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Are circle hooks effective in reducing incidental captures of loggerhead sea turtles in a Mediterranean longline fishery?

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ABSTRACT

1. A known fishing hot spot for loggerhead sea turtles (*Caretta caretta*) in the Mediterranean Sea is in the waters of the Strait of Sicily where interactions with fish hooks and branchlines are believed to be a major cause of mortality for sea turtles.

2. Hooks with different shapes but a similar gape width (circle hook size 16/0 vs J hook size 2) were tested in order to determine the potential effectiveness of the hook design to both reduce sea turtle capture as well as to maintain acceptable levels of target species capture rates in a shallow-set longline swordfish fishery in the Mediterranean.

3. Seven experimental fishing trips, 30 000 hooks total, were conducted on a single commercial fishing vessel (18 m in length) in the Strait of Sicily during the months of July through October over a period of three years from 2005 to 2007. Circle and J hooks were alternated along the mainline.

4. A total of 26 sea turtles were hooked, all immature-size *Caretta caretta*. Turtles were caught at a statistically greater frequency on J hooks than on circle hooks. The capture rate, weight, and upper jaw fork length of the target species were not significantly different between the two types of hooks employed.

5. Five sea turtles swallowed the hook and in all such cases these were J type. Circle hooks tended to be located externally and were more easily detected by fishermen, and could be removed with the correct dehooking action before returning the turtle to the sea.

6. These findings suggest that 16/0 circle hooks can effectively reduce the incidental capture of immature loggerhead sea turtles in a Mediterranean swordfish longline fishery without affecting the catch size of the target species. Copyright © 2009 John Wiley & Sons, Ltd.

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KEY WORDS: loggerhead sea turtle; *Caretta caretta*; circle hook; pelagic longline; bycatch mitigation; Mediterranean Sea

INTRODUCTION

Pelagic longline fishing has been identified as a significant threat to endangered sea turtle populations in the Mediterranean Sea since the late 1980s (Camiñas, 1988; De Metrio and Megalofonou, 1988). The fishing gear consists of a long drifting mainline to which short branchlines arranged at regular intervals, each one fitted with a baited hook, are attached. Pelagic longline is selective for large pelagic fish, such as swordfish (*Xiphias gladius*) and tuna (*Thunnus* spp.), but it is also responsible for the incidental capture of non-target species, or 'bycatch', such as sea turtles and other protected species (Lewison *et al*., 2004).

A previously identified hot spot for loggerhead sea turtles (*Caretta caretta*) is located in the centre of the Mediterranean Sea, in the waters of the Strait of Sicily (Groombridge, 1990) (Figure 1). As one of the most important fishing grounds for swordfish (Di Natale and Mangano, 2008), the Strait of Sicily has a high rate of longline fishing effort. A useful index to represent fishing efficiency, or species capture rates, is to report the number of specimens caught per 1000 hooks, and is expressed as catch per unit of effort (1000 hooks), hereafter CPUE. In the

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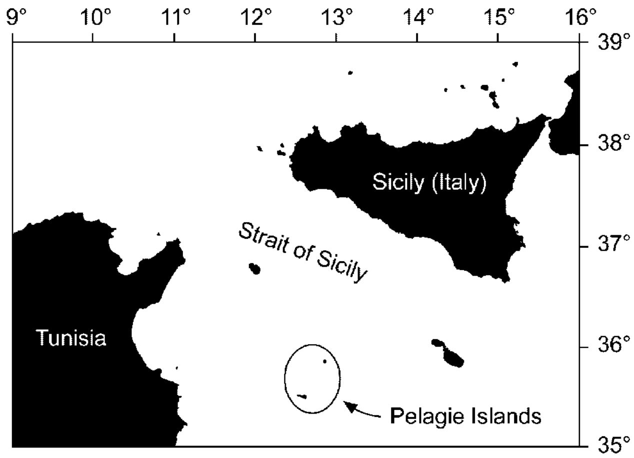

Figure 1. Area where experimental trials were carried out in the Strait of Sicily, central Mediterranean Sea. This is a hot spot area for loggerhead sea turtles *Caretta caretta* (Groombridge, 1990), and one of the most important fishing grounds for swordfish (Di Natale and Mangano, 2008). Estimates of the loggerhead catch per unit of effort for the waters surrounding the Pelagie Islands range from 0.88 to 0.98 sea turtles per 1000 hooks (Piovano *et al.*, 2006; Casale *et al.*, 2007a) (figure prepared with SEATURTLE.ORG Maptool. 2002. SEATURTLE.ORG, Inc. http://www.seaturtle.org/maptool).

Sicilian waters of the central Mediterranean Sea, the loggerhead turtle bycatch from the Italian pelagic longline fishing activity is relatively high with CPUE = 0.46 (Guglielmi *et al.*, 2000). However, an even higher rate of loggerhead capture has been reported for the waters surrounding the Pelagie Islands (Figure 1), with CPUE estimates ranging from 0.88–0.98 (Piovano *et al.*, 2006; Casale *et al.*, 2007a). The interactions with hooks and branchlines are believed to be a major cause of mortality for sea turtles in the Mediterranean Sea (Casale *et al.*, 2007b).

Studies have been carried out in captivity and at sea to identify methods to reduce sea turtle bycatch in longline fisheries (Piovano *et al.*, 2004; Swimmer *et al.*, 2005; Watson *et al.*, 2005; Gilman *et al.*, 2006). Nevertheless, due to numerous confounding factors affecting fishing operations and catch efficiencies, it is difficult to determine the relative roles of each variable on the impacts of bycatch (Gilman *et al.*, 2007). The most obvious and simplest approach to solve bycatch problems is to reduce the fishing effort; however, for a number of economic and sustenance reasons, this is not a desired or viable option. A different approach is to identify means to reduce the bycatch per unit of effort (Hall *et al.*, 2000), such as changing specific variables including bait and hook selection.

Circle hooks have become popular after they were identified as a promising tool to reduce the interaction rates with sea turtles in some shallow-set pelagic longline fisheries (Watson *et al.*, 2005), and their use is a current requirement in both Atlantic and Pacific shallow-set swordfish-targeting longline fisheries in the USA (Gilman *et al.*, 2007). However, there are concerns that the efficacy of circle hooks may differ among fisheries (Read, 2007), thereby prompting research in a variety of fisheries and ocean basins. The research conducted in this study aimed to test the use of circle hooks to determine the potential effectiveness of the hook design to reduce sea turtle capture and to maintain acceptable levels of target species capture rates in a shallow-set longline swordfish fishery in the Mediterranean.

METHODS

Fishing gear and operations

The relative hooking rates of a protected bycatch species, the loggerhead sea turtle *Caretta caretta,* and the target swordfish species *Xiphias gladius* between circle and J hooks, with particular attention paid to hook measurements such as the gape width and the narrowest width, were assessed. The gape width, i.e. the distance between the point and the shank (Cortez-Zaragoza *et al.*, 1989), is one parameter proposed for hook size standardization among manufacturers (ASMFC, 2003). It is a functional parameter that affects the possibility of jaw hooking in fish (Cooke *et al.*, 2005), and can be conveniently related to the size of the fish mouth (Hovgård and Lassen, 2000). In this study, the gape width, or minimum inner width (Yokota *et al.*, 2006), was assumed as a primary measure for hook size, thus hooks with an equal gape width are considered hooks of the same size. The narrowest width, or minimum total width (Yokota *et al.* 2006), was measured because it is a functional parameter that affects the possibility of sea turtles swallowing the hooks (reviewed in Gilman *et al.*, 2006).

Local fishermen selected the type and size of circle hook to be tested based on their traditional practices and experiences, from among a pool of hooks already in commercial use in other countries. The circle hook with a gape width similar to that of the J hooks locally employed was chosen in order to optimize the jaw hooking of the target species.

A circle hook (OPI, made in Korea, Lindgren-Pitman design) size 16/0 with a gape width of 2.7 cm was tested and compared with the traditional J hook (Mustad) size 2 with a gape width of 2.6 cm. The narrowest width was 4.4 cm for the circle hook and 3.3 cm for the J hook (Figure 2), thus because of the shape the circle hook was 33% wider than the J hook. Both hooks were kirbed offset (10° for the circle hook and 20° for the J hook), ending with a barb point, eye in-line with the hook shank, and no ring. The 10° difference in hooks offsets at present is inconclusive (Prince *et al.*, 2002; Skomal *et al.*, 2002; Cooke and Suski, 2004), and considered to be not relevant (Swimmer, unpublished data).

The experiment was conducted on a single commercial fishing vessel, 18 m in length, in an effort to minimize the number of confounding variables. The design (Figure 3) was as follows: baited circle and J hooks alternated along the length of the mainline, on 1000 branchlines were deployed per set. Five baited hooks were placed between floats, and the captain was free to choose the fishing location.

All seven experimental field trips were conducted during the months of July through October over a period of 3 years from 2005 to 2007. All fishing was conducted in the Strait of Sicily. There were 30 sets total, with an average of 4.3 sets (SD $\pm$ 1.1) per trip. A total of 30 000 baited hooks (1000 hooks per set, 50% J and 50% circle hooks) were tested. Of the hooks deployed, 2.5% ($n = 746$) were lost at sea during fishing; thus the CPUE with respect to the 97.5% ($n = 29\,254$; circle hooks = 14 664, J hooks = 14 590) of hooks for which the captures were known. Before each fishing set, the

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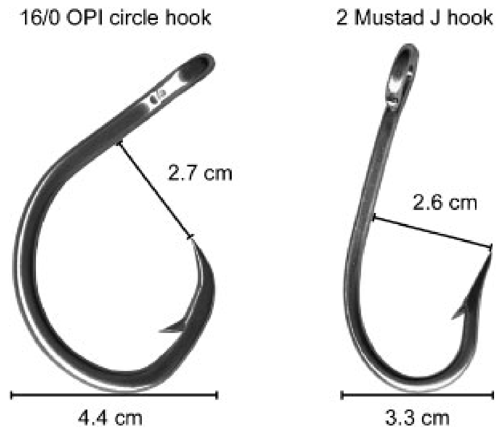

Figure 2. Gape width (centre) and narrowest width (bottom) of a OPI circle hook size 16/0 (made in Korea, Lindgren-Pitman design) and a Mustad J hook size 2. Measurements were taken according to previous studies (Cortez-Zaragoza *et al.*, 1989; Gilman *et al.*, 2006; Yokota *et al.*, 2006).

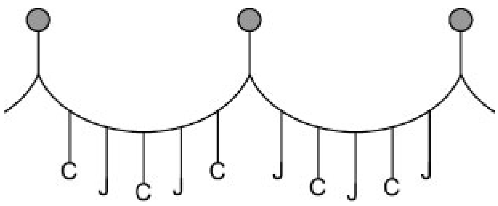

Figure 3. Experimental design consisting of circle (C) and J hooks alternating along the mainline, with five hooks between two floats.

four-member boat crew replaced missing hooks in order to maintain an arrangement of 1:1 J and circle hooks alternating along the mainline. The length of the mainline was approximately 52 km (European Community Council Regulation 1626/1994 prohibits setting more than 60 km of mainline per vessel). All aspects of the fishing gear (i.e. branchlines, number of hooks per float) remained constant throughout the trips.

Each Italian longline fishing vessel employs slightly different gear with its own characteristics, even when targeting the same species. Moreover, the captain can change these characteristics daily during the fishing season, even in just a part of the gear, in order to increase the catch size. The characteristics of the experimental fishing gear were within the range of variability known for the local drifting longline fisheries targeting swordfish (Piovano, 2007).

The gear was fixed at shallow hook depths, ranging from approximately 18 m to 50 m. The hooks were manually baited with frozen mackerel (*Scomber* spp.), average size 30 cm length and 200 g in weight. All fishing operations were done by hand except during hauling, when a line-hauler was in use for the mainline. Snaps were employed in knotting branchlines to the mainline. Branchlines and the mainline were made of nylon monofilament. Every branchline was 18 m long and had a battery operated green light stick attractor approximately 3 m from the hook. Plastic balls were employed as floats and floatlines made of nylon monofilament were 18 m length. High flyers were located every 5 km, on average. Gear deployment took approximately 4 h (15.30–19.30), while hauling operations took approximately 8 h (02.00–10.00), thus the gear soaked during the night.

Data collection

Fishing operations were monitored by an onboard observer. Every captured specimen was identified to species level. Information about the hook type and category of interaction were collected for all specimens of both catch and bycatch species. Turtles were boated with a large dipnet. Observers and crew attempted to remove superficial hooks with a short handled dehooker (ARC 17″ Bite Block Deep-hooked Sea Turtle Dehooker). Per standard procedures, Italian longline fishermen cut the branchline near the mainline to release the hooked or entangled sea turtle (Guglielmi *et al.*, 2000).

The minimum curved carapace length (CCLmin) and the curved carapace length notch-to-tip (CCLn-t) of sea turtle specimens according to Bolten (1999) were measured with a precision of 0.5 cm, however, because the difference between the two measures averaged 1 cm, only CCLmin data were analysed. The life stage was assigned according to the size at sexual maturity. Mediterranean loggerheads mature at an average size greater than 70 cm when using CCLn-t (Margaritoulis *et al.*, 2003), while Atlantic loggerheads mature at a larger size (Dodd, 1988).

The upper jaw fork length (UJFL) of swordfish was measured with a precision of 0.1 cm. Swordfish weights were measured after they had been eviscerated, with a precision of 0.5 kg. Of the hooked specimens, 98% were measured and weighed.

Statistical analysis

SPSS 15.0 software was used for statistical analysis. The Wilcoxon signed ranks test was used to assess whether circle and J hook CPUEs differ significantly in each set: irrespective of the species, and only on sea turtles (test performed only on those sets where turtles were captured). To investigate the difference in the hook location observed using the two hook types, the chi-square test (χ^2) with Yates correction per one degree of freedom was run on paired circle and J hook CPUEs per set. The homogeneity of variance in turtles' mean length size CCLmin was evaluated with the Levene test. Since the differences in variance were statistically significant (see results), the Mann–Whitney U test was performed to investigate the equality of length with respect to the type of hook. Continuous data were log transformed to achieve the homogeneity of variances prior to the ANOVAs. The full factorial analysis two-way ANOVA was applied to verify the importance of the random factor 'fishing set' and the fixed factor 'type of hook' of hooked swordfish CPUE. It was assumed that the hooking performance on every fishing set can be affected by those variables, such as target and bycatch species presence, that cannot be controlled. In order to verify the hooking performance of the two hook types within all the experimental sets, the chi-square test (χ^2) was applied to determine the target species catch rate of J and circle hooks with respect to the swordfish legal commercial size (Italian regulation allows fishermen to sell only swordfish longer than the minimum size 140 cm UJFL (DPR 1639/68)).

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RESULTS

All species overview

A total of 553 specimens belonging to 12 species were hooked during the experimental trips. The total numbers of individuals per species captured and corresponding CPUE values are summarized in Table 1. Circle hooks appeared more selective than J hooks when considering the whole of hooked specimens per set, although the difference between hooking rates was suggestive, but inconclusive (Wilcoxon signed ranks test: $Z = -1.959$, $P = 0.050$).

Sea turtles

In total, 26 sea turtles were hooked, all immature-size *Caretta caretta* specimens. No entanglement was observed.

Circle hooks were involved in the capture of 23% ($n = 6$; 95% CI = 6.6–39.6%) of the turtles, while J hooks were responsible for the remaining 77% ($n = 20$; 95% CI = 60.4–93.4%), which was a statistically significant difference (Wilcoxon signed ranks test: $Z = -2.768$, $P = 0.006$). Loggerhead CPUEs were 0.409 on circle hooks and 1.371 on J hooks (Table 1).

Regarding hook location, 81% of the hookings occurred in the mouth, while 19% were swallowed (Figure 4), all of which were on J hooks. There is evidence of a statistical difference in the hook location observed between the two hook types ($\chi^2 = 3.82$, df = 1, $P < 0.05$).

A significant difference in the loggerheads length size variances was noted, with circle hooks showing a greater variance than J hooks (Levene test: $F_{1,24} = 4.809$, $P = 0.038$). However, the mean length size of turtles caught on circle hooks (CCLmin = 49.7 cm, $n = 6$, SD = 8.5) was not statistically different from the mean size of those caught on J hooks (CCLmin = 49.8 cm, $n = 20$, SD = 4.9) (Mann–Whitney U test: U = 57.000; $n = 26$; $P = 0.854$) (Figure 5).

Target species

In total, 410 swordfish were captured, six of which were entangled. Of the 404 hooked specimens, nearly half were caught on each hook type (47% on circle hooks and 53% on J hooks, 95% CI = 42.4–52.2%, 47.8–57.6% respectively). Swordfish CPUEs were 13.025 on circle hooks and 14.559 on J hooks (Table 1). Weights of hooked swordfish (98% of the total, $n = 397$) were also similar between hook types, 47% on circle hooks and 53% from J hooks. CPUEs weight per 1000 hooks was 171.918 on circle hooks and 193.934 on J hooks.

To analyse the effects of hook type and fishing set on both the body size and the weight of captured swordfish, two-way mixed ANOVAs were carried out in which the type of hook was considered as a fixed factor and the fishing set as a random factor. Data show that neither the weight ($F_{1,88} = 0.017$, $P = 0.897$) nor the length UJFL ($F_{1,87} = 0.014$, $P = 0.906$) were significantly affected by the type of hook employed, whereas both of them were significantly influenced by the random factor fishing set (weight: $F_{29,28} = 3.145$, $P = 0.002$; UJFL: $F_{29,28} = 2.409$, $P = 0.011$). Moreover, the analyses showed that

Table 1. Numbers and CPUEs (number of specimen per 1000 hooks) for each species captured by circle hooks (size 16/0, OPI, made in Korea, Lindgren-Pitman design, [C]), J hooks (size 2, Mustad, [J]), and in total (irrespective of the type of hook). Species are listed in decreasing captures order, except *Caretta caretta*

	Captured specimens			CPUE (per 1000 hooks)	
Species	Total	C	J	C	J
Caretta caretta	26	6	20	0.409	1.371
Xiphias gladius	404	191	213	13.025	14.599
Pteroplatytrigon violacea	75	13	62	0.887	4.249
Ruvettus pretiosus	28	12	16	0.818	1.097
Heptranchias perlo	7	2	5	0.136	0.343
Coryphaena hippurus	5	4	1	0.273	0.069
Prionace glauca	2	0	2	0.000	0.137
Tetrapterus belone	2	2	0	0.136	0.000
Alopias vulpinus	1	0	1	0.000	0.069
Lepidopus caudatus	1	0	1	0.000	0.069
Thunnus alalunga	1	0	1	0.000	0.069
Thunnus thynnus	1	1	0	0.068	0.000

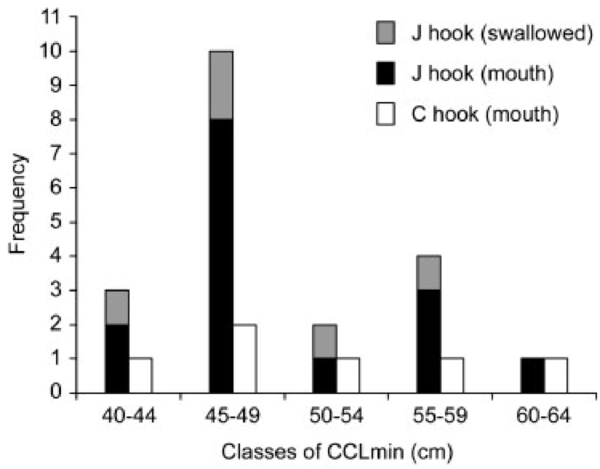

Figure 4. Frequency of the classes of *Caretta caretta* minimum curved carapace length (CCLmin), measured from the anterior point at midline (nuchal scute) to the posterior notch at midline between the supracaudals (Bolten, 1999), with respect to the hook type (J or circle [C]) and location (mouth or swallowed).

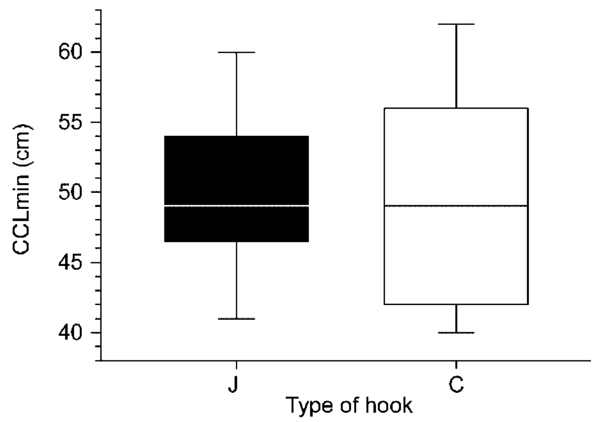

Figure 5. Minimum curved carapace length (CCLmin) distribution of *Caretta caretta* with regard to the type of hook (J or circle [C]) responsible for the capture. CCLmin was measured from the anterior point at midline (nuchal scute) to the posterior notch at midline between the supracaudals (Bolten, 1999). Each box-plot displays the middle 50% of the turtle lengths, the line inside the box shows the median; the whiskers represent the minimum and the maximum values. Samples size: 20 turtles captured by J hooks, six by circle hooks.

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the interaction between the two independent factors did not have a significant effect on the body weight variation ($F_{28,338} = 1.013$, $P = 0.451$), nor on UJFL ($F_{28,338} = 1.025$, $P = 0.433$). Thus, there was strong evidence that the hooking performance did not differ when comparing the catch size obtained from circle hooks and J hooks and that the catch size for circle and J hooks did not have the same relative results throughout all the experimental fishing sets. The type of hook did not affect the number of hooked swordfish even with regards to undersized specimens (less than 140 cm UJFL) (23.9%, $\chi^2 = 0.031$, df = 1, $P < 0.05$) (Figure 6).

DISCUSSION

The findings suggest that 16/0 circle hooks can effectively reduce the number of immature loggerhead sea turtles incidentally captured in swordfish longline fishery operations by up to 70% without affecting the capture rate of target species, when compared with J hooks with a similar gape width (~2.6 cm). These results are especially significant given that they help resolve the importance of hook shape as opposed to size, which has not been possible in earlier studies due to differences in both parameters.

It has been previously established that the size class of loggerhead turtles encountered in this study is particularly vulnerable to shallow-set swordfish-style longline activity in the Mediterranean Sea (Laurent *et al.*, 1998; Deflorio *et al.*, 2005; Casale *et al.*, 2007a; Jribi *et al.*, 2008). Mortality of such individuals can hinder population recovery efforts as population models have indicated that immature individuals are critical for population growth and recovery (Crouse *et al.*, 1987; Heppell, 1998). Moreover, in the Mediterranean Sea loggerheads reach maturity at a smaller size than in other ocean basins (Margaritoulis *et al.*, 2003). Based on the evidence that circle hooks reduce these rates of interactions, the adoption of such hooks in areas with high-fishing density could have a positive effect on population dynamics of loggerhead turtles in the Mediterranean Sea.

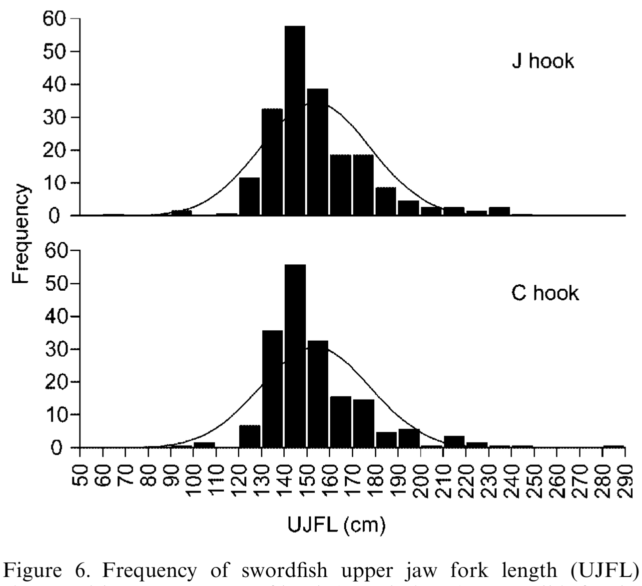

Figure 6. Frequency of swordfish upper jaw fork length (UJFL) classes, with respect to type of hook (J or circle [C]) responsible for the capture. Normal curves with the same mean and standard deviation as the data distribution are superimposed.

The 16/0 circle hook employed was smaller than those previously tested in the Atlantic Ocean (18/0) which also found clear reductions in rates of hookings of sea turtles compared with traditionally-used 9/0 J hooks (Watson *et al.*, 2005). The finding that a smaller hook was effective at reducing sea turtle bycatch is remarkable in that fishermen are usually reluctant to employ a relatively larger 18/0 circle hook for fear that it would reduce the CPUE of target species. The number, length and total weight of swordfish captured by circle hooks were similar to those of swordfish caught by J hooks, per fishing set; such a gear modification should therefore be acceptable to fishermen. In addition, the proportion of undersized swordfish (UJFL < 140 cm) was similar for catches from both hook types, indicating that circle hooks were not more selective for larger swordfish than J hooks. Nevertheless, fishermen are usually conservative and unwilling to change, unless a clear economic benefit is showed. Therefore they would probably not shift to circle hooks by themselves; however, such a goal can be reached through appropriate outreach and education programmes.

In the present study, all hooked turtles were brought on board and released alive, irrespective of the type of hook. This confirms the very low direct mortality rate due to shallow-set longline gear activities, as reported in previous studies (Pinedo and Polacheck, 2004; Deflorio *et al.*, 2005; Camiñas *et al.*, 2006; Gilman *et al.*, 2007; Jribi *et al.*, 2008; Swimmer *et al.*, 2009). However, it is possible that hook location can play a fundamental role in the post-release survivorship of sea turtles, especially when hooks remain lodged in a turtle's body with trailing fishing line. Until recently, it has been difficult to quantify the rate of mortality, but new evidence using pop-up satellite archival tag (PSAT) technology for loggerhead turtles caught and released from US longline vessels operating in the Pacific Ocean also found direct mortality to be relatively low (~10%), which was also attributed to fishermen's 'turtle-safe' handling practices (Swimmer *et al.*, 2009). Nevertheless, many authors assume a higher mortality of turtles when hook and line were both present, than for the two separated factors (Casale *et al.*, 2007b). Mediterranean guidelines for fishermen advocate cutting the line as close as possible to the hook eye (e.g. Gerosa and Aureggi, 2001), which is more practicable when the turtle is superficially hooked.

The rotating effect of circle hooks, which set themselves when pressure is applied, apparently increases the proportion of mouth-hookings as opposed to deeper in the body, as has been well documented in fish species (Cooke and Suski, 2004). There is mounting evidence for sea turtles that circle hooks tend to be located mostly externally in the jaw or mouth as opposed to deeper hookings (Watson *et al.*, 2005; Gilman *et al.*, 2006, 2007; Read, 2007). Hooks that are lodged externally (e.g. jaw) are easily detected by fishermen and can be removed with the correct dehooking action prior to returning the turtle to sea. Fishermen's actions at this time can greatly affect a turtle's probability of surviving. In this study, fishermen and onboard observers were provided with short-handled dehookers; however, fishermen reported they found it more difficult to release circle hooked turtles than J hooked ones, possibly due to the length of the barb of the circle hook type that was tested. Furthermore handling the dehooking tool to remove circle hooks required more skill and

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time than is necessary to remove J hooks. At present, it seems improbable that fishers will perform the dehooking by themselves when not supervised by onboard observers. However, fishermen can change their habits, as shown by Hall *et al*. (2000) in the case of cetacean interactions with fishing gears.

At present, there is insufficient information to assess how the reduction of longline bycatch alone would effect the recovery trend of loggerhead turtles in the Mediterranean Sea. It is more likely, however, that such a result would be achieved by combining the positive effects of a range of different actions. These results suggest that circle hooks should be seriously considered and incorporated into management plans in order to enhance the sustainability of the Mediterranean swordfish longline fishery as part of an ecosystem-based approach. Working alongside the fishing community and incorporating their experiences will likely assist in both the discovery and adoption of fisheries bycatch mitigation measures that will ultimately prove the most successful. This project took the first step by involving fishermen in the selection of the type and size of circle hooks to be tested. The results now need to be shared in order to provide them with information about the importance of adopting circle hooks to help in sea turtle conservation. One option would be to include this topic in an ad-hoc campaign to raise awareness of the marine ecosystem problems, and what can be done to reduce the damaging effects of fishing on those non commercial species that are protected by national and international laws.

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