BULLETIN OF MARINE SCIENCE. 88(3):499–511. 2012
http://dx.doi.org/10.5343/bms.2011.1069

CIRCLE HOOK PERFORMANCE IN THE URUGUAYAN PELAGIC LONGLINE FISHERY

Andrés Domingo, Maite Pons, Sebastián Jiménez, Philip Miller, Caren Barceló, and Yonat Swimmer

ABSTRACT

Circle hooks have been promoted as an alternative to traditional J-hooks in pelagic longline fisheries to minimize bycatch mortality and injury to sea turtles and other marine wildlife. We evaluated the effect of hook type (circle hook vs J-hook) on the catch and length composition of target and non-target species in the Uruguayan pelagic longline fishery, for both American- and Spanish-style longlines. The sample unit used for comparing catches was two consecutive sections of the longline, each with a different hook type. For the American-style longline 39,822 hooks were deployed in 108 paired sections, and for the Spanish-style 45,142 hooks were deployed in 238 paired sections. The catch of albacore tuna, *Thunnus alalunga* (Bonnaterre, 1788), was higher with circle hooks with both gears. The catch of shortfin mako shark, *Isurus oxyrinchus* (Rafinesque, 1810), also increased with the use of circle hooks, but only with the American-style longline. A decrease was observed in the catch of pelagic stingray, *Pteroplatytrygon violacea* (Bonaparte, 1832), with both gears, though it was significant only with the Spanish-style longline. The performance of circle hooks for other target species, such as swordfish, *Xiphias gladius* (Linnaeus, 1758), and sharks, and for bycatch species including sea turtles and seabirds remains unclear and requires further research.

The incidental catch of non-target species has been implicated as one of the main factors leading to population declines of many large marine vertebrates (e.g., sea turtles, seabirds, marine mammals, and sharks; Robertson and Gales 1998, Spotila et al. 2000, Baum et al. 2003, Read et al. 2006). During pelagic longline fishing operations, many of these taxa are incidentally wounded and/or killed when hooked and/or entangled in the gear (Brothers et al. 1999, Hall et al. 2000, Lewison et al. 2004, Domingo et al. 2006a, Jiménez et al. 2010). Various bycatch mitigation measures have been tested and implemented by several pelagic longline fleets worldwide (Gilman et al. 2007, Read 2007, Curran and Bigelow 2011, Løkkeborg 2011). Such mitigation measures involve using new or modified technologies and devices, introducing changes to gear design, fishing operations, and/or onboard handling of the catch (Hall et al. 2000, FAO 2009, Løkkeborg 2011).

Among the measures proposed to reduce sea turtle bycatch are setting the hooks deeper in the water, using different bait (e.g., mackerel instead of squid), and changing the shape and size of the hooks (FAO 2009). Circle hooks have been promoted as an alternative to traditional J-hooks in pelagic longline fisheries to minimize sea turtle captures and injuries (Watson et al. 2005, Gilman et al. 2007, see review by Read 2007). Some studies have shown that, apart from potentially reducing sea turtle bycatch, circle hooks mostly lodge in the mouth instead of resulting in deep hooking (e.g., in the esophagus or lower digestive tract), which may increase post-release survival (Cooke and Suski 2004, Epperly and Boggs 2004). However, the results of

studies comparing circle hooks and conventional hooks (J-hooks and tuna hooks) in pelagic longline fisheries lack consistency due to a variety of factors (Cooke and Suski 2004, Read 2007, Serafy et al. 2009). Hence, a recent review recommended the use of circle hooks in specific pelagic longline fleets only after properly designed field experiments have been completed, the results of which support the use of this hook type (Read 2007). However, see Serafy et al. (2009) for a different view.

The loggerhead (*Caretta caretta* Linneaus, 1758) is the main sea turtle species caught as bycatch in pelagic longline fisheries operating in the southwestern Atlantic Ocean (López-Mendilaharsu et al. 2007, Giffoni et al. 2008, Pons et al. 2010). Individuals from different genetic stocks converge in this region (Caraccio et al. 2008), which is an important foraging and development area for juveniles and subadults of this species (Domingo et al. 2006a).

The southwestern Atlantic incidental catch rates of loggerheads are among the highest in the world (Domingo et al. 2006b, Giffoni et al. 2008, Sales et al. 2008), occurring mainly in Uruguayan and adjacent international waters over the continental shelf and slope (Pons et al. 2009, 2010). Additionally, this region also has high seabird (i.e., several globally threatened albatross and petrel species; Jiménez et al. 2009, 2010) and elasmobranch [e.g., *Pteroplatytrygon violacea* (see Table 1 for species authorities); Domingo et al. 2005, Forselledo et al. 2008] bycatch levels associated with pelagic longline fisheries.

In the present study, we compare the performance of circle hooks with that of conventional J-hooks on the catch and length composition of target and non-target species (retained and discarded) with American- and Spanish-style pelagic longlines. We also analyze differences in the condition of the sea turtles caught with each hook type upon gear retrieval, as well as hooking location.

Materials and Methods

Study Area and Sampled Fleet

The present study was conducted over the continental slope in the Exclusive Economic Zone (EEZ) of Uruguay and international waters north of the Rio Grande Rise (Fig. 1). The experiment was conducted on vessels of the Uruguayan pelagic longline fleet. This fleet of nine vessels uses an American-style longline, targets swordfish (*Xiphias gladius*), tunas (*Thunnus* spp.), and pelagic sharks (mainly blue shark, *Prionace glauca*), and keeps its catch on ice for about 20 d, except for a single freezer vessel, which employs a Spanish-style longline, targets mainly blue shark, and makes trips lasting from 1 to 3 mo (Domingo et al. 2005, Jiménez et al. 2009). In our study, the performance of circle hooks and J-hooks was analyzed for each longline style as they present differences in their configuration (e.g., line materials, size of J-hook, branch line configuration) and the main bait they use.

Specifically, 61 American-style longline sets were monitored during seven fishing trips between August 2008 and December 2010. Four of these trips were conducted on two commercial fishing vessels (total lengths = 22 and 26 m) and three on a Uruguayan research vessel (total length = 37 m). The research vessel operated similarly to the commercial fishing vessels using the same longline style, gear configuration, and with skippers and some crew members of the commercial fleet. One-hundred-and-seven sets with Spanish-style longline were monitored on a single 28-m long vessel in two commercial fishing trips (January–March and June–August) in 2007.

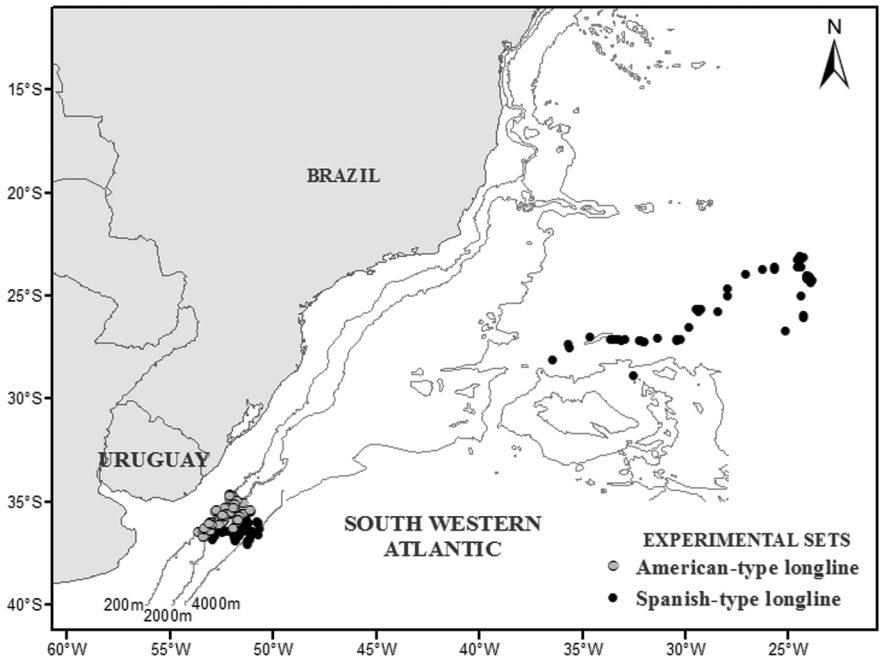

Figure 1. Study area and location of longline sets using American- and Spanish-style gears.

Fishing Gear and Experimental Hooks

American-Style Longline.—The American-style longline gear consisted of a 3.6-mm polyamide monofilament mainline with polyamide or polyester buoy lines 9–36 m long. Four types of buoys were used (foam bullets, rigid floats, polyform inflatable buoys, and radio-beacons). Five 2.0-mm polyamide branch lines 12–14 m long were placed between buoys (Fig. 2A) at intervals of 10–14 s (approximately 50 m, range 42–56 m). Branch lines had two segments, one spanning from the mainline to a weighted swivel (75 g) and another from the swivel to the hook. Each section of the gear was delimited by a radio-beacon, and had 75–300 hooks (160 was the most common number of hooks deployed) of only one type: the reversed 10° offset 18/0 circle hooks or the kirbed 10° offset 9/0 J-hooks (Fig. 3; J-hooks are the hooks traditionally used by the fleet).

Spanish-Style Longline.—The Spanish-style longline gear consisted of a 5-mm polyethylene multifilament mainline with buoy lines (similar to the mainline both in thickness and material) 12–18 m long. Four different sizes of polyform inflatable buoys were used. Eight branch lines 8.5–13 m long were placed between buoys (Fig. 2B) at a fixed interval of 32 m. Each branch line had a terminal segment of three twisted wire threads close to the hook. Each section of the gear was delimited by a radio-beacon, and had 96 hooks of only one type: the reversed 10° offset 18/0 circle hooks or the straight (0° offset) 17/0 J-hook (Fig. 3; this J-hook is the one commonly used on the vessel).

For all experimental trips, the longline was set over the vessel's stern, typically after sunset. However, some sets started prior to sunset (i.e., diurnal sets), finishing always at night. Early in the morning, the gear was hauled onboard at the starboard side of the vessel.

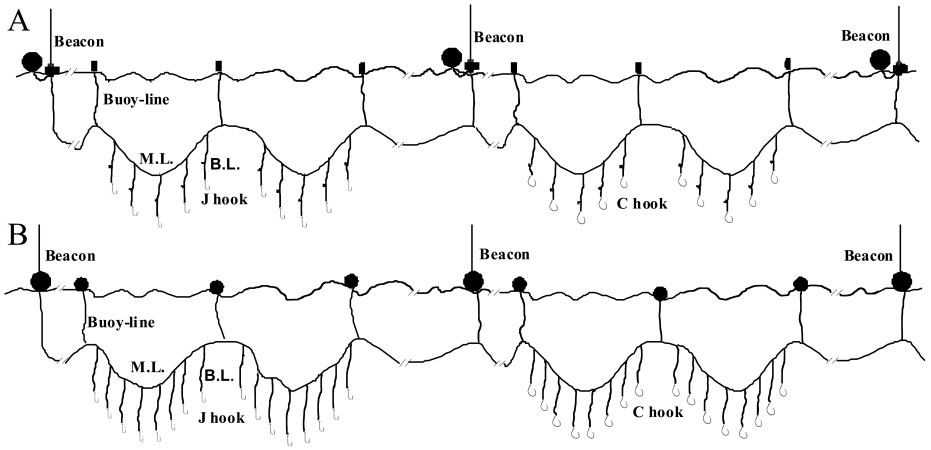

Figure 2. Pair of longline sections used as a sample unit during the experiment. (A) American-style longline gear. (B) Spanish-style longline gear. Refer to the text for details on the buoy-line, branch-line (B.L.), and main-line (M.L.) for each gear.

Experimental Design

A pair of adjacent sections, one with only circle hooks and the other with only J-hooks, was treated as the sample unit. This configuration was chosen for the experiment to minimize interference with normal fishing operations, as alternating hooks would have caused delay and complicated set maneuvers.

Most sections in the American-style longline had 160 hooks; infrequently, the number varied from 75 to 300 hooks per section, but the number of hooks was the same for each member of paired sections. The experiment with the American-style longline analyzed catch data from a total of 39,822 hooks (50% circle hooks and 50% J-hooks) distributed in 108 pairs that were deployed in 61 sets. Hooks were baited either with squid [*Illex argentinus* (Castellanos, 1960) in 87% of the sets] or mackerel (*Scomber* spp. in 13% of the sets); the same bait was used for the two hook types. All sections in the Spanish-style longline had 96 hooks. The experiment with the Spanish-style longline analyzed a total of 45,142 hooks (50% J-hooks and 50% circle hooks) distributed in 238 pairs that were deployed in 107 fishing sets. Hooks were baited with mackerel in 62% of the sets, and in 38% of the sets there were 2 hooks baited with mackerel for every hook that was baited with squid. The baiting regime was the same for the two hook types. For both American- and Spanish-style longlines, the experiment was designed to keep variables as consistent as possible except for the hook type.

Data Collection

There was 100% scientific observer coverage during hauling operations. Observers recorded the total catch (in number of individuals) and, when possible, identified the species and measured the length of each specimen caught. Fork length (FL) was measured for all fish species and minimum curved carapace length (CCL min) for sea turtles (following Bolten 1999). In the case of sea turtles caught with American-style longline, the hooking locations, as well as the condition of the animal at haul-back (dead or alive), were also recorded. Hooking locations were classified as: (1) external (hook lodged in flippers), (2) mouth (hooked in lower jaw, upper jaw, jaw hinge or tongue), or (3) swallowed (hook swallowed, whether or not the shank was visible).

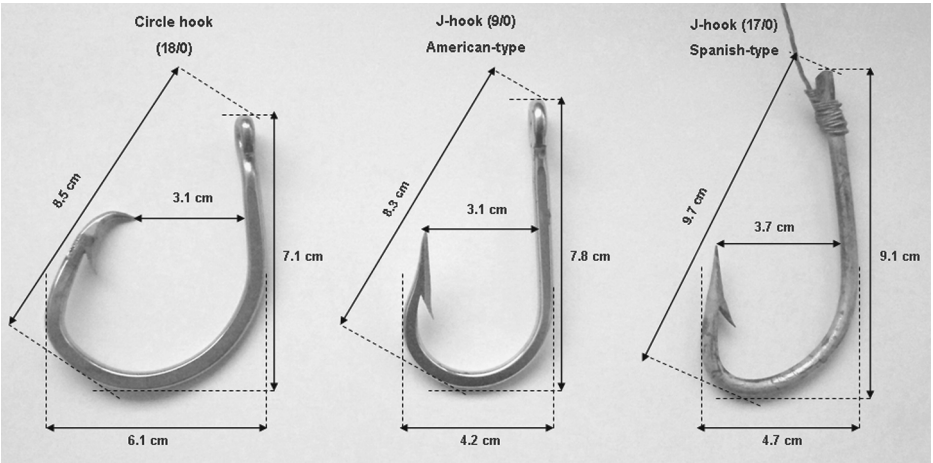

Figure 3. Circle hook and J-hooks employed during the experiment with their respective dimensions.

Data Analysis

For most individuals caught (fishes and other taxa), statistical analyses were performed at the species level. However, prior to statistical analysis some sharks and seabirds species were grouped into higher taxonomic categories (i.e., genus or family). Thresher sharks (*Alopias* spp.) include common thresher, *Alopias vulpinus* (Bonnaterre, 1788), and bigeye thresher, *Alopias superciliosus* (Lowe, 1841). Hammerhead sharks comprise smooth hammerhead, *Sphyrna zygaena* (Linnaeus, 1758), and scalloped hammerhead, *Sphyrna lewini* (Griffith and Smith, 1834). The category *Carcharhinus* consists of the bronze whaler, *Carcharhinus brachyurus* (Günther, 1870), dusky shark, *Carcharhinus obscurus* (Lesueur, 1818), and oceanic whitetip shark, *Carcharhinus longimanus* (Poey, 1861). The night shark, *Carcharhinus signatus* (Poey, 1868), was analyzed separately. Since few albatrosses were caught with both gear styles, species were pooled as Diomedeidae for analysis.

A randomization test was used to assess catch differences between hook types (see IATTC 2008). Randomization tests are particularly suitable for analyzing data that do not have a specific probability distribution and have a high number of extreme or tied values (Manly 2007). These tests allowed examination of the null hypothesis of no differences in catches between adjacent sectional pairs, each with different hook types. The average differences in total numbers of hooked animals in paired sections were used as summary statistics. Data were randomized and resampled 99,999 times and scored for whether or not the resampled value was equal to or greater than the original observed value. This process resulted in a probability of randomness (P) estimate that was used as a measure of statistical significance against a null hypothesis (Manly 2007, IATTC 2008, Curran and Bigelow 2011). If the null hypothesis was not rejected, then all possible orders for the data were equally likely to have occurred.

To test for differences in mean length of the catch between circle hook and J-hooks, we used Student's t-tests (Sokal and Rohlf 1979). Also, Fisher's exact test for count data was used to test for significant differences in hook location and differences in status at haulback (i.e., alive or dead, independent of hook location) between hooks types (Agresti 2007) in American-style longline. For all analyses, significance was declared at $P < 0.05$.

Results

Catches

American-Style Longline.—The tuna catch with the American-style longline was higher with circle hooks (Table 1); however, this difference was statistically significant only for albacore (*Thunnus alalunga*, $P = 0.00$). Significanlty more shortfin mako sharks (*Isurus oxyrinchus*) were caught with circle hooks than with J-hooks ($P = 0.03$, Table 1). The catch of other commercially important sharks, including blue (*Prionace glauca*) and porbeagle (*Lamna nasus*) sharks exhibited a similar trend, but the differences were not significant (Table 1). There was a 24% non-significant decrease ($P = 0.06$) in swordfish catch with circle hooks as compared to J-hooks.

Thirteen albatrosses, including 11 Black-browed Albatross, *Thalassarche melanophrys* (Temminck, 1828), and 2 Shy-type Albatross, *Thalassarche* spp., were caught with J-hooks and 5 albatrosses [4 Black-browed and 1 Southern Royal, *Diomedea epomophora* (Lesson, 1825)] were caught with circle hooks. However, there was no significant hook difference (Table 1). The catch of these birds was concentrated in just 7% of the paired sections.

We observed a 25% decrease in the catch of loggerheads with circle hooks, but this difference also was not significant (Table 1). In addition, four leatherback turtles were captured, two with circle hooks and two with J-hooks.

Spanish-Style Longline.—Overall, the catch of target species was higher with circle hooks than with J-hooks (Table 1). For tunas, the difference was only significant for albacore ($P = 0.01$). There was a large ($P = 0.00$) decrease in catches of the pelagic stingray with circle hooks, representing just 10% of catches with J-hooks (Table 1). Catches of swordfish increased about 6% with circle hooks vs J-hooks, but this increase was not significant.

Six Albatrosses, 4 Black-browed, 1 Atlantic Yellow-nosed (*Thalassarche chlororhynchos* Gmelin, 1789), and 1 Wandering Albatross (*Diomedea exulans* Linnaeus, 1758) were caught with J-hooks and only 1 Black-browed Albatross and 2 petrels (1 White-chinned, *Procellaria aequinoctialis* Linnaeus, 1758, and 1 unidentified) were caught with circle hooks. The percentage of paired sections that caught seabirds was only 2% of the total.

For loggerhead sea turtles, we observed a decrease of 45% in their catch with circle hooks, compared to J-hooks (Table 1). However, this difference was not significant ($P = 0.15$). The percentage of paired sections that caught loggerheads was 9% of the total. Two leatherback sea turtles were caught as well, one with each hook type.

Length Distribution

Body length data were obtained for 72% and 25% of the individuals caught during the experiments with the American-style and Spanish-style longlines, respectively. There were no significant differences in the mean length of the analyzed species (swordfish and blue shark in both longline types, and tuna and shortfin mako in American-style longline).

Loggerhead sea turtles caught during the experiment ranged in size from 45 to 80 cm CCL min with a mean of 59 cm on American-style longline. On Spanish-style longline the range was 53 to 73 cm CCL min with a mean length of 62 cm. There were no significant differences in mean size between hook types for either American-style ($t = -0.22$, $P = 0.85$, $n = 79$) or Spanish-style longline ($t = 1.14$, $P = 0.14$, $n = 22$).

Table 1. Number of individuals of each species caught in Uruguayan and international waters with circle hooks (C) and J-hooks (J) in the American- and Spanish-style longlines. *P* corresponds to the probability value of the randomization test. Dash lines means that no statistical analyses were performed.

		American-type longline			Spanish-type longline		
Species	Common name	C	J	*P*	C	J	*P*
Tunas							
Thunnus alalunga (Bonnaterre, 1788)	Albacore	549	251	0.000	66	28	0.010
Thunnus albacares (Bonnaterre, 1788)	Yellowfin tuna	196	146	0.238	2	1	----
Thunnus obesus (Lowe, 1839)	Bigeye tuna	36	27	0.234	5	1	----
Billfishes							
Xiphias gladius Linnaeus, 1758	Swordfish	148	195	0.063	148	139	0.324
Sharks							
Prionace glauca (Linnaeus, 1758)	Blue shark	933	860	0.345	446	339	0.101
Isurus oxyrinchus Rafinesque, 1810	Shortfin mako	39	20	0.030	9	7	0.398
Lamna nasus (Bonnaterre, 1788)	Porbeagle	8	6	0.441	21	11	0.255
Carcharhinus signatus (Poey, 1868)	Night shark	27	22	0.392	0	0	----
Carcharhinus spp.		9	20	0.176	0	2	----
Alopias spp.	Thresher sharks	3	11	0.080	0	1	----
Sphyrna spp.	Hammerheads	15	23	0.356	5	3	0.359
Rays							
Pteroplatytrygon violacea (Bonaparte, 1832)	Pelagic stingray	6	11	0.304	4	44	0.000
Other teleosts							
Coryphaena hippurus Linnaeus, 1758	Dolphin fish	20	18	0.454	2	2	-----
Lepidocybium flavobrunneum (Smith, 1843)	Escolar	14	16	0.432	22	16	0.207
Mola mola (Linnaeus, 1758)	Sunfish	53	52	0.567	3	4	0.506
Ruvettus pretiosus Cocco, 1833	Oilfish	9	13	0.303	16	19	0.385
Acanthocybium solandri (Cuvier in Cuvier and Valenciennes, 1832)	Wahoo	0	0	----	6	14	0.075
Sea turtles							
Dermochelys coriacea (Vandelli, 1761)	Leatherback	2	2	----	1	1	----
Caretta caretta (Linnaeus, 1758)	Loggerhead	36	48	0.238	11	20	0.155
Birds							
Diomedeidae	Albatrosses	5	13	0.356	1	6	----
Procellariidae	Petrels	0	0	----	2	0	----

Hooking Location and Condition in Sea Turtles

Information about hooking location was recorded for 61 of the 84 loggerheads caught with the American-style longline. Most of the hooks were found in the mouth for both types of hooks (68% with circle hooks and 81% with J-hooks). Very few external hooking events were observed for either hook type (12% and 3% for circle hooks and J-hooks, respectively). The percentage of swallowed hooks was similar between hook types: circle hooks (20%) as compared to J-hooks (17%). There were no significant differences between hook types for any category of hooking location ($P > 0.05$). For the American-style longline, the percentage of turtles that were observed dead upon retrieval between circle hooks (43%) and J-hooks (32%) did not differ significantly ($P = 0.22$). All loggerheads caught with circle hooks ($n = 11$) with Spanish-style longline were alive when hauled onboard. Only one of the sea turtles caught with J-hooks ($n = 20$) was dead.

Discussion

Our results show that the use of 10° offset 18/0 circle hooks reduces the capture of a few bycatch species and increases the catch of some target species as compared to the kirbed 10° offset 9/0 J-hooks used in American-style longline and the straight 17/0 J-hooks employed in Spanish-style longline. Catches of albacore and shortfin mako increased with circle hooks, while an opposite trend was observed in the catch of pelagic stingrays. On the other hand, a decrease of 24%, though not significant, was observed in the catch of swordfish in the American-style gear. As swordfish is the main target species in this fishery, stakeholders might be reluctant to adopt circle hooks. In the Spanish-style longline fishery, catches of swordfish showed a non-significant increase of 6%, but as previously noted this fishery targets mostly sharks.

The bait used during the experiments is a recognized caveat to our study, as it was a factor that could not be entirely controlled. Vessels that operate with American-style gear mostly employed squid as bait, while the vessel that operates with Spanish-style gear fished mainly with mackerel. However, in the experiments conducted on commercial vessels the bait varied depending on its availability and the skippers' preference, something likely to occur under typical fishing conditions. The bait composition did not vary within sectional pairs: the same bait type or mix of baits was used in both sections of a pair.

Target Species

Tuna catches with 18/0 circle hooks increased relative to J-hooks on both styles of longline with significant differences only in the case of albacore. This increase in tuna catch with circle hooks is consistent with prior studies conducted in different parts of the world (Kerstetter and Graves 2006, Ward et al. 2009, Sales et al. 2010, Pacheco et al. 2011). The catch of albacore with circle hooks was over twice the catch with J-hooks. In particular, these results are consistent with those reported by Sales et al. (2010) in the southwestern Atlantic Ocean.

We found no significant difference in the mean body size of tuna captured with either hook type in American-style longline gear. This lack of difference in size selectivity between circle hooks and J-hooks has also been documented (Kerstetter and Graves 2006, Ward et al. 2009) in other longline fisheries.

For vessels using American-style longline, there was a non-significant decrease in the catch of swordfish. In contrast, in the experiments performed with Spanish-style longline, although the main target species was the blue shark, there was a non-significant increase in the catch of swordfish. This opposite trend could be explained by the different bait used in each gear style: Watson et al. (2005) and Read (2007) found that circle hooks significantly increase the catch rates of swordfish when they were baited with mackerel instead of squid. There was no difference in the body length of swordfish caught on the two hook types in either style of gear, which is also consistent with other studies (Kerstetter and Graves 2006, Ward et al. 2009, Pacheco et al. 2011).

Catches of shark species increased with circle hooks; however, this was only significant for the shortfin mako in the American-style longline. Other studies found a significant increase in catches of sharks, mainly blue sharks, with circle hooks (Watson et al. 2005, Gilman et al. 2007, Sales et al. 2010). Some authors suggest that hooks baited with squid result in an increase in shark catch rates while the use of mackerel, either with circle hooks or J-hooks, results in a reduction of these catches (Gilman et al. 2007, Read 2007). The effect of the bait type on the catches should be specifically addressed in future research.

Recently, Afonso et al. (2011) found that the use of circle hooks reduces the rate of deep hooking and increases the proportion of mouth hooking in shark species (including blue shark). Watson et al. (2005) and Afonso et al. (2011) suggested that the increase in blue shark catches using circle hooks could be misleading because sharks that are deep-hooked by J-hooks probably bite the polyamide monofilament leader and escape before being hauled on board. Although this could account for the increased shark catch rates recorded in American-style longline using circle hooks, this idea is unlikely to apply to the Spanish-style longline where the leader consists of three twisted wire threads used to avoid shark loss.

Sea Turtles

The highest values of loggerhead catch per unit effort in longline fisheries in the southwestern Atlantic occur over the Uruguayan continental slope (Pons et al. 2009, 2010). The gear is a significant factor that affects the catch rates observed in this area for this species. Specifically, vessels that use American-style longline have higher catch rates of loggerheads than those that use Spanish-style longline (Pons et al. 2010). We observed a non-significant reduction of loggerhead bycatch with the use of circle hooks in both gear styles. While our results are not conclusive, the potential for circle hooks to reduce sea turtle catches may be greater where mackerel is used as bait. Several studies found that circle hooks (18/0) baited with mackerel were more effective at reducing sea turtle interactions than those baited with squid (Watson et al. 2005, Brazner and McMillan 2008).

Most of the loggerhead hooking locations recorded in our study occurred in the mouth for both circle hooks and J-hooks. Similar results were found by Brazner and McMillan (2008), who recorded 89% of turtles hooked in the mouth with 16/0 circle hooks and 87% with J-hooks. The percentage of loggerheads that swallowed hooks was approximately equal for each hook type (approximately 20%), although few sea turtles in this category were recorded. This was an unexpected result since several studies, reviewed by Gilman et al. (2006) and Read et al. (2007), have suggested that circle hooks reduce the proportion of turtles that swallow the hook and therefore the post-release mortality rate. However, other studies found no differences in hook location for loggerheads caught with J-hooks vs circle hooks (e.g., Carruthers et al. 2009).

Only six leatherback sea turtles were caught over the course of the present study and in equal number for each hook type. This species is typically hooked externally or entangled in the mainline, branch lines, or buoy lines (Watson et al. 2005), as observed in the present study. Therefore, hook type does not appear to have a major effect on bycatch of this species in the fishery. However, sample sizes were small in the present study.

Other Bycatch Species

Our results also indicate that circle hooks could reduce the bycatch of the pelagic stingray in the Spanish-style gear (>90%). In the American-style gear, although the catch was 45% lower with circle hooks, this reduction was not significant. After the blue shark, the pelagic stingray is the second elasmobranch species most commonly captured by the Uruguayan pelagic longline fleet (Forselledo et al. 2008). Although a large proportion of specimens are discarded alive, post-release mortality is probably high since most of the rays suffer severe trauma or even lose their jaws when discarded (Domingo et al. 2005, Forselledo et al. 2008). The reduction in the pelagic stingray catch we observed in the Spanish-style gear is consistent with the findings by previous studies (Kerstetter and Graves 2006, Piovano et al. 2009, 2010, Curran and Bigelow 2011, Pacheco et al. 2011). A possible explanation, as suggested by Piovano et al. (2010), could be the relationship between the size of the gape of the stingray mouth and the size and shape of the hook.

The bycatch of albatrosses is a major conservation issue in the Uruguayan fishery because their catch rates are among the highest reported worldwide (Jiménez et al. 2009, 2010). Although we observed a tendency for J-hooks to catch more albatrosses than circle hooks, this pattern was not significant. It should be noted that occasionally paired sections were deployed in different light conditions. J-hooks in daylight and circle hooks immediately after dusk. Considering that these species are captured in the first seconds after the hooks are deployed and the time of the set (day or night) is one of the main factors affecting their catch (Jiménez et al. 2009), the difference in setting times may have confounded the hook type effect on albatrosses bycatch. However, the potential of circle hooks to reduce albatross bycatch deserves further research.

Our results show that the use of circle hooks reduces the capture of a few bycatch species while increasing the catch of some target species. However, other factors such as size and shape of hooks, gear configuration, type and size of bait, and time of setting, among others, should also be considered in future studies (ICCAT 2011).

Acknowledgments

We thank the crews and boat owners of the Uruguayan fleet, and the crew of the research vessel Aldebarán for their continued cooperation. This work was made possible by the Programa Nacional de Observadores de la Flota Atunera Uruguaya (PNOFA), Departamento de Recursos Pelágicos, Dirección Nacional de Recursos Acuáticos (DINARA). Thanks to PNOFA observers and colleagues from CICMAR. This work was partially funded by NOAA-NMFS-PIFSC (contract #AB133F08SE3042), DINARA, and CICMAR.

Literature Cited

Afonso AS, Hazin FHV, Carvalho F, Pacheco JC, Hazin H, Kerstetter DW, Murie D, Burgess GH. 2011. Fishing gear modifications to reduce elasmobranch mortality in pelagic and bottom longline fisheries off Northeast Brazil. Fish Res. 108:336–343. http://dx.doi.org/10.1016/j.fishres.2011.01.007

Agresti A. 2007. An introduction to categorical data analysis. 2nd ed. Wiley-Interscience. http://dx.doi.org/10.1002/0470114754

Baum JK, Myers RA, Kehler DG, Worm B, Harley SJ, Doherty PA. 2003. Collapse and conservation of shark populations in the northwest Atlantic. Science. 299:389–392. PMid:12532016. http://dx.doi.org/10.1126/science.1079777

Bolten AB. 1999. Techniques for measuring sea turtles. *In:* Eckert KL, Bjorndal KA, Abreu-Grobois FA, Donnelly M, editors. Research and management techniques for the conservation of sea turtles. IUCN/SSC Marine Turtle Specialist Group Publication No. 4.

Brazner JC, McMillan J. 2008. Loggerhead turtle (*Caretta caretta*) bycatch in Canadian pelagic longline fisheries: relative importance in the western North Atlantic and opportunities for mitigation. Fish Res. 91:310–324. http://dx.doi.org/10.1016/j.fishres.2007.12.023

Brothers NP, Cooper J, Løkkeborg S. 1999. The incidental catch of seabirds by longline fisheries: worldwide review and technical guidelines for mitigation. Rome, FAO Fisheries Circular No. 937.

Caraccio MN, Domingo A, Márquez A, Naro-Maciel E, Miller P, Pereira A. 2008. Las aguas del Atlántico Sudoccidental y su importancia en el ciclo de vida de la tortuga cabezona (*Caretta caretta*): evidencias a través del análisis del ADNmt. Col Vol Sci Pap. ICCAT. 62:1831–1837.

Carruthers EH, Schneider DC, Neilson JD. 2009. Estimating the odds of survival and identifying mitigation opportunities for common bycatch in pelagic longline fifisheries. Biol Conserv. 142:2620–2630. http://dx.doi.org/10.1016/j.biocon.2009.06.010

Cooke S, Suski C. 2004. Are circle hooks an effective tool for conserving marine and freshwater recreational catch-and-release fisheries? Aquat Conserv Mar Freshwat Ecosyst. 14:299–326. http://dx.doi.org/10.1002/aqc.614

Curran D, Bigelow K. 2011. Effects of circle hooks on pelagic catches in the Hawaii-based tuna longline fishery. Fish Res. 109:265–275. http://dx.doi.org/10.1016/j.fishres.2011.02.013

Domingo A, Menni RC, Forselledo R. 2005. Bycatch of the pelagic ray *Dasyatis violacea* in Uruguayan longline fisheries and aspects of distribution in the southwestern Atlantic. Sci Mar. 69:161–166.

Domingo A, Bugoni L, Prosdocimi L, Miller P, Laporta M, Monteiro DS, Estrades A, Albareda D. 2006a. El impacto generado por las pesquerías en las tortugas marinas en el Océano Atlántico Sud occidental. WWF Programa Marino para Latinoamérica y el Caribe, San José, Costa Rica.

Domingo A, Sales G, Giffoni B, Miller P, Laporta M, Maurutto G. 2006b. Captura incidental de tortugas marinas con palangre pelágico en el Atlántico Sur por las flotas de Brasil y Uruguay. Col Vol Sci Pap. ICCAT. 59:992–1002.

Epperly SP, Boggs C. 2004. Post-hooking mortality in pelagic longline fisheries using "J" hooks and circle hooks. Application of new draft criteria to data from the Northeast Distant Experiments in the Atlantic. Southeast Fisheries Science Center. Miami, FL, USA.

FAO Fisheries Department. 2009. Guidelines to reduce sea turtle mortality in fishing operations. FAO, Rome.

Forselledo R, Pons M, Miller P, Domingo A. 2008. Distribution and population structure of the pelagic stingray, *Pteroplatytrygon violacea* (Dasyatidae), in the south-western Atlantic. Aquat Living Resour. 21:357–363. http://dx.doi.org/10.1051/alr:2008052

Giffoni B, Domingo A, Sales G, Niemeyer-Fiedler F, Miller P. 2008. Interacción de tortugas marinas (*Caretta caretta* y *Dermochelys coriacea*) con la pesca de palangre pelágico en el atlántico sudoccidental: una perspectiva regional para la conservación. Col Vol Sci Pap. ICCAT. 62:1861–1870.

Gilman E, Kobayashi D, Swenarton T, Brothers N, Dalzell P, Kinan-Kelly I. 2007. Reducing sea turtle interactions in the Hawaii-based longline swordfish fishery. Biol Conserv. 139:19–28. http://dx.doi.org/10.1016/j.biocon.2007.06.002

Gilman E, Zollet E, Beverly S, Nakano H, Davis K, Shiode D, Dalzell P, Kinan I. 2006. Reducing sea turtle by-catch in pelagic longline fisheries. Fish Fish. 7:2–23. http://dx.doi.org/10.1111/j.1467-2979.2006.00196.x

Hall M, Alverson DL, Metuzals KI. 2000. By-catch: problems and solutions. Mar Pollut Bull. 41:204–219. http://dx.doi.org/10.1016/S0025-326X(00)00111-9

IATTC. 2008. Special Report No. 17. Workshop on turtle bycatch mitigation for longline fisheries: experimental design and data analysis. 7–8 November, 2007. San Ramón, Alajuela, Costa Rica.

ICCAT 2011. 2011 Inter-sessional meeting of the sub-committee on ecosystems. ICCAT. Miami, FL, United States. May 9–13, 2011. Available at: http://www.iccat.es/Documents/Meetings/Docs/2011_SC_ECO_REP_ENG.pdf. Accessed January 26, 2011.

Jiménez S, Abreu M, Pons M, Ortiz M, Domingo A. 2010. Assessing the impact of the pelagic longline fishery on albatrosses and petrels in the southwest Atlantic. Aquat Living Resour. 23:49–64. http://dx.doi.org/10.1051/alr/2010002

Jiménez S, Domingo A, Brazeiro A. 2009. Seabird bycatch in the southwest Atlantic: interaction with the Uruguayan pelagic longline fishery. Polar Biol. 32:187–196. http://dx.doi.org/10.1007/s00300-008-0519-8

Kerstetter DW, Graves JE. 2006. Effects of circle versus J-style hooks on target and non-target species in a pelagic longline fishery. Fish Res. 80:239–250. http://dx.doi.org/10.1016/j.fishres.2006.03.032

Lewison RL, Freeman SA, Crowder LB. 2004. Quantifying the effects of fisheries on threatened species: the impact of pelagic longlines on loggerhead and leatherback sea turtles. Ecol Lett. 7:221–231. http://dx.doi.org/10.1111/j.1461-0248.2004.00573.x

Løkkeborg S. 2011. Best practices to mitigate seabird bycatch in longline, trawl and gillnet fisheries efficiency and practical applicability. Mar Ecol Prog Ser. 435:285–303. http://dx.doi.org/10.3354/meps09227

López-Mendilaharsu M, Sales G, Giffoni B, Miller P, Niemeyer Fiedler F, Domingo A. 2007. Distribución y composición de tallas de las tortugas marinas (*Caretta caretta* y *Dermochelys coriacea*) que interactúan con el palangre pelágico en el Atlántico Sur. Col Vol Sci Pap. ICCAT. 60:2094–2109.

Manly BFJ. 2007. Randomization, bootstrap and Monte Carlo methods in biology. 3rd ed. Chapman and Hall/CRC.

Pacheco JC, Kerstetter DW, Hazin FH, Hazin H, Segundo RSSL, Graves JE, Carvalho F, Travassos PE. 2011. A comparison of circle hook and J hook performance in a western equatorial Atlantic Ocean pelagic longline fishery. Fish Res. 107:39–45. http://dx.doi.org/10.1016/j.fishres.2010.10.003

Piovano S, Clò S, Basciano G, Giacoma C. 2010. Reducing longline bycatch: the larger the hook, the fewer the stingrays. Biol Conserv. 143:261–26. http://dx.doi.org/10.1016/j.biocon.2009.10.001

Piovano S, Swimmer Y, Giacoma C. 2009. Are circle hooks effective in reducing incidental captures of loggerhead sea turtles in a Mediterranean longline fishery? Aquatic Conserv Mar Freshwat Ecosyst. 19:779–785. http://dx.doi.org/10.1002/aqc.1021

Pons M, Domingo A, Sales G, Niemeyer Fiedler F, Miller P, Giffoni B, Ortiz M. 2010. Standardization of CPUE of loggerhead sea turtle (*Caretta caretta*) caught by pelagic longliners in the southwestern Atlantic Ocean. Aquat Living Resour. 23:65–75. http://dx.doi.org/10.1051/alr/2010001

Pons M, Marroni S, Machado I, Badih G, Domingo A. 2009. Machine learning procedures: an application to by-catch data of the marine turtles *Caretta caretta* in the southwestern Atlantic Ocean. Col Vol Sci Pap. ICCAT. 64:2443–2454.

Read A. 2007. Do circle hooks reduce the mortality of sea turtles in pelagic longlines? A review of recent experiments. Biol Conserv. 135:155–169. http://dx.doi.org/10.1016/j.biocon.2006.10.030

Read AJ, Drinker P, Northridge S. 2006. Bycatch of marine mammals in US and global fisheries. Conserv Biol. 20:163–169. PMid:16909669. http://dx.doi.org/10.1111/j.1523-1739.2006.00338.x

Robertson G, Gales R. 1998. Albatross biology and conservation. Surrey Beatty and Sons, Chipping Norton.

Sales G, Giffoni B, Barata P. 2008. Incidental catch of sea turtles by the Brazilian pelagic longline fishery. J Mar Biol Assoc UK. 88:853–864.

Sales G, Giffoni B, Fiedler F, Azevedo V, Kotas J, Swimmer Y, Bugoni L. 2010. Circle hook effectiveness for the mitigation of sea turtle bycatch and capture of target species in a Brazilian pelagic longline fishery. Aquat Conserv Mar Freshwat Ecosyst. 20:428–436. http://dx.doi.org/10.1002/aqc.1106

Serafy J, Kerstetter D, Rice P. 2009. Can circle hook use benefit billfishes? Fish Fish. 10:132–142. http://dx.doi.org/10.1111/j.1467-2979.2008.00298.x

Sokal R, Rohlf F. 1979. Biometría. Principios y métodos estadísticos en la investigación biológica. BLUME, Barcelona, España.

Spotila JR, Reina RR, Steyermark AC, Plotkin PT, Paladino FV. 2000. Pacific leatherback turtles face extinction. Nature. 405:529–530. PMid:10850701. http://dx.doi.org/10.1038/35014729

Watson J, Epperly S, Foster D, Shah A. 2005. Fishing methods to reduce sea turtle mortality associated with pelagic longlines. Can J Fish Aquat Sci. 62:965–981. http://dx.doi.org/10.1139/f05-004

Ward P, Eea S, Kreutz D, Lawrence E, Robins C, Sands A. 2009. The effects of circle hooks on bycatch and target catches in Australia's pelagic longline fishery. Fish Res. 97:253–262. http://dx.doi.org/10.1016/j.fishres.2009.02.009

Date Submitted: 11 July, 2011.
Date Accepted: 18 June, 2012.
Available Online: 5 July, 2012.

Addresses: (AD, MP, SJ, CB, PM) *Departamento de Recursos Pelágicos, Dirección Nacional de Recursos Acuáticos (DINARA), Montevideo, Uruguay. Constituyente 1497, Montevideo, Uruguay. CP: 11200.* (MP, SJ, CB, PM) *Centro de Investigación y Conservación Marina (CICMAR), Giannattasio km. 30.5 El Pinar, Canelones, CP 15008, Uruguay.* (CB) *College of Earth, Ocean and Atmospheric Sciences, Oregon State University, Corvallis, Oregon 97330.* (YS) *NOAA Fisheries, Pacific Islands Fisheries Science Center, 2570 Dole St, Honolulu, Hawaii 96822.* Corresponding Author: (AD) *Email: <dimanchester@gmail.com>.*