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EFFECTS OF SMALL (13/0) CIRCLE HOOKS ON LOGGERHEAD SEA TURTLE BYCATCH IN A SMALL-SCALE, ITALIAN PELAGIC LONGLINE FISHERY

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ABSTRACT

Incidental catches by pelagic longline fisheries are recognized as serious threats to the loggerhead sea turtle, *Caretta caretta* (Linnaeus, 1758). In the present study, we assessed the effects of small (13/0) circle hooks on the catches of *C. caretta* in a small-scale, pelagic longline fishery off the southern coast of Ionian Calabria (southern Italy). Experiments were conducted on a commercial fishing vessel using circle hooks (Mustad 13/0, *n* = 2320) alternated with J-hooks (Mustad No. 4, *n* = 2322) along 13 longline sets. The mean catch per unit of effort (CPUE) of the target species *Thunnus thynnus* (Linnaeus, 1758) (*n* = 30) per fishing set and its mean body size did not differ significantly between the two hook types. No significant differences emerged in the sea turtle CPUE for each hook type; however, there was a significant reduction in mean body size with circle hooks due to a decrease in the catch rate of large juvenile loggerhead turtles. Although more data are necessary to obtain a comprehensive picture, the widespread adoption of 13/0 circle hooks has the potential for benefitting large juveniles and nesting adult sea turtles. Our data also suggest that adoption of 13/0 circle hooks would not adversely impact the economic viability of the fishery.

Six of the seven extant species of sea turtles are listed as threatened in the IUCN's Red List, three as critically endangered, two endangered, and one vulnerable (IUCN 2010); incidental catches by fishing operations are recognized as a likely cause of sea turtle population declines (Spotila et al. 2000, Lewison et al. 2004).

To reduce sea turtle bycatch and/or post-release mortality in pelagic longline fisheries, simple operational modifications, such as changing gear components or the bait, are often easier to implement than effort restrictions and closed areas (Swimmer et al. 2010). In this context, the use of circle hooks may not only reduce the incidental catches of sea turtles and improve post-release survival (Watson et al. 2005), but may also be more readily adopted by fishers than other management measures. While the effectiveness of large (e.g., 18/0) circle hooks for reducing sea turtle bycatch has been demonstrated in several studies (i.e., Watson et al. 2005, Gilman et al. 2007, Read 2007, Sales et al. 2010), few experiments using small (e.g., ≤15/0) circle hooks have been conducted in longline fisheries and the results are not conclusive that they reduce capture and/or injury of sea turtles and other bycatch species (Largarcha et al. 2005, Ward et al. 2009). Gilman et al. (2006) hypothesized that small circle hooks are possibly too small to prevent sea turtles from being hooked, but they could reduce the incidence of being swallowed (deep hook ingestion). This may result in a higher post-release survival rate of the hooked sea turtles, as suggested by Casale et al. (2008), where sea turtles hooked in the lower esophagus seemed to have higher post-hooking mortality rates than those hooked in the mouth. This is of particular interest in small-scale longline fisheries, which usually employ relatively small J-hooks, and often have a high sea turtle catch rate (Gilman et al. 2006).

The loggerhead sea turtle, *Caretta caretta*, is the most abundant of the three marine turtle species occurring in the Mediterranean Sea (Groombridge 1990). Data suggest that the number of marine turtles caught annually with pelagic longlines in the basin may exceed 57,000 and the Alboran/Balearic sector, the central area and the Ionian Sea, are the fishing grounds with the highest catch risks (Casale 2011). Although small-scale fleets form a large component of the pelagic longline fishery in many regions (Laurent et al. 1990, Jribi et al. 2008, Báez et al. 2009), and are suspected to have a bycatch of at least 25,000 sea turtles each year (Casale 2011), most bycatch mitigation studies in the basin have focused on large-scale pelagic longline fisheries using large circle hooks (e.g., Piovano et al. 2009) and only one experimental study has been carried out to test small (12/0) circle hooks in the southwest Mediterranean Sea (Sagarminaga et al. 2012).

Caretta caretta is the most abundant species of marine turtle found in Italian waters. It is estimated that 500 loggerhead bycatches are caused by small-scale vessels using pelagic longlines each summer season along the southern Ionian coast of Calabria (Cambiè et al. 2010). Besides being located off the largest Italian loggerhead nesting site (Mingozzi et al. 2007), this fishing ground is also part of a wider foraging area for juvenile sea turtles from different Mediterranean nesting areas (Casale et al. 2010). Therefore, the risk of catching nesting females has to be added to the already high bycatch of juveniles in this area. Hence, assessing mitigation measures for reducing interactions between sea turtles and longline fisheries has become an urgent conservation priority, and testing circle hooks is an important step toward achieving this. In 2010, the first experiments with small-sized circle hooks used by a small-scale longline vessel operating in this area were conducted to determine: (1) their effectiveness in reducing the incidental capture of loggerhead sea turtles; (2) if they reduced the number of deep hooking events and/or immediate mortality rates; and (3) whether potential changes in the species and size composition were associated with their use.

Materials and Methods

Study Area, Gear Characteristics, and Experimental Design.—A total of 13 fishing sets was conducted by a single commercial fishing vessel (11 m long) using surface pelagic longlines from 25 June to 19 August, 2010. Longline sets were deployed in the main fishing ground of the small-scale pelagic longline fleet (from 37°43′ to 37°53′N and 16°02′ to 16°32′E, Fig. 1), which is located off the loggerhead sea turtle nesting beaches on the southern coast of Ionian Calabria (Cambiè et al. 2010). Mean soak time was approximately 20 hrs; however, it changed significantly throughout the fishing season. The fisher decided to change soak time to increase the target species catchability. The fisher also selected the type and dimensions of the circle hooks to be tested in accordance with his fishing strategy. He chose the circle hook with the narrowest width similar to that of the J-hooks normally employed because, in his opinion, the bait would not conceal wider hooks. Frozen squid, *Illex argentinus* (Castellanos, 1960), was used as bait for all fishing sets. Equal numbers of 13/0 non-offset circle hooks (type Mustad Duratin 39960D) and J-hooks No. 4 with a 10° offset (type Mustad Duratin 2331XT) were alternated along the main line (Fig. 2).

Data Collection.—For each longline set, an onboard observer recorded information on the technical characteristics of the fishing set and on the commercial and discarded species

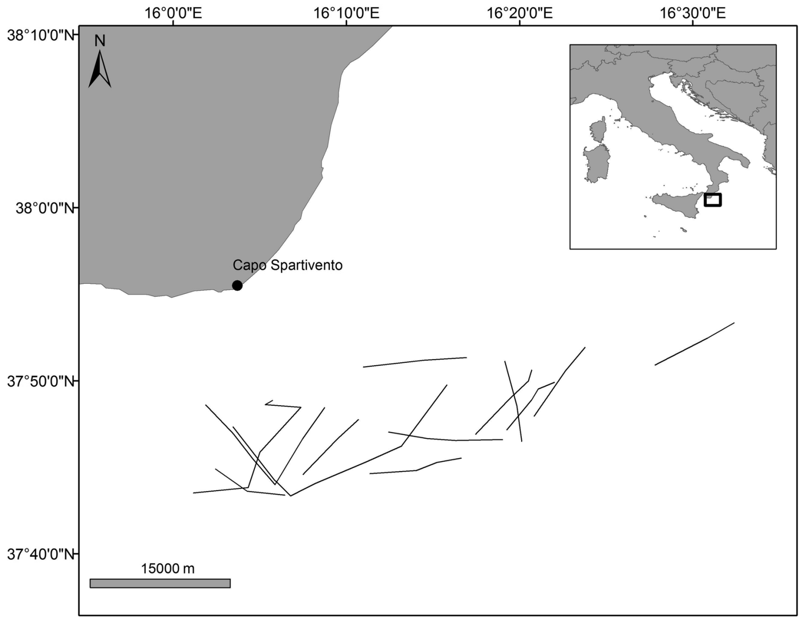

Figure 1. Study area off the southern coast of Ionian Calabria (Italy) with the location (black lines) of the fishing sets (n = 13, surface longlines) observed during the summer of 2010. Each line corresponds to the location where the longline was deployed.

caught by each hook type. Times of gear deployment and retrieval were recorded and the sequence of hook types, fishing lights, and floats were regularly monitored during deployment to ensure that the gear configuration was consistent along the entire longline. The hook type with which each species was caught and the position of the hook between the floats and on the main line was recorded, as well as animal condition at haulback (dead or alive). All commercial species were measured (total length to the nearest cm) and weighed once they were landed. When possible, these data were also collected for bycatch species, with particular attention placed on sea turtles. The curved carapace length notch-to-tip (CCLn-t, Bolten 1999) of each sea turtle caught was measured (cm) and hooking location classified according to Epperly and Boggs (2004). When possible, loggerheads were dehooked using release equipment according to the handling and release protocols of Epperly et al. (2004).

Statistical Analysis.—Catch per unit of effort (CPUE) per set was expressed per 1000 hooks and mean body size of target and non-target species, as well as the hooking locations for the sea turtles, were compared for the J- and circle hooks. The Wilcoxon signed ranks test was used to assess significant differences in circle and J-hook CPUEs in each set. For both bycatch and target species (loggerhead sea turtle and Atlantic bluefin tuna, respectively), the test was performed only on those sets where specimens were captured, according to Piovano et al. (2009). For sea turtles in particular, the CPUE was first estimated considering all loggerhead turtles caught and then the catches were divided into two size classes: small juveniles (CCLn-t ≤ 40 cm) and large juveniles (CCLn-t > 40 cm). The size cut-off point was established at 40 cm according to Lazar and Gračan (2011) and was the median of our data.

For continuous variables with normal distribution (the mean body size of captured species), we carried out the Levene's test for homogeneity of variance and declared significance at $P <$ 0.05. If homogeneity of variance assumption was confirmed, a one-way analysis of variance (ANOVA) was conducted with hook type as the categorical predictor. In addition, to investigate the difference in the hook location observed using the two hook types, the chi-square test

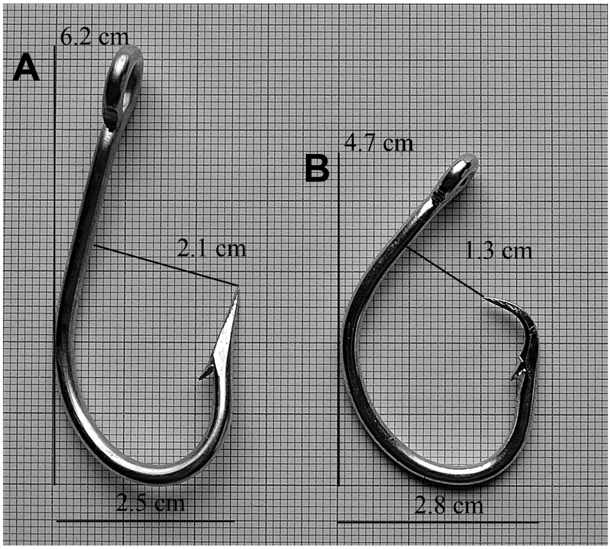

Figure 2. View of (A) J-hook Mustad No. 4, 10° offset and (B) circle hook Mustad 13/0 non-offset used during the summer of 2010 off the southern Ionian coast of Calabria (Italy). Hook dimensions: gape width (center), narrowest width (bottom), and total length (sideline, photo G Cambiè).

(χ^2) with Yates correction for continuity per one degree of freedom was performed on paired circle and J-hook sea turtle bycatch per set.

As 26% (n = 6) of the sea turtles hooked were dead at haulback, an analysis of immediate survival (survival at the time of gear retrieval) was performed using a generalized linear mixed model (GLMM). The initial exploratory data analysis showed a relationship between the response variable dead/alive and the CCLn-t as well as soak time. Therefore, a binomial GLMM (with Laplace likelihood approximation) was fit to the binary outcomes (dead or alive), where the size of the sea turtles was considered as the fixed factor and the soak time, with five different levels, was treated as a random factor because it depended on the fishing strategy of each fisher and was not controlled. This model for one random effect is specified by a response variable Y_{ij} (Eq. 1) and the logit link (Eq. 2):

$$Y_{ij} \sim \mathrm{Bin}(1, p_{ij}) \qquad \text{(Eq. 1)}$$

$$\mathrm{logit}\,(p_{ij}) = \beta_0 + \beta_1 \times \text{CCLn-t} + a_i \qquad \text{(Eq. 2)}$$

where Y_{ij} is 1 if turtle j caught in soak time i was alive and 0 if dead. The logit $(p_{ij}) = \log(p_{ij}/1 - p_{ij})$ is the link function, p_{ij} is the probability that sea turtle j caught in soak time i would be found alive, i = 1,...,5 identifies the levels of the random factor (soak time), a_i is the random intercept which is assumed to be normally distributed with mean 0 and variance σ_a^2, β_0 is the independent term, and β_1 is the coefficient associated with the fixed factor CCLn-t. The random factor "soak time" was divided into five levels according to the observed fishing practices: (1) <14 hrs (n = 3), (2) 14–18 hrs (n = 1), (3) 19–23 hrs (n = 5), (4) 24–28 hrs (n = 3), and (5) >28 hrs (n = 1). If the variance σ_a^2 was small, then the contribution of a_i was also small, and all soak time groups had a similar logistic curve. However, if σ_a^2 was relatively large, then each time group had very different intercepts (Zuur et al. 2008). Analyses were performed using the open-source statistical software R (R Development Core Team 2010) with the "lme4" package for the mixed model analysis (Bates and Sarkar 2006).

Table 1. Results of the 13 fishing sets observed during the summer of 2010 off the southern Ionian coast of Calabria (Italy). Number of hooks (J- vs circle), and number of loggerhead turtles and Atlantic bluefin tuna caught in each set are shown.

Date	J-hooks	Circle hooks	Total hooks	Soak time (hrs)	Loggerhead sea turtles caught	Atlantic bluefin tuna caught
06/25	311	311	622	13:50	1	9
06/28	312	313	625	17:50	1	0
06/29	268	267	535	13:00	8	2
07/02	141	141	282	23:00	2	0
07/06	148	147	295	24:40	0	2
07/09	147	147	294	23:00	0	4
07/13	151	150	301	25:50	3	6
07/17	172	172	344	26:00	1	3
07/28	137	137	274	19:00	0	3
08/02	140	139	279	22:50	0	0
08/09	132	133	265	20:00	1	0
08/14	134	134	268	07:40	0	0
08/19	129	129	258	31:00	7	1
Total	2,322	2,320	4,642	267:40	24	30

Results

A mean of 357 (±38.4 SE, range 258–625) baited hooks was deployed with each surface longline set with a mean of 7 (range 6–9) hooks between floats. A total of 4642 hooks was deployed, 2322 J- and 2320 circle hooks, for a total of approximately 268 cumulative hrs (Table 1). For three fishing sets, the gear was set around dusk and retrieved around dawn ("night sets") with a mean soak time of about 11 hrs. The gear was both set and retrieved around dawn for the remaining 10 sets ("night and day sets"), with a mean soak time of 23 hrs.

Table 2. Catch species composition (numbers) in the longline study comparing J- and circle hooks.

Species	J-hooks	Circle hooks	Total
Caretta caretta (Linnaeus, 1758)	14	9	23
Thunnus thynnus (Linnaeus, 1758)	13	17	30
Pteroplatytrygon violacea (Bonaparte, 1832)	4	1	5
Mola mola (Linnaeus, 1758)	3	0	3
Coryphaena hippurus (Linnaeus, 1758)	2	1	3
Centrolophus niger (Gmelin, 1789)	1	1	2
Ruvettus pretiosus (Cocco, 1829)	1	0	1
Tetrapturus belone (Rafinesque, 1810)	1	0	1
Xiphias gladius (Linnaeus, 1758)	1	1	2
Euthynnus alletteratus (Rafinesque, 1810)	0	1	1
Prionace glauca (Linnaeus, 1758)	0	2	2
Total	40	33	73

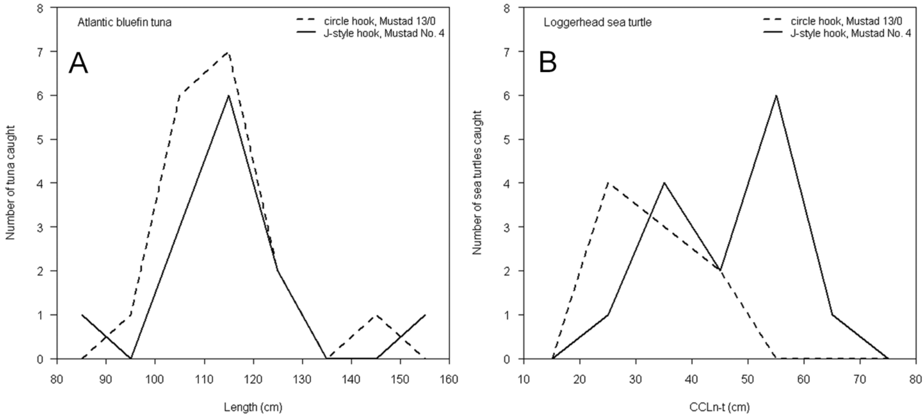

Figure 3. Length frequency distribution of (A) Atlantic bluefin tuna (n = 30) and (B) loggerhead sea turtles (n = 23), caught in the study area during the summer of 2010 by each hook type.

Catch Species Composition.—In total, 74 specimens comprising 11 species were caught with the pelagic longlines during the 13 fishing sets: 40 with J-hooks, 33 with circle hooks, and one specimen found entangled in the line (Table 2). The nominal catch rate of all species combined was 17.23 and 14.22 per 1000 hooks for J- and circle hooks, respectively. However, for both J- and circle hooks, the species caught most frequently were the loggerhead sea turtle (n = 14 and n = 9, respectively) and Atlantic bluefin tuna *Thunnus thynnus* (n = 13 and n = 17, respectively). For J- and circle hooks, swordfish *Xiphias gladius*, was only 2.5% (n = 1) and 3% (n = 1) of the total catch, respectively.

Although circle hooks were responsible for 57% of the Atlantic bluefin tuna catch, this was not significantly different than the 43% caught by J-hooks (Wilcoxon signed ranks test: P = 0.11). Similarly, mean body size of tuna caught did not differ significantly between the two hook types (one-way ANOVA: P = 0.541; Fig. 3A).

Sea Turtle Bycatch.—In total, 24 (32.4%) loggerhead sea turtles were caught in the longline sets (23 loggerheads hooked and one entangled in the line). The total estimated sea turtle CPUE was 5.17 loggerheads per 1000 hooks, while for J- and circle hooks, the CPUE was 6.0 ± 2.01 SE and 4.0 ± 2.04 SE sea turtles per 1000 hooks, respectively. No significant differences were detected in the total loggerheads CPUE per fishing set between the two hook types (Wilcoxon signed ranks test: P = 0.06) or in the CPUE of small juveniles (Wilcoxon signed ranks test: P = 0.58). However, there was a significant reduction in the bycatch of large juveniles with circle hooks (Wilcoxon signed ranks test: P = 0.03; Fig. 3B). Accordingly, mean body size of loggerheads caught between the two hook types differed significantly (one-way ANOVA: P = 0.008): the mean CCLn-t of the sea turtles caught was 47.6 cm ± 3.01 SE (range: 29–63 cm) for J-hooks and 34.4 cm ± 2.98 SE (range: 23–50 cm) for circle hooks.

Of the 23 sea turtles hooked, 14 were hooked in the lower jaw (seven on J- and seven on circle hooks), two in the tongue (both on J-hooks), and seven in the esophagus (five on J- and two on circle hooks). Hook removal was successful only when the hook was in the lower jaw and not in the tongue, while for the sea turtles hooked in the deep esophagus, no dehooking attempt was made in accordance with proper

Table 3. Fixed and random effects for the Generalized Linear Mixed Model (GLMM) of survival/death of caught loggerheads.

Fixed effects	*n*	Estimate	SE	*P*
CCLn-t (cm)	23	–5.026	0.09	0.05

Random effects	Levels	*n*	Estimate
Soak time (hrs)	<14	3	–4.088
	14–18	1	–4.971
	19–23	5	–4.586
	24–28	3	–5.118
	>28	1	–6.776

handling and release protocols (Epperly et al. 2004). Of the 14 sea turtles hooked in the lower jaw, six were dead, two were not boarded due to their excessive weight (60 and 63 cm CCLn-t), and the remaining six specimens were successfully dehooked. No significant difference was found in the number of deeply hooked loggerheads between the hook types (χ^2 test: $P = 0.82$).

Six of the 23 sea turtles hooked were found dead: two on J-hooks (14%) and four on circle hooks (44%). The GLMM for the binomial response variable dead/alive showed that the probability of surviving incidental capture by a pelagic longline increased significantly with the size of the turtle ($P = 0.05$). The model estimated that the fixed intercept $\beta_0 = -5.026$ and the coefficient of CCLn-t, $\beta_1 = 0.174$. The random intercept a_i had a standard deviation of 1.528 and it was assumed to be normally distributed with a mean of 0 and variance of 1.528^2. This means that 95% of the values of a_i were between -1.96×1.528 and 1.96×1.528. The survival probability of loggerheads caught for the range of CCLn-t was defined by Equation 3:

$$\text{logit}(p_{ij}) = -5.026 + 0.174 \times \text{CCLn-t} + a_i \qquad a_i \sim N(0, 1.528^2) \qquad \text{(Eq. 3)}$$

For a typical soak time ($a_i = 0$), a sea turtle of average CCLn-t (42 cm) had an immediate survival probability of approximately 0.9 (Fig. 4), but juveniles with CCLn-t <29 cm had <0.5 probability. However, depending on the soak time considered, this probability could be anything between 0 and 1. Therefore, there was considerable variation between soak times and this was quantified by extracting the random effects for each soak time level (Table 3). While the random effects associated with soak times <24 hrs resulted in an increase in the survival probabilities with respect to the typical soak time, those associated with soak times >24 hrs led to a decrease in the survival rates.

Discussion

This study presents the preliminary results of using small circle hooks in a small-scale pelagic longline fishery along the southern Ionian coast of Calabria (Italy). As this area is located off the most important nesting ground of the loggerhead sea turtle of Italy (Mingozzi et al. 2007) and is also part of a wider foraging area for juveniles from different Mediterranean nesting areas (Maffucci et al. 2006, Casale et al. 2010), it is essential to assess the effects of mitigation measures for reducing the interactions between sea turtles and the local longline fishery.

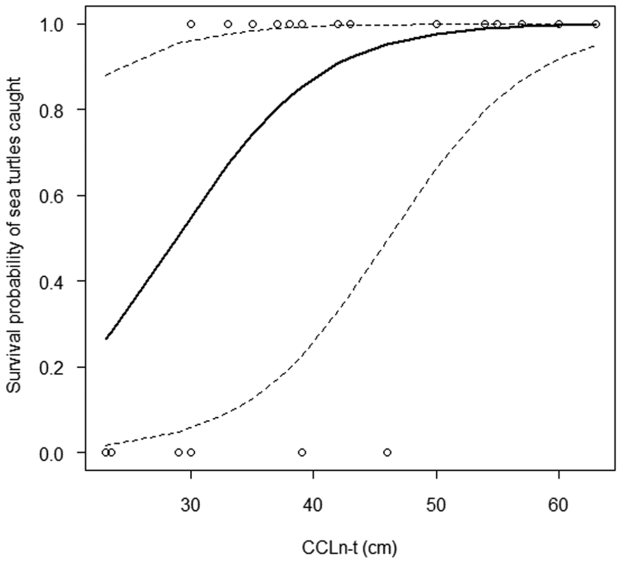

Figure 4. GLMM-predicted probabilities of turtle survival in relation to CCLn-t for turtles caught for all soak times. The thick line represents the survival probability for a "typical" soak time, where "typical" means that $a_i = 0$. The two dashed lines were obtained by adding and subtracting 1.96 × 1.528 for the random intercept to the predictor function. Hence, 95% of the soak times had logistic curves between these two extremes: the space between these two curves shows the variation between the predicted values per soak time level.

Atlantic bluefin tuna was the main target species caught during the fishing season by the observed fishing vessel. In the present study, no significant difference was found in the bluefin tuna CPUE per fishing set by the two different hook types, which demonstrates that circle hooks are associated with neither decreased nor increased revenue for the fishers. Moreover, the tested circle hooks impacted the same size classes of bluefin tuna impacted by J-hooks No. 4, and thus they seem to ensure that the economic gain is maintained. However, more data are needed to confirm this result as tuna catch rates have been found to increase with circle hooks in other studies (Carruthers et al. 2009, Ward et al. 2009).

Although the circle hooks reduced the incidence of turtle bycatch by 36% with respect to J-hooks, this decrease was not statistically significant, which confirms the hypothesis that small circle hooks are too small to prevent sea turtles from fitting them in their mouths (Gilman et al. 2006). However, contrary to the hypothesis of Gilman et al. (2006), we did not find a significant decrease in the number of deeply hooked sea turtles with circle hooks. This discrepancy may be due to the limited sample size of our study and, therefore, caution should be taken in drawing conclusions on this subject. Currently, the only benefit gained by using small circle hooks with respect to hooking position may be the increase in successful hook removals, as around 80% of sea turtles caught with circle hooks were hooked in the lower jaw. However, this may not translate into a real decrease in post-hooking mortality rate because there is no evidence that hook removal is a common practice among fishers in the study area.

Our results also suggest that 13/0 circle hooks mainly impact small (<40 cm CCLn-t) juvenile sea turtles and not larger juveniles or adults. In fact, a significant decrease in the number of sea turtles caught in the large juvenile stage was recorded with circle hooks. This finding contrasts with other studies that found circle hooks (larger than J-hooks) reduced the catches of small sea turtles as they could not swallow the hook (Watson et al. 2003, Sales et al. 2010). In our study, while the narrowest width of the tested circle hooks was similar to that of the J-hooks, the gape width was smaller and this could explain why smaller sea turtles were caught. Our results, therefore, suggest that hook design (shape) of the small circle hooks plays an important role in whether loggerhead turtles are caught. This is contrary to what has generally been demonstrated for large circle hooks, for which the hook design affects the hooking locations and the hook size affects sea turtle catch rates (e.g., Sales et al. 2010). In this context, using small circle hooks would decrease the bycatch impact not only on large juvenile turtles, but also on the Calabrian nesting population of *C. caretta*. This loggerhead population is quite small considering the number of nests in this nesting area (Mingozzi et al. 2007); however, it contributes significantly to the overall haplotype diversity in the Mediterranean (Garofalo et al. 2009).

While the small circle hooks reduced the bycatch rate of large juvenile loggerheads, they seemed to leave unchanged that of small juveniles, which explains why the overall bycatch rate of *C. caretta*, though approaching the conventional threshold of statistical significance, did not significantly change with the tested circle hooks. These preliminary results, therefore, indicate that the potential widespread adoption of this kind of hook would have positive consequences for large juveniles and the nesting population and neutral conservation benefits for small juvenile loggerheads, when compared to J-hooks. This neutrality is particularly relevant, and indicates that the use of 13/0 circle hooks would not increase the already high catch rate of small juvenile turtles observed with J-hooks or their immediate mortality, which is a function of both the small size of the sea turtles caught and long soak times. In fact, we found evidence that smaller loggerheads had reduced chances of surviving incidental capture than larger ones. This finding is consistent with other studies (Cambiè 2011) and could be related to small juvenile sea turtles having a lower tolerance to prolonged periods of apnea and an inability to withstand the weight of the gear in order to stay afloat. Specifically, for the typical soak time of the small-scale pelagic longliners in the study area (around 20 hrs), small juvenile loggerheads with a CCLn-t < 29 cm have a survival probability of <0.5. In addition, although more data are required to better describe the effect of the soak time on sea turtle mortality, we found evidence that the probability of immediate survival decreased with respect to the average trend when the soak time exceeded 24 hrs. This long soak time was recorded in >30% of the observed fishing sets, and could be a new fishing strategy for the longliners in the study area. In fact, the trend in fishing effort for the small-scale pelagic longliners in the study area seemed to be a gradual increase from about 11 hrs in 2007 to about 20 hrs in 2010. This increase was related to the decline in the catch rate of swordfish, as fishers tried to compensate by increasing their hours fishing (Cambiè et al., unpubl data). It is therefore likely that the soak time will continue to be long if the swordfish catch rate remains low, at least as long as there are economic benefits from this activity.

In summary, until further studies are conducted, our data suggest that the use of 13/0 circle hooks would benefit larger sea turtles without increasing catch rate of small juvenile turtles and without adversely impacting the economics of the fishery.

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