JOURNAL OF THE
North Carolina Academy of Science

ASSESSING BYCATCH REDUCTION POTENTIAL OF VARIABLE STRENGTH HOOKS FOR PILOT WHALES IN A WESTERN NORTH ATLANTIC PELAGIC LONGLINE FISHERY

S. M. BAYSE[1] and D. W. KERSTETTER*

Nova Southeastern University Oceanographic Center, 8000 North Ocean Drive, Dania Beach, Florida 33004 USA,
**E-mail: kerstett@nova.edu*

Journal of the North Carolina Academy of Science, 126(1), 2010, pp. 6–14

ASSESSING BYCATCH REDUCTION POTENTIAL OF VARIABLE STRENGTH HOOKS FOR PILOT WHALES IN A WESTERN NORTH ATLANTIC PELAGIC LONGLINE FISHERY

S. M. BAYSE[1] and D. W. KERSTETTER*

*Nova Southeastern University Oceanographic Center, 8000 North Ocean Drive, Dania Beach, Florida 33004 USA, *E-mail: kerstett@nova.edu*

Abstract: The pelagic longline fishery off Cape Hattaras in the western North Atlantic Ocean, which targets swordfish (*Xiphias gladius*, Linnaeus 1758) and tunas (*Thunnus* spp.), has a high frequency of interactions with marine mammals, particularly pilot whales (*Globicephala* spp.). The typical hooks used in the this fishery are size 16/0 "strong" hooks that straighten at 250 lb of pull (113 kg); some fishermen use alternative "weak" hooks that straighten at 150 lb of pull (68 kg). Other commonly used hooks in this fishery are size 18/0 strong hooks that straighten at 350 lb (159 kg) of pull, and the weak equivalent hooks that straighten at 225 lb (102 kg). Taking advantage of the size difference between large bycatch animals and relatively smaller target species, weak hooks could be implemented to reduce bycatch. Twenty-one pelagic longline sets were made targeting yellowfin tuna (*T. albacares*, Bonnaterre 1788) and bigeye tuna (*T. obesus*, Lowe 1839) using alternating 16/0 strong and weak hooks. Nine additional sets targeted swordfish with size 18/0 hooks and the same alternating hook methodology. No significant reduction in total tuna catch ($\alpha < 0.05$) or of any target species, although weak hooks exhibited higher catch per unit effort (CPUE) for tuna and swordfish. The only species with a significant difference in total catch between strong and weak 16/0 hooks was the pelagic stingray (*Pteroplatytrygon violacea*, Bonaparte, 1832), with more individuals caught by the strong hook. The sets with 18/0 hooks had similar catches for all species, except the target species swordfish. Swordfish CPUE was higher with the strong hooks, and had significantly higher total catches. Seven weak hooks were retrieved straightened, and one of these hooks was observed being straightened by a pilot whale. While not conclusive, such results suggest further research into weak hooks for the reduction of large animal bycatch in the pelagic longline fishery.

Key Words: Terminal tackle; weak hooks; bycatch; pelagic longline; pilot whale.

INTRODUCTION

The U.S. pelagic longline fishery in the western Atlantic Ocean has historically had a high frequency of bycatch interactions with istiophorid billfish, marine turtles, sharks, and some marine mammals (Yeung 1999; Cramer 2003; ICCAT 2006). Several approaches have been used to reduce the frequency of bycatch and bycatch mortality in this fishery, including time/area closures, a mandatory change in terminal gear from J-style hooks to circle hooks, minimum gangion line lengths relative to buoy line lengths, and federal safe-handling and release training requirements (Watson et al. 2005). The National Marine Fisheries Service (NMFS) statistical area within the western Atlantic Ocean known as the "Mid-Atlantic Bight" (MAB[2])is concerned with increasing interaction rates with pilot whales (*Globicephala* spp.).

Two species of pilot whales, the long-finned pilot whale (*G. melas*, Traill 1809) and the short-finned pilot whale (*G. macrorhynchus*, Gray 1846), interact with pelagic longline gear, and their physical characteristics are similar, making them difficult to distinguish while in the water from both boat-side perspectives and aerial surveys. Both species also have wide geographic ranges, and their populations overlap within the MAB statistical area between 35° and 39° North latitude (Payne and Heinemann 1993; Bernard and Reilly 1999).

Pilot whales primarily interact with pelagic longline gear during their depredations on hooked fish, especially bigeye tuna (*Thunnus obesus*, Lowe 1839) (NMFS, unpubl. data). Pilot whales diet consists primarily of deep-water squid (Gannon et al. 1997a; Gannon et al. 1997b; Mintzer et al. 2008). Presumably, depredation of hooked tuna (*Thunnus* spp.) and swordfish (*Xiphias gladius*, Linnaeus 1758) is a learned behavior (DAPLTRT 2006). Pilot whales also occasionally become entangled in the mainline (Garrison 2005), with

[1] Present address: Florida Fish and Wildlife Conservation Commission, Division of Marine Fisheries Services, 2590 Executive Center Circle E, Suite 201, Tallahassee, FL 32301 USA.

[2] Regional names signify National Marine Fisheries Service (NMFS) pelagic fishery statistical area boundaries and do not necessarily relate to distinct geographical areas (Richards 1999).

anecdotal reports of individuals "scratching" themselves on the mainline to remove ectoparasites (pers. comm., Captains G. O'Neill, F/V *Carol Ann* and A. Mercier, F/V *Kristen Lee*).

A total of 113 reported pilot whale interactions occurred in the western North Atlantic U.S. pelagic longline fishery (including the Gulf of Mexico) during 1992 to 2005, including 61 categorized as serious injuries and four observed dead (Johnson et al. 1999; Yeung 2001; Garrison 2005; Garrison and Richards 2004; Fairfield-Walsh and Garrison 2006). "Serious injury" is defined as an injury sustained by a marine mammal that will likely result in death. These injuries are determined individually from fishery observers data and focus on whether the animal was gut hooked (or hooked in a non-visible location), amount of fishing gear still attached at release, the apparent injuries, and the animal's ability to swim away normally (Angliss and DeMaster 1998). Of the 61 serious injuries, five were mouth hooked, 20 were released with entangled gear, and 36 were a combination of the two (DAPLTRT 2006).

From 2001 to 2005, a total of 46 observed interactions with pilot whales occurred, of which 43 were within the MAB (DAPLTRT 2006). These were estimated to 86 serious injuries to pilot whales (Waring et al. 2007). For management purposes a five year average is considered to minimize the effect of a single "bad" year (Barlow et al. 1995). The number of serious injuries was below the potential biological removal (PBR), which for the western Atlantic Ocean is 249 (Wade and Angliss 1997). The status of the western Atlantic stock is unknown, nevertheless, the PBR is above the insignificance threshold of 10% and therefore required a take reduction plan for the U.S. Atlantic pelagic longline fishery under the Marine Mammal Protection Act (MMPA; Waring et al. 2007).

The vast majority of the U.S. Atlantic longline fishery uses one of two types of hooks: the forged "strong" hook straightens out at a higher pull force, than the bent wire "weak" hook. Weights of pilot whales commonly exceed 227 kg, and can reach 1,300 kg for adults, whereas yellowfin tuna (*T. albacares*, Bonnaterre 1788) and bigeye tuna rarely exceed 90 kg (Collette and Nauen 1983; Wynne and Schwartz 1999; Jefferson et al. 2008). Although swordfish can reach a maximum size of greater than 450 kg, individuals of this size are rare in the U.S. fishery; the majority of the catch is much smaller with a mean weight of 15.4 kg (Cramer and Adams 1999).

The pelagic longline fishery in the MAB statistical area, North Carolina to Rhode Island, is primarily a mixed tuna/swordfish fishery and is fished year round by a fleet from Wanchese, North Carolina, as well as seasonally by other vessels along the U.S. coast. Anecdotal reports suggest that when the weak hooks were tried by North Carolina vessels, some were straightened and fishermen became concerned about loss of potential catch (pers. comm., Captain D. Hemilright, F/V *Tar Baby*). Thus, the fishery now uses primarily strong hooks.

Terminal gear changes from J-style to circle hooks has shown to decrease bycatch interactions and mortality in pelagic longline fisheries while not significantly affecting the catch rates of target species (Hoey 1996; Falterman and Graves 2002; Watson et al. 2005; Kerstetter and Graves 2006). Specifically for pilot whale interactions, changes in hook strength could take advantage of the size disparity between pilot whales and tunas and swordfish. Weaker strength hooks might retain target fish yet release pilot whales. Evidence of little or no change in catches could support a precautionary change within the MAB fishery to weaker hooks, thereby decreasing the number of observed interactions with pilot whales.

The use of weak hook technology for reducing the bycatch of large fishes (e.g., bluefin tuna *T. thynnus*, Linnaeus, 1758) from pelagic longline fisheries has been discussed, but the potential reduction of other marine bycatch species has not been thoroughly examined. We studied the comparison of the catch rates of target and non-target species caught with strong and weak circle hooks in the western North Atlantic pelagic longline fishery to assess the utility of these hooks for reducing the interaction rate in this fishery with pilot whales.

MATERIALS AND METHODS

Two separate experiments compared two types of non-offset hooks each, one "strong" and one "weak" size 16/0 hook, and one "strong" and one "weak" size 18/0 hook. Hooks were alternated "strong-weak-strong-weak-strong" for each five-hook basket (hooks between floats), with the next basket alternated "weak-strong-weak-strong-weak." All gear configurations remained consistent with regulations for the U.S. Atlantic pelagic longline fishery. Hook spacing was uniform within each set, and the choices of gangion and buoy line lengths and set locations were typical of the fishery. Squid (*Illex* spp.) was the only bait used for all experimental sets. All vessels had NOAA-required live-release equipment, and the captains and crews were certified on the techniques used to release bycatch species with minimal injury.

Fisheries observers trained by the NMFS Pelagic Observer Program (POP) used standard POP data sheets and recorded information on all caught animals including: species identification, measured length, hook type, location of the hook on the organism, and disposition (alive or dead) at gear retrieval. Fish that did not obviously move while hooked in the water or on deck were considered dead (Falterman and Graves 2002;

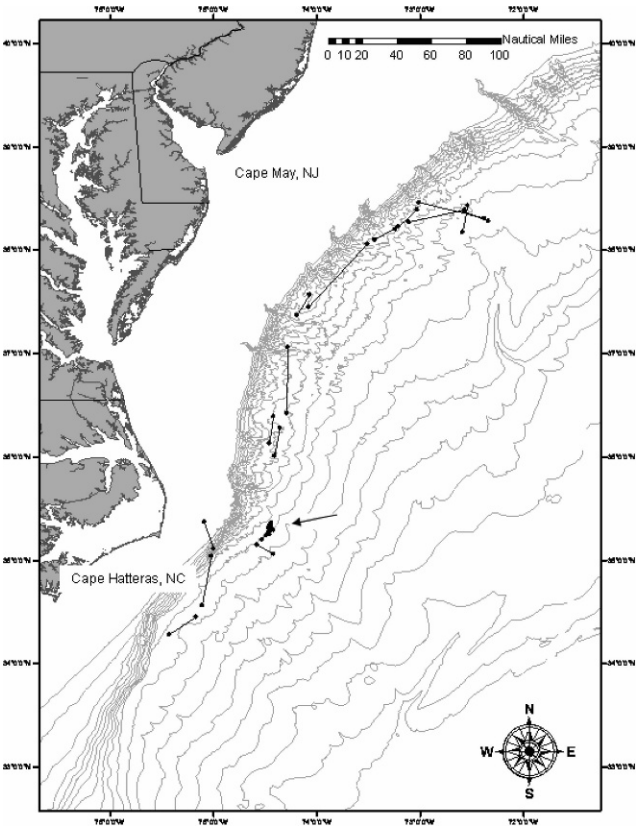

FIG. 1. Areas fished in the Mid-Atlantic Bight using size 16/0 hooks. Lines represent where 21 pelagic longlines sets initially were set out. Arrow denotes "compressed" area where 8 of the 21 sets were made.

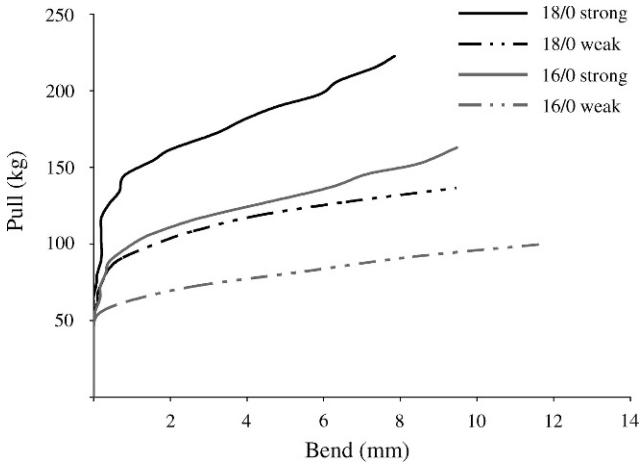

FIG. 2. Net hook deformation from unstressed shape of two hook strengths and two hook sizes used during comparative research in the western North Atlantic pelagic longline fishery.

Kerstetter and Graves 2006). Hooking location was divided into three categories: mouth hooked, foul hooked, or gut hooked. Lengths of large bycatch species were estimated, as were the lengths of target species that were damaged from sharks, marine mammals, or other causes (e.g., squid). Dressed weights were recorded for headed-and-gutted fish, but only for species that are weighed individually for sale (tunas and swordfish).

16/0 Hooks Experiment

A hook comparison study was conducted in the MAB (Fig. 1) from 1 August to 2 October 2008. A total of 21 sets, targeting tuna, fished 15,568 hooks aboard the commercial pelagic longline vessel F/V *Southern Lady* (ca. 23 m length overall). The two size 16/0 hooks used were: 1) the forged or "strong" hook by Lindgren-Pitman, Inc. that straightens at 250 lbs of pull force (113 kg) and 2) the bent wire or "weak" hook by Mustad (model #39960) that straightens at 150 lbs of pull force (68 kg) (Fig. 2). The amount of gear and times fished varied slightly throughout the trips as local weather and location changed. Hook depth range was calculated with POP protocols and varied from 9.0–19.5 fathoms (ca. 16.5–35.7 m). Mainline length per set varied from 16.0–26.4 nm (ca. 29.6–48.9 km).

18/0 Hooks Experiment

A hook comparison study was conducted in the Florida East Coast (FEC) and South Atlantic Bight (SAB) NMFS statistical areas (Fig. 3) from 17 February to 4 March 2008. A total of 9 sets, targeting swordfish, fished 4,655 hooks aboard the commercial pelagic longline vessel F/V *Carol Ann* (ca. 16 m length overall). The two size 18/0 hooks used were: 1) the forged or "strong" hook by Lindgren-Pitman, Inc. that straightens at 350 lbs of pull force (159 kg) and 2) the bent wire or "weak" hook by Mustad (model #39960) that straightens at 225 lbs of pull force (102 kg) (Fig. 1). The amount of gear and times fished varied slightly throughout the trips as local weather and location changed. Hook depth range was calculated with POP protocols and varied from 17.0–20.0 fathoms (ca. 31.1–36.6 m). Mainline length per set varied from 18.0–28.1 nm (ca. 33.3–52.0 km).

Statistical Analysis

Chi-square (χ^2) tests were used to determine if catch rates differed significantly between species with 10 or more individuals caught between size 16/0 strong and size 16/0 weak, or between size 18/0 strong and size 18/0 weak at an expected ratio of 1:1 (Stone and Dixon 2001; Kim et al. 2006). Catch per unit effort (CPUE) was measured as catch per 1,000 hooks. Catches and catch rates were compared as total catch, as well as set by set where there were 10 or more individuals of a species caught (method per Stone and Dixon 2001; Kerstetter and Graves 2006). *t* tests were used to compare between

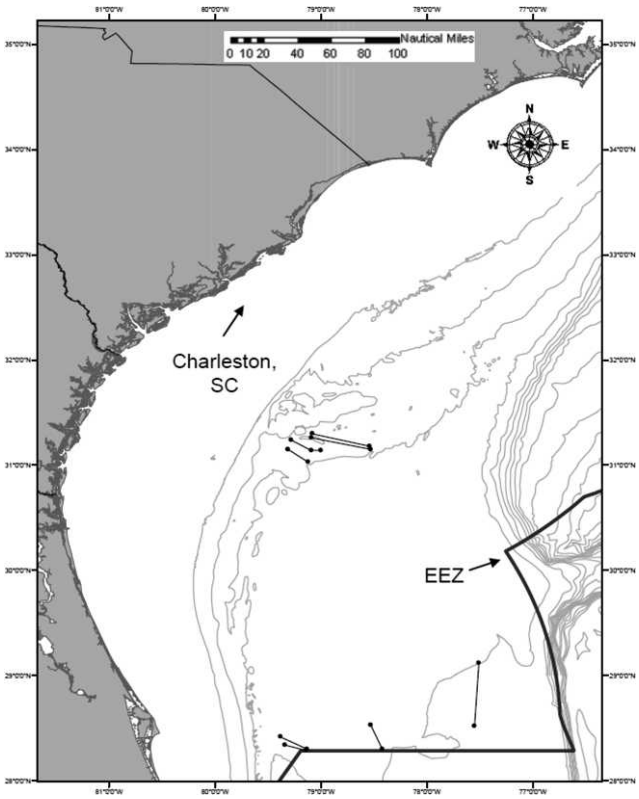

FIG. 3. Areas fished in Southern Atlantic Bight and the Charleston Bump using size 18/0 hooks. Lines represent where nine pelagic longline sets were initially set out.

hook types for individual fish lengths and dressed weights. The Cochran–Mantel–Haenszel chi-square test (CMH χ^2) was used to compare differences in survival at haulback for infrequently caught species because of the robust nature of the test to relatively low sample sizes; it was also used to compare differences in hooking location between the two hook types. Odds ratios were used to calculate the relative increase of certain conditions (e.g., being dead at haulback on a weak hook versus strong hook). All statistical significance was assessed at $\alpha < 0.05$ level.

RESULTS

16/0 Hooks

A total of 744 animals were caught representing 32 different species; 51.1% were caught by the strong hook and 48.9% were caught by the weak hook, or a 1.04:1 ratio (Table 1a). Yellowfin tuna, pelagic stingray (*Pteroplatytrygon violacea*, Bonaparte 1832), and bigeye tuna were the three most common species, representing 391 fish and 52.5% of the total catch. Yellowfin and bigeye tunas, which were targeted, made up 34.5% of the total catch, at an average of 12.2 tuna per set. All tuna species combined, including blackfin (*T. atlanticus*, Lesson 1831) and skipjack tuna (*Katsuwonus pelamis*, Linnaeus 1758), comprised 39.9% of the total catch.

Species with 10 or more individuals caught over the 21 total sets were compared for significant differences in catch rates between the hook types (Table 1a). Ten different species fit this criterion, with six species caught more frequently by the weak hook (yellowfin tuna, bigeye tuna, swordfish, blackfin tuna, scalloped hammerhead shark (*Sphyrna lewini*, Griffith & Smith 1834), blue shark (*Prionace glauca*, Linnaeus 1758), and three caught more by the strong hook (pelagic stingray, dolphinfish (*Coryphaena hippurus*, Linnaeus 1758), dusky shark (*Carcharhinus obscurus*, Lesueur 1818). However, only the pelagic stingray significantly differed from a 1:1 ratio at $p < 0.001$. Skipjack tuna ($n = 12$) was caught equally by strong and weak hooks. Ten or more individuals of a single species were caught within a single set 19 times, of which 15 resulted in an insignificant difference (Table 2). Five occurrences were significant; four were higher for the strong hook. One was for yellowfin tuna (significant at $p = 0.012$, 4.3:1), and the others pelagic stingrays (2.7:1, 3:1, 2.8:1). The one occurrence of significantly higher catch for the weak hook within a set was for the blue shark at a 3.7:1 ratio.

The mean CPUEs per set for yellowfin tuna (6.60 weak and 5.99 strong) and bigeye tuna (3.48 weak and 2.78 strong) were not significantly different (Fig. 4). Yellowfin tuna caught with strong hooks had a mean length of 114.2 ($\pm$ 10.6) cm, which was significantly greater than those caught by the weak hook, 109.2 ($\pm$ 12.9) cm at $p = 0.006$. Yellowfin tuna caught by the strong hook had a mean weight of 23.1 ($\pm$ 6.1) kg, which was not significantly higher than those caught by the weak hook at 21.5 ($\pm$ 5.8) kg. As with yellowfin tuna, both the fork lengths and dressed weights for bigeye tuna were higher with the strong hook, 118.2 $\pm$ 17.8 cm to 115.0 $\pm$ 11.5 cm and 29.3 $\pm$ 14.1 kg to 24.8 $\pm$ 6.8 kg, but neither were significantly different.

Seven size 16/0 weak hooks returned straightened (point bent beyond 90°). The cause of the straightening for six of these hooks was undetermined, but one was the result of an encounter with a pilot whale during the haulback of the gear. The animal showed little resistance during the initial approach, but attempted to escape at the sight of the boat. It then straightened the hook while approximately 10 m from the side of the boat and subsequently swam away with limited apparent injury. A false killer whale (*Pseudorca crassidens*, Owen 1846) also was observed interacting with a hooked yellowfin tuna, but the tuna was brought aboard before the animal became hooked or entangled. Other marine mammals were observed on the fishing grounds throughout the sets, and whale depredation on hooked fishes was determined for six yellowfin tuna and two pelagic stingrays.

Table 1a. Species caught with strong versus weak size 16/0 hooks (n ≥ 10 individuals) showing χ^2 value, p-value, ratio (S = strong, W = weak), and statistical significance at $\alpha < 0.05$. Asterisk (*) indicates significant difference. Numbers include retained and discarded animals.

	% of Total	Strong	Weak	χ^2	$p > \|t\|$
Retained Species					
Yellowfin tuna	23.9	87	91	0.089	0.764
Bigeye tuna	10.6	36	43	0.62	0.431
Swordfish	7.9	28	31	0.152	0.696
Dolphinfish	7.1	30	23	0.924	0.336
all thunnid tunas	38.4	137	149	1.110	0.292
Bycatch Species					
Pelagic stingray	18.0	87	47	11.940*	0.001
Scalloped hammerhead	7.7	28	29	0.017	0.894
Blue shark	4.7	13	22	2.130	0.128
Blackfin tuna	3.8	13	15	0.142	0.705
Skipjack tuna	1.6	6	6	0.000	1.000
Dusky shark	1.6	9	3	3.000	0.083
all billfishes	4.3	13	19	1.125	0.289
all carcharhinid sharks	8.9	30	36	0.546	0.460

18/0 Hooks

A total of 417 animals were caught, consisting of 19 different species (Table 1b). Swordfish, the targeted species for all sets, made up 56.8% of the total catch at 26.3 swordfish per set. Total catches of swordfish were greater with the strong hook versus the weak hook (135 to 102) and differed significantly (p = 0.032). There were no significant differences within a single set for swordfish, although the strong hook caught more than the weak hook on every set when the set caught more than 10 swordfish (Table 2). The night shark (*C. signatus*, Poey 1868) and silky shark (*C. falciformis*, Müller & Henle 1839) made up the majority of the bycatch at 27.1% of the total catch, with no significant difference for either species between hook types. Ten or more night sharks were caught on two sets, and neither was significantly different.

The strong hook had a mean CPUE per set at 29.78 swordfish per 1,000 hooks, compared to 22.58 for the weak hook (Fig. 4). Lengths of the swordfish were longer for the weak hook (137.7 ± 26.6 cm LJFL) than

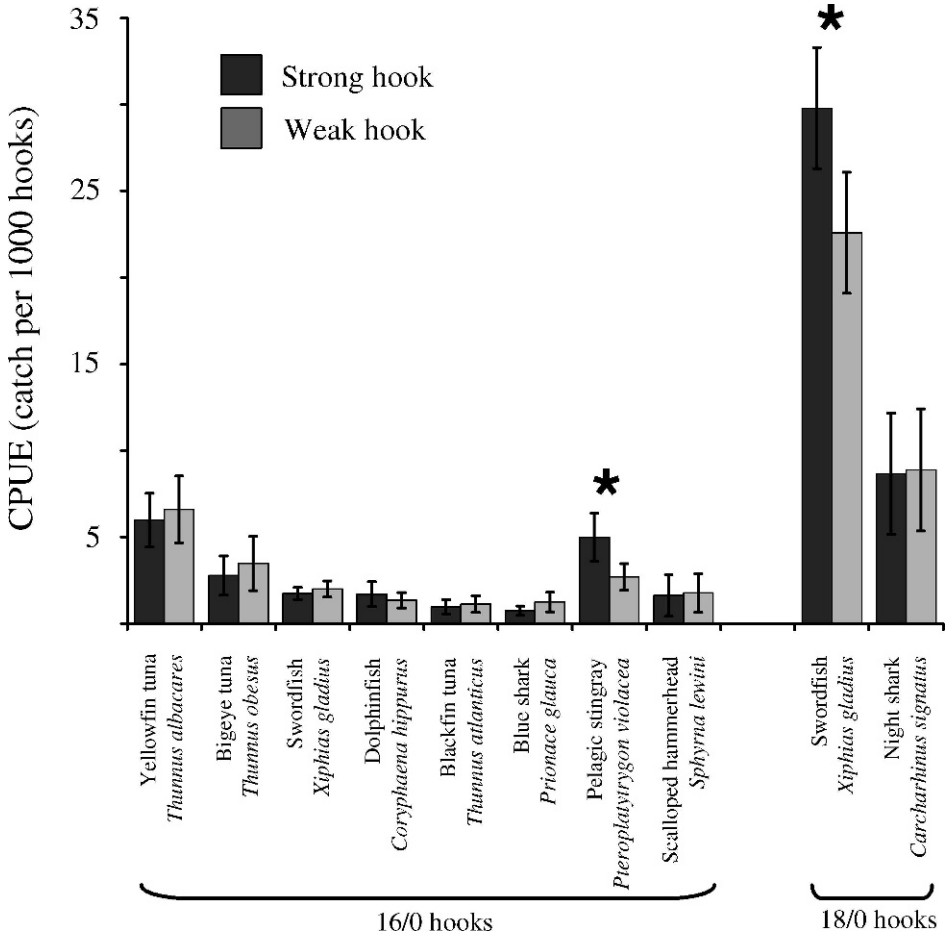

FIG. 4. Mean CPUE (catch per unit effort, as number of individual animals per 1,000 hooks) values for species in which more than ten individuals were caught during comparative hook research in the western North Atlantic pelagic longline fishery. Asterisks (*) indicate species with significant CPUE differences between strong and weak hooks.

Table 1b. Species caught with strong versus weak size 18/0 hooks (n ≥ 10 individuals over 9 sets) showing χ^2 value, p-value, and statistical significance at $\alpha < 0.05$. Asterisk (*) indicates significant difference. Numbers include retained and discarded animals.

	% Total	Strong	Weak	χ^2	$p > \|t\|$
Retained Species					
Swordfish	56.8	135	102	4.59*	0.032
Dolphinfish	2.9	6	6	0	1
Bycatch Species					
Night shark	18.9	39	40	0.01	0.91
Silky shark	8.1	15	19	0.47	0.493

the strong (133.2 ± 22.4 cm), but not significant (Table 3). Dressed weights were significantly higher for the weak hook (36.5 ± 24.5 kg) than the strong (28.7 ± 17.4) at p = 0.037.

No size 18/0 weak hooks were returned completely straightened. One weak hook was partially straightened by a manta ray (*Manta* spp.), although the ray remained on the gangion.

Table 2. Species caught with strong and weak size 18/0 hooks of (greater than 10 individuals within a set) showing χ^2 value, p-value, and statistical significance at $\alpha < 0.05$. Asterisk (*) indicates significant difference. Numbers include retained and discarded animals.

Set Number	Species	Strong	Weak	*t*-value	$p > \|t\|$
16/0 Hooks					
1	Swordfish	4	6	0.4	0.527
	Blue shark	3	11	4.57*	0.033
4	Yellowfin tuna	13	3	6.25*	0.012
	Pelagic stingray	7	4	0.82	0.366
5	Pelagic stingray	13	11	0.17	0.683
6	Yellowfin tuna	6	7	0.08	0.782
	Dolphinfish	12	7	1.32	0.251
	Pelagic stingray	16	6	4.55*	0.033
9	Pelagic stingray	9	4	1.92	0.166
	Scalloped hammerhead	22	17	0.64	0.423
10	Pelagic stingray	12	4	4.00*	0.046
11	Pelagic stingray	14	5	4.26*	0.039
12	Yellowfin tuna	18	14	0.5	0.48
14	Scalloped hammerhead	4	10	2.57	0.109
17	Yellowfin tuna	4	10	2.57	0.109
	Bigeye tuna	7	16	3.52	0.061
18	Yellowfin tuna	11	22	3.67	0.056
	Bigeye tuna	11	9	0.2	0.655
21	Yellowfin tuna	8	7	0.07	0.796
18/0 Hooks					
5	Swordfish	16	13	0.31	0.577
	Night shark	16	15	0.03	0.857
6	Swordfish	31	25	0.64	0.423
7	Swordfish	28	22	0.72	0.396
8	Swordfish	31	18	3.45	0.063
	Night shark	10	12	0.18	0.67
9	Swordfish	16	13	0.31	0.577
	Night shark	6	4	0.4	0.527

Percent Mortality and Hooking Location

Percent mortality at haulback was insignificant for tuna species between the two 16/0 hooks. Swordfish was the only species caught in sufficient numbers for comparisons between hook sizes. Mortality at haulback for swordfish was significantly higher for fish caught by the smaller 16/0 hooks compared to 18/0 hooks (CMH χ^2; = 18.4. $p \ll 0.001$); only one swordfish was alive at haulback for the 16/0 strong hook, resulting in 96.4% dead at haulback, compared to 77.4% dead for the weak hook. The 18/0 hooks had opposite results; weak hooks had a higher percent mortality at 61.8% than the 18/0 strong hook at 51.9%. Hooking location was primarily external (mouth or foul) across all hook types, sizes, and individual species, as has been generally observed with circle hook studies (Cooke and Suski 2004).

DISCUSSION

Alternating hook methodology has been previously used to determine differences in catch rates for target and bycatch species in the pelagic longline fishery (Falterman and Graves 2002; Watson et al. 2005; Kerstetter and Graves 2006; Kim et al. 2006). The alternating hook method ensures an equal probability of animals encountering the test and standard hooks, as well as to minimize variability because of the patchy distribution of highly migratory species, the change in temperature ranges, and the different distributions in depths because of the catenary curve of pelagic longline gear (Yoshihara 1951; Stone and Dixon 2001). Alternating between experimental and control (standard commercial) hooks also helps encourage participation in cooperative scientific research because many vessel captains and owners believe that only half of their catch could be lost in a "worst-case" scenario.

Since strong and weak hooks used in this study were circle hooks of similar dimensions, and are commercially labeled as such; the only difference between them from a regulatory perspective is the amount of pull strength required to straighten the hook beyond its ability to retain its catch. We defined this ability as a 90° opening of the hook point, at which stage the animal should be able to pull off the hook. Although by regulation, offset size 16/0 circle hooks cannot be used in the U.S. Atlantic pelagic longline fishery, size 18/0 or larger circle hooks may be offset up to a 10° difference. This offset may affect (but we did not evaluate) catch rates or mortality at gear retrieval and that any manual offsetting may also reduce the strength of the hook through deformation of the metal.

The sets for the size 16/0 hooks encountered low catch rates for the majority of the study, which prevented many comparisons across different bycatch species, as well as limiting within-haul comparisons. As expected,

Table 3. Comparison of lengths and dressed weights for target species caught during comparison of "strong" and "weak" hooks in the western North Atlantic pelagic longline fishery. (See text for full explanation of strength differences between hook types.) All lengths are fork length except for swordfish, which are presented as lower jaw fork length. The low number of swordfish caught in 16/0 hook research did not permit meaningful statistical comparisons, so no *t*-value is listed. No dressed weights are presented for dolphinfish because they are not individually weighed in common fishery practice. Asterisk (*) indicates significant difference between strong and weak hook types at $\alpha < 0.05$ level.

	Length (cm)					Dressed Weight (kg)				
	n	Strong	Weak	*t*-value	$p > \|t\|$	n	Strong	Weak	*t*-value	$p > \|t\|$
16/0 Hook										
Yellowfin tuna	176	114.2 ± 10.6	109.2 ± 12.9	2.80*	0.006	136	23.1 ± 6.1	21.5 ± 5.8	1.62	0.106
Bigeye tuna	78	118.2 ± 17.8	115.0 ± 11.5	0.95	0.345	59	29.2 ± 14.1	24.7 ± 6.8	1.6	0.116
Swordfish	59	121.6 ± 21.2	112.4 ± 16.3	1.88	0.065	18	69.0 ± 46.0	44.7 ± 11.6	–	–
Dolphinfish	41	100.7 ± 16.0	100.1 ± 18.2	0.11	0.91	–	–	–	–	–
18/0 Hook										
Swordfish	216	133.2 ± 22.4	137.7 ± 26.6	−1.36	0.176	130	63.2 ± 38.2	80.3 ± 53.8	−2.11*	0.037

catches for target and bycatch species were similar throughout the study between strong and weak hooks of both sizes. Pelagic stingrays, a relatively small species of no known management concern, were the exception, and catches of this batoid favored the strong hook even though size is likely not an issue (maximum weight of 12 kg; Mollet et al. 2002). Yellowfin and bigeye tunas caught by the strong hook were longer and heavier than those caught by the weak hook, with the individual fish lengths being significantly different. Even though the yellowfin caught by the strong hook were longer, the lack of a significant difference in weight suggested the size difference in fish between hook types was minimal. These results suggested that fishermen would have similar ex-vessel landings totals if either hook was used.

Swordfish were caught significantly more often with 18/0 hooks, but these fish were significantly smaller than the fish caught by the weak hooks. The mean difference in dressed weight for each hook type was 17.2 pounds (7.8 kg) and the weak hook caught five swordfish that had dressed weights between 100–199 lbs (45.5–90.5 kg), and four swordfish that had dressed weights between 200–280 lbs (90.9–127.3 kg). Two important observations can be made from these results: one, catches by weak hooks that were significantly less than strong hooks are made irrelevant by the significant weight difference (ex-vessel fish value is directly related to weight), and two, nine very large swordfish caught by the weak hooks prove their ability to catch large target species.

When testing the bycatch reduction potential of weak hooks, one could argue that it is more important to actually test the hooks' ability to free pilot whales from pelagic longline gear, than to compare the catches of target species. This is difficult to test using the methods of this study and would require a larger scale study well beyond the scope and funding of this experiment. A preliminary power analysis of historical pilot whale CPUE in this fishery suggested that between 28,626 and 90,595 hooks would be required to detect a 75% reduction in catch rate controlling α at 0.10 and β at 0.20 (pers. comm., G*Power 3, Faul et al., 2007 and A. Shaw). Perhaps and more importantly, any deliberate targeting of pilot whales for test purposes would conflict with the MMPA and the National Oceanic and Atmospheric Administration (NOAA) offices charged with enforcing MMPA provisions. Nevertheless, one pilot whale was quickly released by a weak hook with minimal injury (as defined by NOAA standards of no trailing gear). Six other hooks were straightened without confirmation of perpetrator, but it may have been a marine mammal because of their large size and constant presence on the fishing grounds, especially during haulback.

Several marine mammal species occurred on the fishing grounds, including a variety of dolphin species, most commonly pilot whales and false killer whales ranging from single animals to pods of six individuals. On one particular occasion, the captain forcefully removed a hooked tuna from the mouth of a false killer whale as the fish was pulled onboard by the gangion. Other evidence of whale depredation was observed during five different hauls, involving six yellowfin tuna and two pelagic stingrays; all six of the non-attributed straightened hooks also came from these five hauls. These observations and results, either directly or indirectly, suggest that weak hooks potentially lessened the amount of serious injuries that might have occurred to as many as seven marine mammals.

Our study suggests that the bycatch reduction potential of weak hooks is limited to species that can obtain the relatively large mass, such as pilot whales, and may not be a viable option for reducing the catches of other relatively large bycatch species commonly interacted with in the pelagic longline fishery, such as marine turtles, large sharks, manta rays, marlins and sunfish (*Mola* spp.). We did not test the ability of strong or weak hooks to catch tuna or swordfish in the pelagic longline fishery, although we did show that catches of target species are very similar between strong and weak

hooks for individual fishes weight and count. Additionally, we demonstrated that weak hooks can land large target species up to 280 lbs (127.3 kg), and – with the exception of pelagic stingrays – neither hook seems to retain a higher proportion of bycatch species. The reason for the increased catch of pelagic stingrays with strong hooks is undetermined, but is unlikely an effect of the hook strength.

Current federal regulations highlight the observed interactions between marine mammals and pelagic longline fisheries, suggesting a cryptic effect of these fisheries on marine mammal populations. Specifically, observed interactions are used to extrapolate total interactions and serious injuries. A terminal gear change would probably not reduce the number of interactions between pelagic longlines and pilot whales. However, the ability of weak hooks to bend and free the animal could reduce the number of cryptic, non-observed serious injuries to pilot whales, in addition to minimizing the injury and capture effects of those animals which are actually observed during fishery interactions. The use of weak hooks would probably not impact catch rates and species composition of the catch. Given that hooks are already a regulated component of the fishery's gear, enforcement costs would likely be minimal. Such a change in hook type would therefore be a minimal and more viable management option versus time-area closures or increased observer coverage.

Acknowledgments: We would express our appreciation to Captain R. Ross and the crew of F/V *Southern Lady* and Captain G. O'Neill and the crew of F/V *Carol Ann*. We would also thank E. Machemer (NSU OC) and M. Maiello (NOAA) for their fieldwork assistance and E. Brooks (Lindgren-Pitman, Inc.) for his assistance with hook strength testing, and for helpful comments during the work from K. Mansfield (University of Miami) and J. Rehage (Florida International University). This research was funded by North Carolina Sea Grant award number 07-DMM-04.

LITERATURE CITED

ANGLISS, R. P., AND D. P. DEMASTER. 1998. Differentiating serious and non-serious injury of marine mammals taken incidental to commercial fishing operations. NOAA Tech. Memo. NMFS-OPR-13. 48 p.

BARLOW, J., S. L. SWARTZ, T. C. EAGLE, AND P. R. WADE. 1995. U.S. Marine Mammal Stock Assessments: Guidelines for Preparation, Background, and a Summary of the 1995 Assessments. NOAA Tech. Memo. NMFS-OPR-6. 71 p.

BERNARD, H. J., AND S. B. REILLY. 1999. Pilot Whales - *Globicephala* (Lesson, 1828). Pp. 245–279 in S. H. Ridgeway and R. Harrison (eds.), Handbook of Marine Mammals. Academic Press, San Diego.

COLLETTE, B. B., AND C. E. NAUEN. 1983. FAO (Food and Agriculture Organization) Species catalogue, vol. 2. Scombrids of the World: An annotated and illustrated catalogue of tunas, mackerels, bonitos and related species known to date. FAO Fisheries Synopsis, Rome: 80–93.

COOKE, S. J., AND C. D. SUSKI. 2004. Are circle hooks effective tool for conserving freshwater and marine catch-and-release fisheries? Aquat. Conserv.: Mar. Freshw. Ecosyst. 14:299–326.

CRAMER, J. 2003. Pelagic Longline Bycatch. ICCAT (International Commission for the Conservation of Atlantic Tunas). Collective Vol. Sci. Papers ICCAT 55:1576–1586.

CRAMER, J., AND H. M. ADAMS. 1999. Pelagic Longline Bycatch. ICCAT (International Commission for the Conservation of Atlantic Tunas). Collective Volume of Scientific Papers ICCAT 49:288–299.

DAPLTRT (DRAFT ATLANTIC PELAGIC LONGLINE TAKE REDUCTION TEAM). 2006. Draft Atlantic pelagic longline take reduction plan. National Marine Fisheries Service, National Oceanic and Atmospheric Administration, Dept. of Commerce: 18–20.

FAIRFIELD-WALSH, C., AND L. GARRISON. 2006. Estimated bycatch of marine mammals and turtles in the U.S. Atlantic pelagic longline fleet during 2005. NOAA Tech. Memo. NMFS-SEFSC-539. 56 p.

FALTERMAN, B., AND J. E. GRAVES. 2002. A comparison of the relative mortality and hooking efficiency of circle and straight shank ("J") hooks used in the pelagic longline industry. in A. Studholme and J. Lucy (eds.), Catch and release in marine recreational fisheries. Am. Fish. Soc., Sympos. 30, Bethesda, Maryland: 80–87.

FAUL, F., E. ERDFELDER, A. G. LANG, AND A. BUCHNER. 2007. G*Power 3: A flexible statistical power analysis program for the social, behavioral, and biomedical sciences. Behavior Res. Methods 39:175–191.

GANNON, D. P., A. J. READ, AND J. G. MEAD. 1997a. Stomach contents of long-finned pilot whales (*Globicephala melas*) stranded on the U.S. mid-Atlantic coast. Mar. Mamm. Sci. 13:405–418.

GANNON, D. P., A. J. READ, J. E. CRADDOCK, K. M. FRISTUP, AND J. R. NICOLAS. 1997b. Feeding ecology of long-finned pilot whales (*Globicephala melas*) in the western North Atlantic. Mar. Ecol. Prog. Ser. 148:1–10.

GARRISON, L. P. 2005. Estimated bycatch of marine mammals and turtles in the U.S. Atlantic pelagic longline fleet during 2004. NOAA Technical Memorandum NMFS-SEFSC-531. 51 p.

GARRISON, L. P. 2005. Estimated bycatch of marine mammals and turtles in the U.S. Atlantic pelagic longline fleet during 2004. NOAA Technical Memorandum NMFS-SEFSC-531. 51 p.

GARRISON, L. P., AND P. M. RICHARDS. 2004. Estimated bycatch of marine mammals and turtles in the U.S. Atlantic pelagic longline fleet during 2003. NOAA Tech. Memo. NMFS-SEFSC-527. 40 p.

HOEY, J. J. 1996. Bycatch in western Atlantic pelagic longline fisheries. Pp. 193–203 in T. Wray (ed.), Solving Bycatch: considerations for today and tomorrow. Alaska Sea Grant College Prog., No. 96-03, Univ. Alaska, Fairbanks, Alaska.

ICCAT (INTERNATIONAL COMMISSION FOR THE CONSERVATION OF ATLANTIC TUNAS). 2006, Report for the biennial period, 2004–2005. Part II (2005) - Vol. 2 (English version), Standing Committee Res. Statistics (SCRS). ICCAT, Madrid. 136 p.

JEFFERSON, T. A., M. A. WEBBER, AND R. L. PITMAN. 2008. Marine mammals of the world. Elsevier, London.

JOHNSON, D. R., C. YEUNG, AND C. A. BROWN. 1999. Estimates of marine mammal and marine turtle bycatch by the U.S. Atlantic pelagic longline fleet in 1992–1997. NOAA Tech. Memo. NMFS-SEFSC-418. 53 p.

KERSTETTER, D. W., AND J. E. GRAVES. 2006. Effects of circle versus J-hooks on target and non-target species in a pelagic longline fishery. Fish. Res. 80:239–250.

KIM, S., D. MOON, C. BOGGS, D. AN, AND J. KOH. 2006. Comparison of circle hooks and J-hooks in the catch rate of target and bycatch species taken in the Korean tuna longline fishery. Western and Central Pacific Fisheries Commission. Scientific Committee Second Regular Session. WCPFC-SC2-2006/EB WP-12. Manila, Philippines. 12 p.

MINTZER, V. J., D. P. GANNON, N. B. BARROS, AND A. J. READ. 2008. Stomach contents of mass-stranded short-finned pilot whales (*Globicephala macrorhynchus*) from North Carolina. Mar. Mamm. Sci. 24:290–302.

MOLLET, H. F., J. M. EZURRA, AND J. B. O'SULLIVAN. 2002. Captive biology of the pelagic stingray, *Dasyatis violacea* (Bonaparte, 1832). Mar. Freshw. Res. 53:531–541.

PAYNE, P. M., AND D. W. HEINEMANN. 1993. The distribution of pilot whales (*Globicephala* spp.) in the shelf/shelf-edge and slope waters of the northeastern United States, 1978–1988. Pp. 51–68 in G. P. Donovan, C. H. Lockyer, and A. R. Martin (eds.), Biology of Northern Hemisphere Pilot Whales. Special Issue 14. International Whaling Commission, Cambridge.

RICHARDS, W. J. 1999. Problems with unofficial and inaccurate geographical names in the fisheries literature. Mar. Fish. Rev. 61:56–57.

STONE, H. H., AND L. K. DIXON. 2001. A comparison of catches of swordfish, *Xiphias gladius*, and other pelagic species from Canadian longline gear configured with alternating monofilament and multifilament nylon gangions. Fish. Bull. 99:210–216.

WADE, P. R., AND R. P. ANGLISS. 1997. Guidelines for assessing marine mammal stocks: Report of the GAMMS Workshop April 3–5, 1996, Seattle, Washington. U.S. Dept. of Comm., NOAA Tech. Memo. NMFS-OPR-12. 93 p.

WARING, G. T., E. JOSEPHSON, C. P. FAIRFIELD, AND K. MAZE-FOLEY. 2007. U.S. Atlantic and Gulf of Mexico Marine Mammal Stock Assessments - 2006. NOAA Tech. Memo. NMFS NE 201. 93 p.

WATSON, J. W., S. P. EPPERLY, A. K. SHAH, AND D. G. FOSTER. 2005. Fishing methods to reduce sea turtle mortality associated with pelagic longlines. Can. J. Fish. Aquat. Sci. 62:965–981.

WYNNE, K., AND M. SCHWARTZ. 1999. Guide to Marine Mammals and Turtles of the U.S. Atlantic and Gulf of Mexico. Rhode Island Sea Grant, University Rhode Island.

YEUNG, C. 1999. Estimates of Marine Mammal and Marine Turtle Bycatch by the U.S. Atlantic Pelagic Longline Fleet in 1998. NOAA Tech. Memo. NMFS-SEFSC-430. 26 p.

YEUNG, C. 2001. Estimates of marine mammal and marine turtle bycatch by the U.S. Atlantic pelagic longline fleet in 1999–2000. NOAA Tech. Memo. NMFS-SEFSC-467. 43 p.

YOSHIHARA, T. 1951. Distribution of fishes caught by the longline. II. Vertical distribution. Bull. Jpn. Soc. Sci. Fish. 16:370–374.