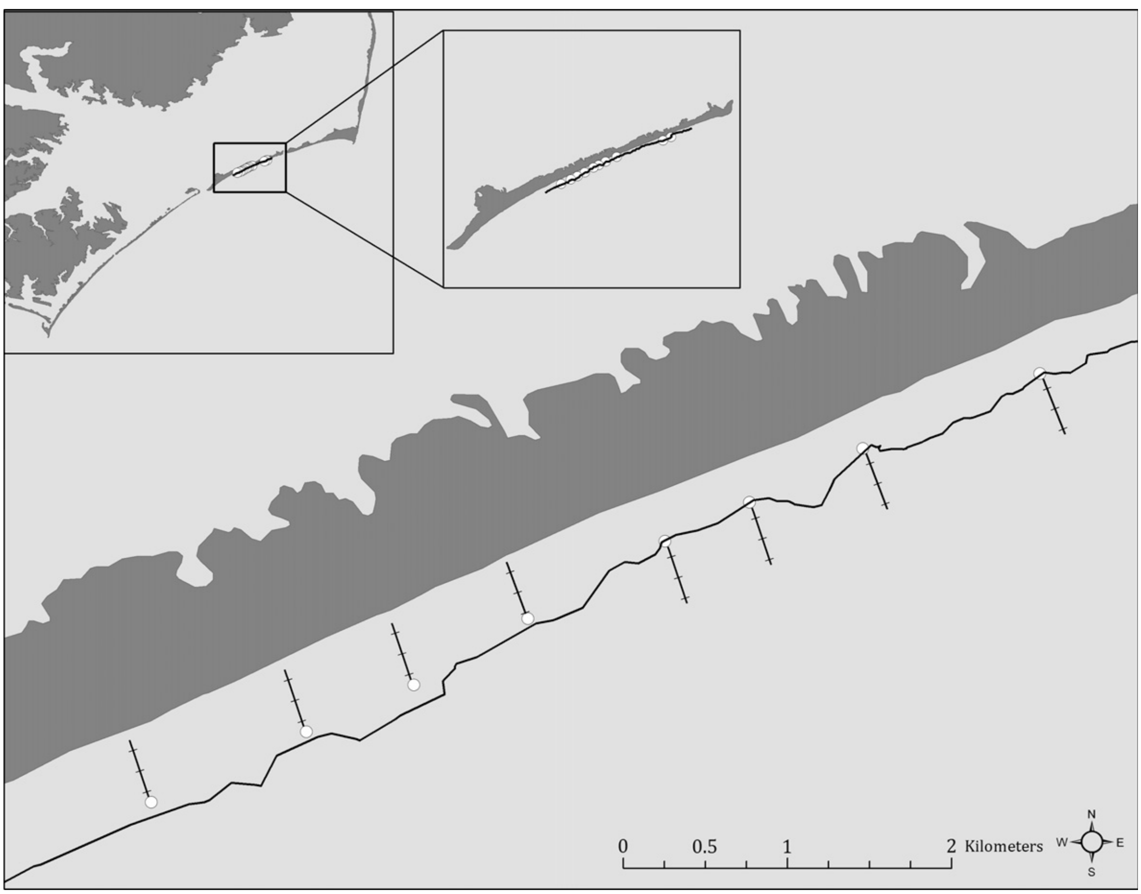

Fig. 4. Focal follow of a female bottlenose dolphin on 30 June 2003. This individual encountered 10 Spanish mackerel gillnets as she moved from east to west. Circles indicate inshore and offshore gillnet buoys. Dashed lines indicate the length and direction of the gillnets.

three nets but did not interact with any of them and traveled past the inshore buoys. Dolphins also interacted with three of the four nets without SaveWave® devices: "with net" on two occasions and diverting around one net. In the remaining encounter the dolphin traveled past the inshore end of the net and did not interact with the net.

We analyzed acoustic recordings made during nine focal follows of dolphins around commercial gillnets in 2003. Dolphins encountered 18 nets during these follows, but we heard dolphin echolocation infrequently. In 396 min of recordings, the mean occurrence of echolocation was only 2.7 (±7.3) seconds during each minute; thus for most of the time during our follows dolphins were silent. When dolphins were recorded more than 500 m from a gillnet (193 min) the mean occurrence of echolocation was 2.6 (±6.6) seconds per minute, but when dolphins were recorded less than 500 m from a gillnet (203 min) the mean occurrence of echolocation was 2.8 (±8.0) seconds per minute. There was no significant variation in the occurrence of echolocation behavior as a function of distance from the net (Wilcoxon rank-sum test, $z = 1.39$, $p = 0.1632$). In general, the dolphins we followed in 2003 were very quiet and did not appear to use echolocation to detect the nets or navigate around them, even when in close proximity to nets.

We also analyzed acoustic recordings made during seven focal follows of dolphins around gillnets in 2004—four follows around active sets, two around control sets, and one around a net without devices. When dolphins were recorded within 500 m of a gillnet equipped with active Savewave® devices (39 min) the mean occurrence of echolocation was 9.6 (±14.8) seconds per minute, but when dolphins were recorded within 500 m of a gillnet equipped with control SaveWave® devices (48 min) the mean occurrence of echolocation was 4.9 (±9.8) seconds per minute. During these follows dolphins spent significantly more time echolocating while they were in the proximity of active versus control gillnets ($z = 2.735$, $p = 0.006$).

4. Discussion

Bottlenose dolphin encounters and interactions with Spanish mackerel gillnets occurred commonly during our study. Dolphins encountered almost a quarter of all commercial gillnets we monitored and interacted with these nets by diverting around them, patrolling along their length, engaging in depredation and, occasionally, begging for fish. Despite these relatively common interactions, however, we did not observe any entanglements. Observations from the NOAA Fisheries Observer Program confirm that very few dolphins become entangled in gillnets each year in this region (Waring et al., 2009). Thus, although depredation by bottlenose dolphins occurs in this fishery, most individuals engaging in this behavior do not become entangled.

We were unable to determine the proportion of the individual dolphins that engaged in depredation because it was not possible to obtain good quality photographic images of dolphins engaged in this behavior. Acts of depredation were very brief (mean duration 42 ± 10 s – see Read et al., 2003). Dolphins typically traveled rapidly to the net, patrolled up and down its length, stopped briefly, presumably to remove fish, and then charged away. The reason for the hurried nature of this behavior is unclear, but it made quantitative observation and photo-documentation difficult and often impossible.

We documented a significant reduction in the CPUE of target and other commercially valuable fish species when bottlenose dolphins interacted with the nets. These results are similar to those of Brotons et al. (2008b), Gazo et al. (2008) and Lauriano et al. (2004), who also found significant decreases in fish catches when bottlenose dolphins interacted with gillnets. Only a small portion of this reduction is due to the direct removal of fish from the nets by dolphins. It is possible that this decrease is caused by the foraging behavior of the dolphins, particularly when they use a net as a barrier against which to chase and capture fish. Fishermen noted that dolphins foraging in this manner could cause fish to swim along the length of the net, rather than into it, thus reducing catch rates.

Our models indicated that the presence of SaveWave® acoustic deterrent devices did not affect catch rates in the Spanish mackerel gillnet fishery. Spanish mackerel do not possess a swim bladder and have poor hearing abilities above 1 kHz (Hawkins, 1986), so it is perhaps not surprising that the catch of this species was unaffected by the high-frequency sounds produced by these devices.

Depredation was very common in this fishery, occurring in more than half of the sets we observed. Bottlenose dolphins were implicated less frequently than sharks in these depredation events. In other parts of the world bottlenose dolphins are frequently blamed for extensive depredation for which they may be only partially responsible (Bearzi et al., 2011; Reeves et al., 2001; Rocklin et al., 2009). It is also interesting to note the considerable annual variation in the amount of depredation attributed to dolphins, with dolphins being responsible for 23% of the depredation in 2003 but only 1% in 2004 and 2005. At the present time we do not understand what factors might cause this inter-annual variation in frequency of depredation, but it could be linked to the availability of alternative food sources, the distribution of depredating individuals, or other factors.

Dolphins were significantly less likely to encounter (approach within 500 m), interact or engage in "with net" behavior in sets with active versus control SaveWave® devices. Given these findings it appears that the SaveWaves® were effective in deterring dolphins from interacting with Spanish mackerel gillnets, although our observations from the research vessel indicate that the ADDs did not eliminate this behavior entirely.

During 2004 and 2005, the 2 years that we trialed the SaveWave® devices, we did not observe enough evidence of depredation by dolphins from the commercial vessel (e.g. the remains of damaged or partially consumed fish) to determine whether or not the devices were effective in reducing the incidence of this specific behavior. Interestingly, Spanish mackerel catch was also lower in 2004 and 2005, with a mean Spanish mackerel CPUE of 2.8 (±5.0) kg/100 m/hr compared to 6.8 (±9.7) kg/100 m/hr in 2003. Despite the lack of depredation by dolphins during the years we were testing the SaveWave® ADDs, our observations from both the commercial and research vessels provided insight into how the dolphins reacted to the devices. The presence of active SaveWave® acoustic deterrent devices significantly influenced dolphin echolocation rates. Dolphins echolocated more frequently when they were close to nets with active devices than when they were near control nets. This is an important finding, as we found no significant difference in echolocation rates as a function of distance from the net in 2003 when SaveWaves® were not employed. We conclude that dolphins used echolocation to investigate the nets equipped with active SaveWave® devices, which would enhance their ability to detect and avoid these nets.

We found several general patterns in our visual observations of dolphins around Spanish mackerel gillnets. Typically, when dolphins encountered gillnets, they traveled past them or diverted around them. In these cases, dolphins demonstrated no motivation to interact with the nets. This behavior was markedly different from the "with net" behavior, which we believe is associated with depredation, in which dolphins traveled rapidly to the net, patrolled up and down its length and then charged away. Dolphins engaged in this behavior appeared to be acutely aware of the presence of the nets and highly motivated to interact with them. Our observations indicate that SaveWave® devices deterred some dolphins from engaging in this behavior and alerted other dolphins from approaching nets. This latter finding could decrease the incidence of accidental encounters and, therefore, the probability of entanglement. If SaveWaves® were used extensively, dolphins could either habituate to the alarm or learn to associate the sound of the alarm with the presence of the net, resulting in a "dinner bell" effect that could have negative consequences for both the dolphins and the fishermen (Bordino et al., 2002; Cox et al., 2001).

Finally, and importantly, the SaveWave® devices were not sufficiently physically robust to be used effectively in the Spanish mackerel gillnet fishery, where gear is deployed and retrieved with a hydraulic net reel system. When the fishermen attempted to wind nets onto their reels with the SaveWaves® attached, the device housings cracked under the weight and tension of the nets. Fishermen instead had to attach and remove the devices by hand each time a net was deployed or retrieved, which proved to be very time consuming. Our findings were similar to those found by Cosgrove et al. (2005) who assessed a variety of acoustic deterrents in net fisheries and concluded that SaveWave® devices were the most likely to become fouled in fishing gear and damaged.

The Spanish mackerel gillnet fishery is an important source of revenue for commercial fishermen along the Outer Banks of North Carolina. In 2010, for example, the fishery reported landings of more than 400 mt, worth more than $1 million (US) ex vessel value (North Carolina Division of Marine Fisheries, 2011). Depredation by a variety of predators, including bottlenose dolphins, reduces the value of landed catch and the by catch of bottlenose dolphins is of significant conservation concern. Thus, finding a way to reduce the frequency of these interactions is of benefit to both fishery participants and the conservation and management communities. At the moment, however, there do not appear to be any simple operational solutions to this problem and thus the interest in the SaveWave® ADDs. These devices showed promise in reducing the frequency of interactions between dolphins and gillnets, but are not practical for use in this fishery, at least in their present form.

In summary, SaveWave® devices did not affect the catch of Spanish mackerel in this fishery, but they did reduce the frequency with which bottlenose dolphins interacted with Spanish mackerel gillnets. The alarms may also serve to alert other dolphins to the presence of nets, a feature that seems to be enhanced by the increased frequency of echolocation around nets equipped with active devices. The SaveWave® alarms did not affect fish catch and reduced interactions between dolphins and the Spanish mackerel fishery, but fishermen would be resistant to using these devices in their current operational state. Our research highlights the importance of testing potential mitigation measures in the field before they are considered for inclusion in management plans.

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