frontiers | Frontiers in Marine Science

TYPE Original Research
PUBLISHED 03 March 2023
DOI 10.3389/fmars.2023.1124093

Mitigating effects on target and by-catch species fished by drifting longlines using circle hooks in the South Adriatic Sea (Central Mediterranean)

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SPECIALTY SECTION
This article was submitted to Marine Fisheries, Aquaculture and Living Resources, a section of the journal Frontiers in Marine Science

RECEIVED 14 December 2022
ACCEPTED 16 February 2023
PUBLISHED 03 March 2023

CITATION
Carbonara P, Prato G, Niedermüller S, Alfonso S, Neglia C, Donnaloia M, Lembo G and Spedicato MT (2023) Mitigating effects on target and by-catch species fished by drifting longlines using circle hooks in the South Adriatic Sea (Central Mediterranean). *Front. Mar. Sci.* 10:1124093. doi: 10.3389/fmars.2023.1124093

Introduction: Longline fishing gear has a higher by-catch rate than any other type of commercial fishing gear. Nowadays, there is an urgent need to find efficient management strategies to mitigate by-catch and the use of new hook types could be one of them. This study investigates the effects of a longline fishery (which targets swordfish, *Xiphias gladius*, in the South Adriatic Sea) replacing the traditional J-type hook with a circle hook (C-type hook) on target and by-catch species.

Methods: For this purpose, a fishing trip of nine days – with seven fishing sets – was monitored. For both targeted swordfish and by-catch specimens caught (i.e., blue shark, *Prionace glauca*; pelagic stingray, *Pteroplatytrygon violacea;* and loggerhead turtle, *Caretta caretta*), data about the hook type used (J-type vs. C-type), the specimen size, and their capture condition were collected.

Results and discussion: With all species, we observed no significant difference in catch-per-unit-effort (CPUE) or specimen lengths between the two hook types. In addition, the hook type did not significantly affect the capture condition of swordfish, pelagic stingray, or loggerhead turtle specimens; however, it significantly affected the capture condition of blue sharks. The percentage of blue shark specimens found in healthy condition was higher when using a C-type hook (71.5%) than when using a J-type hook (22.6%). Overall, these preliminary results suggest that the use of a C-type hook improves the condition of by-caught blue sharks without affecting the CPUE or size of the target species. In conclusion, the use of a C-type hook could reduce the detrimental effects of by-catch on some species in the Adriatic Sea; however, this finding needs to be confirmed by a study with a larger sample size.

KEYWORDS

blue shark, circle hook, loggerhead turtle, pelagic longlines, pelagic stingray, swordfish, by-catch

Introduction

By-catch is the fraction of the catch unintentionally captured during a fishing operation in addition to the target species. It may refer to the capture of other marketable species that are landed, to commercial species that cannot be landed (e.g., undersized, damaged specimens), to non-commercial species, or incidental catches of endangered, vulnerable, or rare species (e.g., sea turtles, chondrichthyans, marine mammals) (FAO, 2015; FAO, 2016). Longline fishing gear has a higher by-catch rate than any other type of commercial fishing gear. Longline (pelagic longline [PLL]) fishing mainly affects pelagic sharks and rays, but also benthic species (bottom longline). Pelagic sharks are caught as by-catch by longline fisheries targeting swordfish and tunas (Oliver et al., 2015); in the Mediterranean, the most common by-catch pelagic shark species are the blue shark (*Prionace glauca*), the basking shark (*Cetorhinus maximus*), the great white shark (*Carcharodon carcharias*), the smooth hammerhead shark (*Sphyrna zygaena*), and the common thresher shark (*Alopias vulpinus*) (FAO, 2016; Carpentieri et al., 2021). The status of such pelagic sharks has worsened over time (Walls and Dulvy, 2021), partly due to by-catch overfishing (Lewison et al., 2004). Pelagic sharks can play important roles in marine ecosystems through many mechanisms; hence, their decline may initiate trophic cascades and affect the overall community structure (Stillwell and Kohler, 1982; Heithaus et al., 2008; Ferretti et al., 2010; Ward and Myers, 2016). Within the Mediterranean basin, the highest by-catch rate for PLL was found in the Alboran Sea, followed by the Adriatic Sea (34.3% and 15.1% of the total catch, respectively) (Megalofonou et al., 2005). Therefore, in this study, the Adriatic Sea was targeted as an important area for the by-catch of pelagic sharks (Bartolí et al., 2017). The blue shark is the most caught species by PLL, representing over 70% of the elasmobranch catch (Bradai et al., 2012), and it is considered a critically endangered species in the Mediterranean by the International Union for Conservation of Nature (IUCN). Sea turtles are another non-targeted species impacted by longline fishing in the Mediterranean Sea. Indeed, both pelagic (e.g., Deflorio et al., 2005; Báez et al., 2007; Casale et al., 2007; Jribi et al., 2008; Cambiè et al., 2010) and bottom (e.g., Casale et al., 2007; Jribi et al., 2008) longlines show a consistent number of sea turtles caught by this gear (Casale, 2011; Carpentieri et al., 2021). Three sea turtle species are present in the Mediterranean: the leatherback turtle (*Dermochelys coriacea*; Dermochelyidae), the green turtle (*Chelonia mydas*; Cheloniidae), and the loggerhead turtle (*Caretta*; Cheloniidae). However, few leatherback turtles enter the Mediterranean from the Atlantic without breeding in the basin (Casale et al., 2003). The other two species present in the Mediterranean are more strongly impacted by PLL fishing activity as by-catch (Encalada et al., 1996; Casale, 2011).

Measures to mitigate by-catch are needed; however, due to the variety of factors influencing the interactions of fisheries with elasmobranchs and other endangered species, simple solutions for mitigation are not available. Importantly, PLL by-catch encompasses several species bearing different tolerances to the impact of (a) being caught or (b) being susceptible to being caught in the first place. Moreover, by-catch mitigation might also be more complex for sharks because some species (e.g., blue shark, shortfin mako, and common thresher shark) might be landed and marketed with a lower value than the target species (swordfish and tunas) (FAO, 2016).

By-catch mitigation strategies typically include modification of the gear and/or of the fishing strategy. To date, longlines are the gear with which most efforts have been made to reduce shark by-catch, probably because longlines have a large impact on by-catch globally (Gilman et al., 2016). The longline gear changes include the distance between floats (to adjust the depth at which the hooks fish), the material of the leaders or branch lines (e.g., wire or nylon), the type of bait, and the shape and size of hooks (Gilman et al., 2016). Effects on target species catch rates are frequently taken into account in by-catch mitigation research because fishers are more likely to adopt mitigation strategies that do not result in a reduction in landed target catch (Hall et al., 2007; Ward and Hindmarsh, 2007; Campbell and Cornwell, 2008). For instance, Beverly et al. (2009) showed that removing shallow hooks from PLL gear reduced catch rates of epipelagic species like endangered sea turtles, while maintaining the catch rates of targeted tunas. In contrast, shorter longline soak times result in lower levels of unwanted catch mortality; however, they may also result in lower catches of the target species (Ward et al., 2004; Carruthers et al., 2009).

There have been opposing findings regarding the impact of hook shape on by-catch. Traditionally, J-shaped hooks (J-type hooks) have had the reputation of resulting in a high by-catch of protected, endangered, or threatened species (PET species), and replacing them with circle hooks (C-type hooks) has been shown to be especially effective in reducing the by-catch of marine turtles (Piovano and Gilman, 2017). Moreover, the use of C-type hooks is considered a relatively low-cost by-catch mitigation tool; therefore, a large number of studies exist globally about the C-type hook effect on by-catch (e.g. Kim et al., 2006; Pacheco et al., 2011; Afonso et al., 2012; Godin et al., 2012; Gilman et al., 2016). Overall, the effects of C-type hooks on by-catch species seem to be species- and area-specific (Pacheco et al., 2011; Gilman et al., 2016). However, due to the small number of studies in the Mediterranean and opposing findings in other regions, there is a need to conduct further research to find effective by-catch mitigation strategies that consider multiple factors and potential trade-offs among species (Lucchetti and Sala, 2010; Piovano et al., 2010). As a result, the objective of this preliminary study is to compare the effects that use of traditional J-type hooks and C-type hooks used by a swordfish fishery in the South Adriatic Sea on target and by-catch species.

Materials and methods

Experimental settings of the pelagic longlines

To test the catch rate of C-type hooks for the target and by-catch species, a nine-day fishing trip in the Adriatic Sea, with seven fishing days and seven PLL sets (one per day), was monitored (Figure 1).

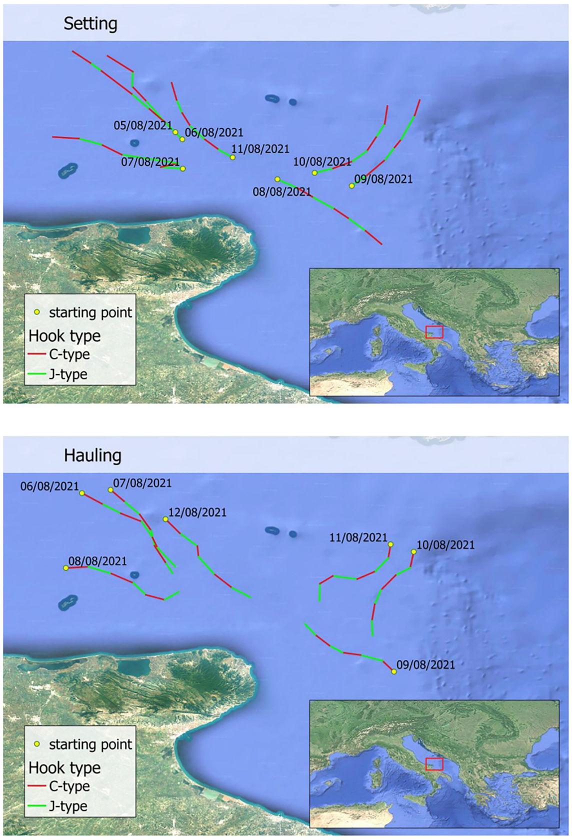

FIGURE 1
Setting and hauling of the longline with J-type hooks (green) and C-type hooks (red) during the fishing trips monitored in the study. The dates of the fishing trips are provided in the figure.

A PLL targeting swordfish was used during the experiment, with a total mainline length between 30 and 40 km. A hook was attached to a dropline with a length of about 13 m, and each dropline was attached to the main line every ~58 m (Figure 2). The configuration of the longline gear used in this study is the same as the configuration used in commercial fisheries.

Usually, the hooks used during the fishing season are J-type hooks that are 76 mm long. The longline was set in the early afternoon (3:00 p.m.-4:00 p.m.), and the operation was completed in about three hours. The longline haulback began at night and finished around 7:00-8:00 a.m. The longline hauling started with the last hooks. Therefore, the hooks remained at sea (soaking time) for between 10 and 20 hours (the time between the last hook set at sea and the first hook recovered). The bait used in the study was frozen mackerel (Scombridae), and an artificial light was attached to the middle of each dropline. The dropline was composed of monofilament. During the fishing trip, each PLL deployed 720 total hooks: half J-type (360 hooks) and half C-type (360 hooks) (Figure 2). The 720 hooks were deployed in six baskets with 120 hooks each. Three baskets were equipped with J-type hooks, and the other three with C-type hooks. The baskets with J-type hooks and C-type hooks were alternated along the longline (Figure 2). The dimensions of each hook type are provided in Figure 3.

Variables monitored

During the experimental fishing, for both target and by-catch specimens caught, data about the hook type and the length in millimeters (i.e., total length [TL] for blue sharks, carapace length [CL] for sea turtles, lower-jaw fork length [LJFL] for swordfish, and disc width [DW] for dark stingrays) were collected. Moreover, the capture condition of each specimen caught was evaluated using a qualitative index system (1 = *healthy*, 2 = *sluggish*, 3 = *moribund or dead*) adapted from Benoît et al. (2010) by putting moribund and dead specimens in a single capture condition category (Dapp et al., 2016) (Table 1).

Statistical analyses

Statistical analyses were performed using R software version 4.0.4 (R Development Core Team, 2021) and carried out at a 95% level of significance. Catch rates were expressed as catch-per-unit-effort (CPUE), calculated as the number of individuals caught per 1000 hooks (Pacheco et al., 2011). CPUE was estimated by fishing set for each species and for each type of hook, and it was compared between the hook types (J vs. C) using Wilcoxon's test due to the small sample size of the dataset (n = 7 fishing sets). Lengths were also compared by hook type using Wilcoxon's test for each species. The percentage of the capture condition was calculated by species, fishing set, and hook type. For each species, the percentage of the capture condition per fishing set was compared by hook type using Wilcoxon's test.

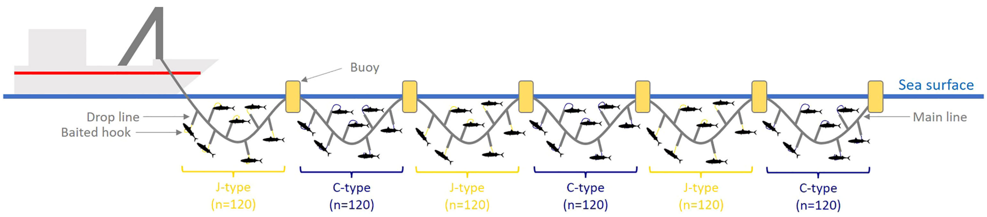

FIGURE 2
Scheme of the functioning of the pelagic longline used in the study and the position of the J-type hooks and C-type hooks along the pelagic longline.

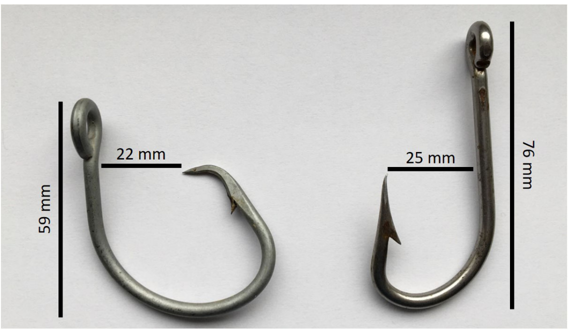

FIGURE 3
C-type hook (left) and J-type hook (right) used in the study and their dimensions.

Results

Catch-per-unit-effort and specimen size

The total catch for each species during the seven fishing sets is reported in Table 2. A total of 81 swordfish, 34 blue sharks, 16 pelagic stingrays, and 11 loggerhead turtles were caught. The target species constituted 57% of the total catch, while the by-catch of blue sharks, stingrays, and loggerhead turtles constituted 24%, 11%, and 8% of the total catch, respectively.

Overall, the average fishing set CPUE by species (Table 3) does not show any significant difference between the two hook types (C-type and J-type) (Figure 4, Table 4; p >.05). Also, the mean body size of specimens was not different between the two hook types regardless of species (Figure 5, Table 4; p >.05).

Catch condition

Only blue sharks show significant differences in catch condition based on hook type (Figure 6, Table 4; p <.05). In particular, the percentage of blue sharks in condition 1 (*healthy*) was significantly higher for those caught by a C-type hook (71.5%) than for those caught by a J-type hook (22.6%). The opposite pattern was observed for condition 2 (*sluggish*): a higher percentage of blue sharks were caught by J-type hooks (57%) than by C-type hooks (19%; Table 4; p <.05). The percentages of blue sharks in condition 3 (*dead or moribund*) did not differ significantly between the two hook types (Table 4; p >.05).

Loggerhead turtles were caught only in conditions 1 (*healthy*) and 2 (*sluggish*), and the percentages did not differ significantly (Table 4; p >.05) between the hook types (Figure 6). For the pelagic stingray, the catch conditions were not significantly different between the two hook types; condition 1 was the most frequent catch condition (~75%; Figure 6). Also, for the target species (swordfish), the percentage of the catch condition did not differ significantly between the hook types (Table 4; p >.05). At the moment of the catch, most of the fish (about 60%) were *dead or moribund*, about 15% were *sluggish*, and about 25% were *healthy* (Figure 6).

Discussion

Several new laws have been adopted in recent years. The primary goal of European Union (EU) Regulation 2019/1241, which has replaced and integrated EU Regulation 812/2004, is to minimize and, whenever possible, eliminate incidental catches of sensitive species to ensure that fishery-related mortality does not jeopardize those species' conservation status. A new binding recommendation of the General Fisheries Commission for the Mediterranean (GFCM/44/2021/16) adopted in 2021 on additional conservation and mitigation measures for the conservation of elasmobranchs in the Mediterranean Sea asks Contracting Parties, *inter alia*, to "*require fishing vessels, catching accessorily and incidentally sharks species, to limit by-catch of sharks*", such as blue sharks, and "*to improve the conservation status of elasmobranch species, mitigate and where possible eliminate the risk of incidental taking of elasmobranch in fishing operations and the associated mortality*". A new "EU action plan: protecting and restoring marine ecosystems for sustainable and resilient fisheries" (2023) also calls on member states to *"swiftly take measures to (…) protect sharks"* and a new GFCM "*Regional Plan of Action to monitor and mitigate interactions between fisheries and vulnerable species in the Mediterranean and the Black Sea*" is in preparation. In the Mediterranean, some by-catch reduction devices (BRDs) (e.g., grid, ultraviolet LED, circle hooks) have been tested to mitigate the impact that several items of fishing gear, such as passive net (Virgili et al., 2018; Lucchetti et al., 2019), trawl net (Lucchetti et al., 2016; Lucchetti et al., 2019), and PLL (Piovano et al., 2009; Piovano and Swimmer, 2017), have on sea turtles. However, the effects of BRDs on sharks have been tested less in the Mediterranean than in other areas (Carpentieri et al., 2021; Bradai et al., 2022).

Measures to mitigate the impact of PLL by-catch include adaptations of the gear, fishing area, bait, soak time, and setting

TABLE 1 Classification categories to evaluate the capture condition used in the study, adapted from Benoît et al. (2010) and Dapp et al. (2016).

Capture condition	Description
1. Healthy	Vigorous body movements
2. Sluggish	Weak body movements; responds to touching and prodding
3. Moribund or dead	No body movements; no response to touching or prodding; movements of the operculum/gill slits noted (moribund) or no movements of the operculum/gill slits noted (dead)

TABLE 2 Number of specimens and size range by species (blue shark, loggerhead turtle, pelagic stingray, and swordfish) and hook type (C and J) caught during the fishing trip (seven fishing sets).

Species	Number of specimens caught by a J-type hook	Number of specimens caught by a C-type hook	Size range of specimens caught by a J-type hook (cm)	Size range of specimens caught by a C-type hook (cm)
Swordfish	43	38	86.0–150.0	80.0–178.5
Blue shark	17	17	140.5–187.0	123.0–207.0
Pelagic stingray	9	7	37.3–47.0	35–85.0
Loggerhead turtle	5	6	28.2–40.1	25.6–41.2

and hauling times of the longline (Bigelow and Maunder, 2007; Coelho et al., 2012; Gilman et al., 2016). The adaptations of the gear include the distance between floats, which affects the hook fishing depth (Afonso et al., 2012), the material of the leaders and/or branch lines (e.g., wire or nylon) (Afonso et al., 2012), the use of repellent (e.g., chemical or magnetic) (Lucas and Berggren, 2022), and hook size and shape (Piovano and Gilman, 2017). The gear modification that is the most commonly tested is hook shape (e.g., Kim et al., 2006; Piovano et al., 2009; Ward et al., 2009; Sales et al., 2010; Pacheco et al., 2011; Afonso et al., 2012; Coelho et al., 2012; Godin et al., 2012; Gilman et al., 2016; Piovano and Gilman, 2017; Guo et al., 2022) – probably for being a relatively low-cost by-catch mitigation measure (Gilman et al., 2016).

Circle hook

Although the substitution of J-type hooks with C-type hooks has been tested in different areas, the effects of this substitution on both target species and by-catch species are not univocal (Gilman et al., 2016). In some cases, the C-type hook was found to have no effect on the catchability and mortality of either the target or by-catch species (Ward et al., 2009; Afonso et al., 2012; Coelho et al., 2012; Godin et al., 2012). In other cases, the C-type hook influenced the quantity of the by-catch species caught (Kim et al., 2006; Piovano et al., 2009; Sales et al., 2010; Gilman et al., 2016) or influenced the mortality of the by-catch and/or target species (Pacheco et al., 2011; Guo et al., 2022). These results from the scientific literature suggest that the effects of replacing the J-type hook with the C-type hook may be related to many factors, such as the species, area of fishing and/or season, bait type, water temperature, hook size, and/or depth (Gilman et al., 2016; Guo et al., 2022). Thus, several aspects should be taken into consideration to better assess the effects of C-type hook use on target and by-catch species, such as possible trade-offs and potential conflicts between different species; the use of a C-type hook can have beneficial or adverse effects, depending on the species (Sales et al., 2010; Pacheco et al., 2011; Piovano and Swimmer, 2017). The sample size of fishing sets in the present preliminary study is small; nevertheless, the results contribute to filling an information gap,

TABLE 3 Estimated mean catch-per-unit-effort (CPUE) for each hook type (C and J) per fishing set by species (blue shark, loggerhead turtle, pelagic stingray, and swordfish).

Fishing set	Hook type	Swordfish	Blue shark	Pelagic stingray	Loggerhead turtle
1	J-type	11.11	2.78	2.78	0
	C-type	8.33	5.56	0	0
2	J-type	22.22	5.56	0	0
	C-type	22.22	5.56	0	5.56
3	J-type	38.89	8.33	0	0
	C-type	16.67	8.33	0	0
4	J-type	16.67	5.56	0	5.56
	C-type	25.00	2.78	2.78	2.78
5	J-type	5.56	8.33	2.78	0
	C-type	5.56	5.56	2.78	2.78
6	J-type	13.89	11.11	13.89	5.56
	C-type	13.89	8.33	11.11	2.78
7	J-type	11.11	8.33	5.56	2.78
	C-type	13.89	8.33	2.78	2.78

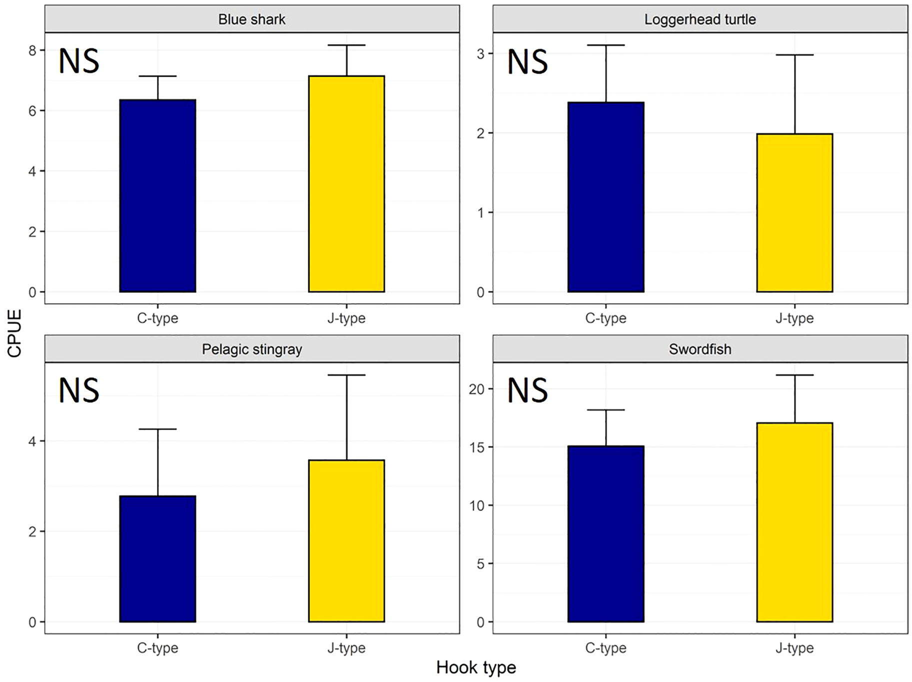

FIGURE 4
Catch-per-unit-effort (CPUE; mean ± se) by species (blue shark, loggerhead turtle, pelagic stingray, and swordfish) and hook type (C and J). NS, not significant (Wilcoxon's test; p >.05).

TABLE 4 Statistics (W value, p-value) and significance level according to the Wilcoxon's tests carried out the different variables investigated (CPUE, length and capture condition) depending on the two hook types (C and J).

Variable	Species	Capture condition	W value	p-value	Significance level
CPUE	Swordfish		24.5	1	NS
	Blue shark		20	0.59	NS
	Pelagic stingray		22.5	0.83	NS
	Loggerhead turtle		28	0.68	NS
Length	Swordfish		711.5	0.32	NS
	Blue shark		128.5	0.59	NS
	Pelagic stingray		18	0.17	NS
	Loggerhead turtle		13	0.79	NS
Capture condition	Swordfish	Condition 1	29.5	0.56	NS
		Condition 2	24.5	1	NS
		Condition 3	22.5	0.85	NS
	Blue shark	Condition 1	41	0.04	*
		Condition 2	6.5	0.02	*
		Condition 3	18.5	0.43	NS
	Pelagic stingray	Condition 1	8.5	1	NS
		Condition 2	6	0.45	NS
		Condition 3	8.5	1	NS

(Continued)

TABLE 4 Continued

Variable	Species	Capture condition	W value	p-value	Significance level
	Loggerhead turtle	Condition 1	8	1	NS
		Condition 2	7	1	NS
		Condition 3	6	NA	NS

An asterisk (*) indicates a significant difference between hook types within a condition (p <.05) and "NS" (not significant) indicates that no differences were found between the hook types within a condition (Wilcoxon's test; p >.05). CPUE, Catch-per-unit-effort. NA, Not Available.

especially in the Mediterranean basin, where few studies of this type exist (e.g., Piovano et al., 2009; Casale, 2011), by showing some of the positive effects of C-type hooks on the capture condition of blue sharks (discussed in detail below). Notably, further research is needed to strengthen the present results and to better understand the influence of factors such as area of fishing and/or season, bait type, water temperature, and hook size on the by-catch in the Mediterranean Sea.

Effects of a C-type hook on swordfish

The CPUE and size of swordfish caught by the two types of hooks did not differ significantly in our experiment. These findings are in accordance with the results obtained in another Mediterranean area (the Strait of Sicily) (Piovano et al., 2009) and the equatorial Atlantic Ocean (Coelho et al., 2012). In contrast, a significant decrease in the capture rate of swordfish was detected when using C-type hooks along the Brazilian coast (Sales et al., 2010). These apparently contradictory results, in addition to reaffirming the influence of the area on the catch-effectiveness of the two hook types, indicate that several factors play a role (e.g., bait, season, position of bait on the hook), and it is not easy to disentangle them to solely evaluate the effect of the hook (Broadhurst and Hazin, 2001; Watson et al., 2005; Pacheco et al., 2011; Coelho et al., 2012). Thus, repeating our experiment in the same area, with the same boat, crew, and bait – and in a limited time frame (seven fishing sets) – could aid in separating the other synergistic effects of the hook effect on the catchability of both target and by-catch species. However, the limited period of time could mask some potential effects from other factors (e.g., water temperature and fishing season). In terms of catch condition, swordfish did not show any significant difference between hook types, and these results are in accordance with Coelho et al. (2012) in the equatorial Atlantic Ocean. In particular, in the present study, the soak time was between 10 and 20 hours, which can induce death due to physiological stress (Carruthers et al., 2011). Therefore, the hook shape's positive effect on mortality could be masked by the soak-time effect (Carruthers et al., 2011). Altogether, our results suggest that the use of the C-type hook instead of the J-type hook did not affect the total number or size range of the targeted specimens (i.e., the swordfish) that were caught.

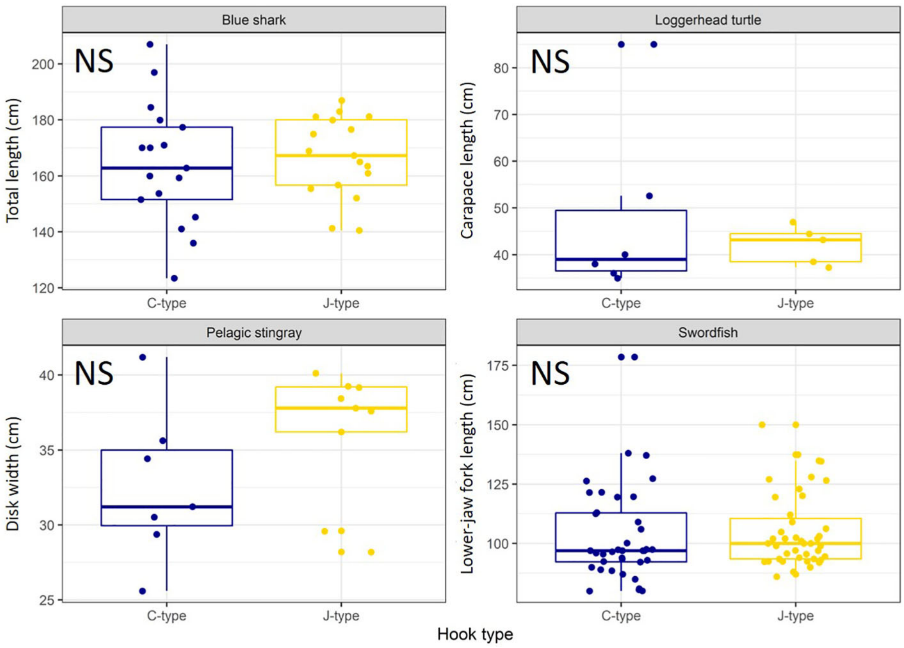

FIGURE 5
Box plot of body size in centimeters (total length for blue sharks, carapace length for Loggerhead turtle, lower-jaw fork length for swordfish, and disc width for dark stingrays) by hook type (C and J). No significant (NS) differences were found between the hook types (Wilcoxon's test; p >.05).

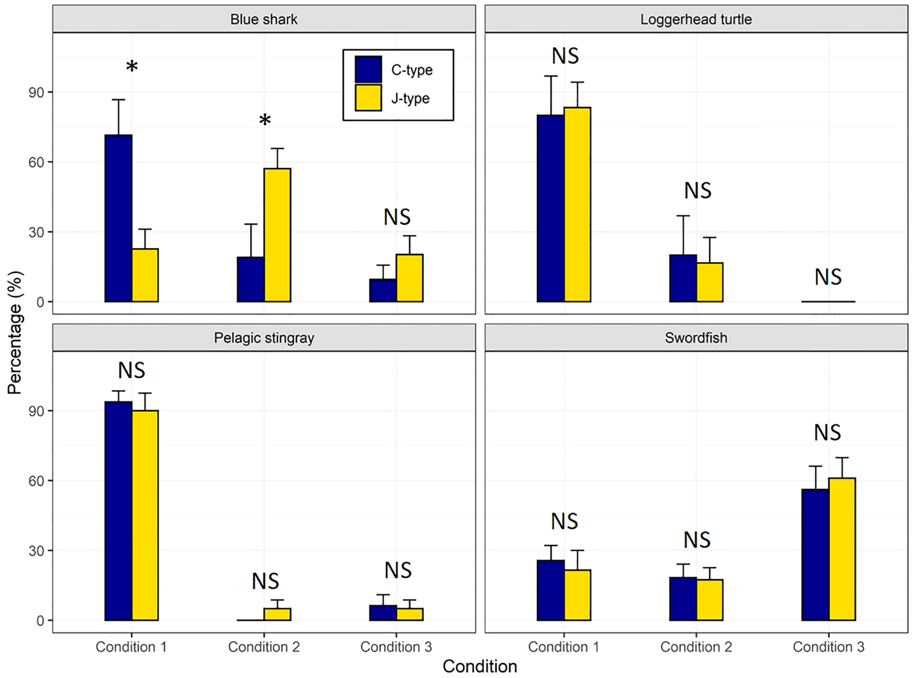

FIGURE 6
Percentage of specimens for each of the three capture conditions by species (blue shark, loggerhead turtle, pelagic stingray, and swordfish) and hook type (C and J). An asterisk (*) indicates a significant difference between hook types within a condition (p <.05) and "NS" (not significant) indicates that no differences were found between the hook types within a condition (Wilcoxon's test; p >.05).

Effects of a C-type hook on blue sharks

In this study, blue shark CPUE and the size of specimens did not show any significant difference between the hook types tested. This result is in accordance with Ward et al. (2009) in Australia, Pacheco et al. (2011) in the Atlantic Ocean, and Coelho et al. (2012) in the equatorial Atlantic Ocean. Along the Brazilian coast, Sales et al. (2010) found that the use of C-type hooks increased the catch rate of blue sharks, whereas Kim et al. (2006) found that C-type hooks decreased the catch rate of blue sharks in the eastern Pacific Ocean. Again, these contrasting results could be the consequence of synergistic effects due not only to the type of hook but also to several other factors (e.g., area, fishing practices, season, bait type, and soak time). Interestingly, in a meta-analysis compiling 15 studies, Godin et al. (2012) found no significant quantitative effects of the C-type hook on blue shark catchability. For the evaluation of the impact of hook type on blue shark catchability, the methodology applied in our study – which tends to decrease variability beyond the type of hook as much as possible – can be very useful (Carruthers et al., 2011; Godin et al., 2012). In addition, we observed that hook type significantly impacted the haulback condition of blue sharks. Indeed, the blue sharks caught by C-type hooks were in significantly better condition than those caught by J-type hooks. The C-type hook is supposed to increase this likelihood because both target and by-catch species are typically hooked in the jaw with this hook type (Ward et al., 2009); in contrast, the J-type hook is reported to become lodged in deeper locations (e.g., throat, esophagus, or stomach), which damages the internal organs and thus increases catch mortality (Falterman and Graves, 2002; Cooke and Suski, 2004; Watson et al., 2005; Carruthers et al., 2009; Afonso et al., 2011; Pacheco et al., 2011). Post-release survival is positively and directly correlated with the haulback condition of captured pelagic sharks, such as blue sharks (Campana et al., 2016; Musyl and Gilman, 2018). Therefore, C-type hooks – although they do not affect catchability – positively affect the haulback condition, which in turn affects post-release survival (Musyl et al., 2009; Musyl and Gilman, 2019; Whitney et al., 2021). Thus, using C-type hooks and releasing by-catch species could be an effective management measure to reduce fishing mortality and improve the conservation of shark populations (Bowlby et al., 2021; Knotek et al., 2022). This needs to be confirmed by a larger sample size in the Mediterranean Sea and the inclusion of other factors, such as seasonality, water temperature, bait type, and depth. Notably, although CPUE is an important indicator of catch rates, there is also the possibility that some species (targeted or not) bite the hook and escape (i.e., "bite-offs") and are, therefore, not included in the calculation of catch rate by CPUE, especially when dropline is composed of monofilament (Afonso et al., 2012). The use of C-type hooks could also benefit the survival of these animals, especially blue sharks, because they are designed to hook fish in the mouth rather than in the gut, reducing the chances of gut hooking with internal injuries and thereby increasing the chances of survival after hooking (Afonso et al., 2011). Hence, blue sharks that were hooked with C-type hooks and managed to free themselves have a better chance of survival compared to animals hooked internally with J-type hooks. This assertion is supported by the present study's findings that blue sharks caught with C-type hooks were generally in better condition than those caught with J-type hooks. This should be better encompassed in future studies comparing the effects of different hook types.

Effects of a C-type hook on loggerhead turtles

In our experiment, the CPUE, size, and haulback conditions of loggerhead turtles did not differ significantly in relation to a hook shape. Unlike our results, a significant reduction in the catch rate and deep-hooking of loggerhead turtles caught by C-type hooks was found in the Atlantic Ocean (Sales et al., 2010) and the Mediterranean Sea (Strait of Sicily) (Piovano et al., 2009). These differences in our experiment could be due to the low number of loggerhead turtle specimens caught by each hook type (Kim et al., 2006). Moreover, the catch conditions of the loggerhead turtles were good in most cases because the branch lines were long enough to allow the hooked specimens to reach the surface and breathe.

Effects of a C-type hook on pelagic stingrays

Similar results to those for the loggerhead turtles were found for the pelagic stingrays; there were no significant differences in CPUE, size, or haulback condition between the two hook types. In contrast, previous studies (e.g., Carruthers et al., 2009; Ward et al., 2009; Pacheco et al., 2011) found significant differences in the catch rate and catch condition. The lack of significant differences in the present study could be due to the low number of specimens caught.

Conclusion

Overall, the results of the present study suggest that using C-type hooks on PLLs does not significantly affect the catch rates and size ranges of the target (i.e., swordfish) and by-catch species, including blue shark. However, the haulback condition of the blue shark was significantly better in specimens caught by C-type hooks compared to J-type hooks. The significantly better catch condition of the blue sharks caught by C-type hooks could increase their post-release survival if a management measure is adopted that mandates the release of by-catch species. Importantly, the absence of differences in the catch rate and size range of the target species (i.e., swordfish) between the C-type hooks and J-type hooks could aid in the introduction of this gear modification (i.e., replacing J-type hooks with C-type hooks) as a by-catch mitigation measure. Indeed, professional fishers can accept a change in fishing equipment as long as there are little to no economic losses (i.e., similar catch rates of target species with the new devices) and a low level of effort required to adopt the new gear or devices. Thus, C-type hooks – a simple technology – could be useful for marine conservation. C-type hooks could reduce the death of sharks caught as by-catch in longline fishing and thus help to achieve the EU's goal of eliminating incidental catches of sensitive species (Regulation 2019/1241). However, the large degree of variation among studies and the low sample size of fishing sets in the present preliminary study emphasize the need for further studies on by-catch species in the Mediterranean to obtain more conclusive findings.

Data availability statement

The raw data supporting the conclusions of this article will be made available by the authors, without undue reservation.

Ethics statement

Ethical review and approval was not required for the animal study because animals used in this study are coming from an authorized professional fishing activity. Moreover the sampling plan was reviewed and approved by the Committee on the Ethics of Animal Experiments of COISPA (Italian Ministry of Health 17/2022-UT).

Author contributions

PC, GP, and SN: conceptualization and funding acquisition. PC: methodology. PC, SA, CN, and MD: formal analysis and data curation. PC, GP, SN, and MS: resources. PC: original draft. PC, GP, SN, SA, CN, MD, and MS: reviewing and editing. PC, GP, SN, MS, and GL: project administration. All authors contributed to the article and approved the submitted version.

Funding

The study was funded by the Med By-Catch Project "Understanding Mediterranean Multi-Taxa By- Catch of Vulnerable Species and Testing Mitigation: A Collaborative Approach", supported by MAVA Fondation Pour la Nature.

Acknowledgments

The authors warmly acknowledge the crew of the Galeone boat, particularly Captain Onofrio Comes. Moreover, the authors acknowledge the reviewers for their constructive comments and suggestions, which greatly helped to improve the manuscript.

Conflict of interest

The authors declare that the research was conducted in the absence of any commercial or financial relationship that could be construed as a potential conflict of interest.

Publisher's note

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