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Effects of a hook ring on catch and bycatch in a Mediterranean swordfish longline fishery: small addition with potentially large consequences

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ABSTRACT

1. The purpose of this study was to investigate the effects of a circle hook ring on catch rates of target fish species and bycatch rates of sea turtles, elasmobranchs, and non-commercial fish in a shallow-set Italian swordfish longline fishery.

2. Results were compared from 65 sets from six commercial fishing vessels totalling 50 800 hooks in which ringed and non-ringed 16/0 circle hooks with a 10° offset were alternated along the length of the longline. In total, 464 individuals were caught in the 4 years of experiment, with swordfish (*Xiphias gladius*) comprising 83% of the total number of animals captured. Catch rates of targeted swordfish were significantly higher on ringed hooks ($CPUE_{ringed\ hooks} = 8.465$, $CPUE_{non\text{-}ringed\ hooks} = 6.654$).

3. Results indicate that ringed circle hooks captured significantly more small-sized swordfish than non-ringed circle hooks (27.7% vs. 19.5%, respectively).

4. For species with sufficient sample sizes, the odds ratio (OR) of a capture was in favour of ringed hooks; significantly for swordfish (OR = 1.27 95%CI 1.04–1.57), and not significantly for bluefin tuna (*Thunnus thynnus*) (OR = 1.50, 95%CI 0.68–3.42) nor for pelagic stingray (*Pteroplatytrigon violacea*) (OR = 1.13, 95%CI 0.54–2.36). All six loggerhead turtles (*Caretta caretta*) and three of the four blue sharks (*Prionace glauca*) were captured on ringed hooks, however, the small sample sizes prevented meaningful statistical analysis.

5. In summary, results from this study suggest that the addition of a ring to 16/0 circle hooks confers higher catchability for small-sized commercial swordfish, and does not significantly reduce catch rate of bycatch species and protected species in a Mediterranean shallow pelagic longline fishery.

6. These findings should motivate fisheries managers to consider factors in addition to hook shape when aiming to promote sustainable fishing practices. The presence of a ring has the potential to negate some conservation benefits.

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KEY WORDS: conservation evaluation; endangered species; fish; fishing; ocean; protected species; reptiles

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INTRODUCTION

Every day, approximately 4.7 million hooks are deployed by pelagic longlines, primarily targeting large pelagic fish such as tunas and swordfish (Clarke *et al.*, 2014). These baited hooks also attract non-commercial and protected species, which can result in population-level impacts across various taxa, including rays, sharks, sea turtles, seabirds, and marine mammals (Gilman *et al.*, 2008, 2016; Wallace *et al.*, 2013; Yeh *et al.*, 2013; Oliver *et al.*, 2015; Werner *et al.*, 2015). In the last decade, this unwanted catch, called 'bycatch', has been identified as one of the major threats to marine megafauna (Lewison *et al.*, 2004, 2014; Gallagher *et al.*, 2014). Management of bycatch and reduction of discards have been prioritized worldwide (FAO, 2011; Gilman *et al.*, 2012), and a great effort has been put in place to identify and test possible ways to minimize bycatch impact on marine populations (Komoroske and Lewison, 2015).

Bycatch of sea turtles by pelagic longline gears has received considerable attention (Gilman *et al.*, 2006, 2007; Wallace *et al.*, 2013). Sea turtle species are characterized by long lifespan, slow growth, and late age at maturity (Piovano *et al.*, 2011; Scott *et al.*, 2012; Avens *et al.*, 2015). Their marine and mostly migratory lifestyle present significant challenges in evaluating sea turtle population size, and thus this is largely estimated through nesting sites surveys (Moore *et al.*, 2013).

In an effort to reduce the rate of sea turtle bycatch in pelagic longlines, or to increase chance of survival of captured animals, behavioural experiments have been conducted in laboratories (Piovano *et al.*, 2004, 2012a, 2013; Southwood *et al.*, 2008), and bycatch reduction technologies, 'BRT', have been tested at sea (Swimmer *et al.*, 2005, 2011; Gilman *et al.*, 2006; FAO Fisheries Department, 2009).

Circle hooks are a BRT that proved to be generally effective in reducing bycatch of threatened sea turtle species on pelagic longlines, with growing published findings on positive results obtained for large (size 16/0 and above) circle hooks (Piovano *et al.*, 2009; Serafy *et al.*, 2012; Andraka *et al.*, 2013), or for large circle hooks combined with other fishing gear modifications (e.g. circle hooks and fish bait: Watson *et al.*, 2005; Gilman *et al.*, 2006; Read, 2007; Sales *et al.*, 2010; Gilman, 2011). Hook shape affects catch rates of leatherback sea turtles, while it affects hooking location but not catch rates of hard shelled sea turtles (Gilman *et al.*, 2006). Wider circle hooks may reduce catch rates of hard shelled sea turtles relative to narrower J-shaped and Japanese-style tuna hooks owing to the difference in minimum width (Gilman, 2011). The use of large circle hooks has become mandatory in some commercial fisheries characterized by high bycatch rates of sea turtles (e.g. in the USA, see Wilson and Diaz (2012)), and recommended or required with some regional fisheries management organizations (e.g. Western and Central Pacific Fisheries Commission). Circle hook use is considered a positive step in the process of sustainable fisheries certification (e.g. Marine Stewardship Council certification). Voluntary adoption of circle hooks associated with the creation of a local fishery product label has been discussed in some Mediterranean local communities (Piovano *et al.*, 2012b).

There are three types of hooks used by pelagic longline fisheries: J-hooks, Japanese-style tuna hooks and circle hooks. Circle hooks are generally characterized by a 'G' shape and a point directed acutely toward the shank, in contrast to J hooks, which have a point more in line with the shank. However, the lack of a consistent definition has led to different G shaped hooks being called 'circle hooks', potentially affecting final understanding of this BRT effectiveness (Serafy *et al.*, 2012). The most consistent standardized definition of a circle hook is a hook with a point angle of at least 90°, a front angle of at least 20°, and a front length about 70–80% of the hook total length (Serafy *et al.*, 2012). However, circle hooks may differ in shank and bend gauge, barb, and offset (see hook description in Beverly (2006)), which may affect their performance on target and bycatch species (Favaro and Côté, 2015; Gilman *et al.*, 2016). For example, hook offset may potentially affect capture and survival rates (Swimmer *et al.*, 2010; Curran and Bigelow, 2011; Epperly *et al.*, 2012; Rice *et al.*, 2012).

However, even standardized circle hooks may differ in the way they are attached to the branchline, which could be by an eye or by a ring (Figure 1). An eye is the fixed circular loop located at the end of the hook shank, usually perpendicular to the plane of the hook and characterized by a constant wire diameter. The branchline is secured through it. The ring, when present, is inserted in the hook's eye and the branchline is then secured through the ring, not the eye. The design of circle hooks was already known to fishermen in Oceania centuries ago (Paulin, 2007, 2011), however, the addition of the ring appeared much more recently. In the 1960s, before being identified as effective in reducing sea turtle bycatch, circle hooks were recommended to target sharks with bottom longlines set in deep water (Hayes-Wagner, 1966). In the 1980s, their use is recorded for the US Pacific north-west halibut fisheries (Keith *et al.*, 2014). The existence of a ring in circle hooks may play a role in the potential for hook deformation, which is reportedly the result of the direction and force of pull, which is affected by hook attachment to the branchline (Bigelow *et al.*, 2012).

A common perception among fishermen is that a ring results in higher target species catch rates. Fishermen's choice of whether to use a ring appears to be driven by several factors, including the diameter of the branchline to be used (to ensure fit with the eye diameter according to fishermen from Sicily, Italy, interviewed in 2012 – Piovano unpublished data) and the mobility of the hook in the water (the ring provides a more flexible joint between the branchline and the eye, which is considered important in particular when a fish strikes, according to fishermen from Apulia, Italy, interviewed in 2007 – Piovano unpublished data). Among US Atlantic coast longline fishermen, personal preferences were also observed regarding the use of ringed and non-ringed circle hooks, where some fishermen chose the ringed hooks and other chose the non-ringed hooks (Bigelow *et al.*, 2012). Other than the occasional survey among fishermen, we are unaware of any study that has specifically attempted to identify how a ring affects catchability, of target as well as non-target species. Given the interest in providing an empirical understanding of the impact of the ring on both target and bycatch species, this study was aimed to evaluate the fishing performance of a ringed versus a non-ringed circle hook in a commercial shallow-set longline fishery targeting swordfish in the central Mediterranean Sea.

Figure 1. Ringed (left) and non-ringed (right) circle hooks size 16/0, 10° offset, used in this experiment.

METHODS

Experiments to test catch rates of target fish and bycatch species were conducted on six commercial longline fishing vessels operating in the central Mediterranean Sea (Strait of Sicily and South Tyrrhenian Sea) during the months of July to September, in 2009, 2010, 2012, and 2013. The vessels primarily targeted swordfish (*Xiphias gladius*). The experimental gear consisted of 16/0 circle hooks, 10° offset, with and without the ring (i.e. ringed and non-ringed, Figure 1), alternated in a 1:1 ratio along the mainline. Fish bait was used for all sets. The average number of hooks per set was 782 (range: 600 to 1100), dependent upon vessel size and captain's choice. All other characteristics of gear configurations were standard for the Sicilian shallow-set pelagic swordfish longline fishery (Piovano *et al.*, 2009). A total of 65 experimental longline sets were conducted, totalling 50 800 hooks (25 400 of each hook type).

Catch data such as species identification, length measurement, and type of hook responsible for the capture were collected by onboard scientific observers who were present for all experimental sets. Catch data have been standardized per the effort (CPUE) as number of individuals caught per 1000 hooks.

One-way ANOVA was used to compare mean fish lengths between the two hook types. Fisher's Exact Test was used to compare total number of individuals captured on the two types of hook. Analysis was performed in R version 3.2.0 (R Core Team, 2015), with packages car (Fox and Weisberg, 2015), doBy (Højsgaard and Halekoh, 2014), and metaphor (Viechtbauer, 2015).

RESULTS

A total of 464 specimens from eight species were captured (Table 1). All were hooked, except for two cases of entanglement which were reported for loggerhead sea turtles.

Target species

Catch rate

The primary target species, swordfish, accounted for 83% of the total catch. The total number of swordfish captured was 215 (CPUE = 8.465) on ringed hooks and 169 (CPUE = 6.654) on non-ringed hooks, which was significantly different (Fisher's Exact Test: $P = 0.021$). The odds ratio of a swordfish being captured on one of the two circle hooks was 1.27 significantly in favour of ringed hooks (Figure 2).

Among the other species recorded, only bluefin tuna *Thunnus thynnus* had total captures ≥30 individuals (Table 1). CPUE was 0.709 animals on 1000 ringed hooks and 0.472 animals on non-ringed hooks. The odds ratio of a bluefin tuna being captured on one of the two circle hooks was 1.50 in favour of ringed hooks, but results from confidence interval show this is not significant (Figure 2).

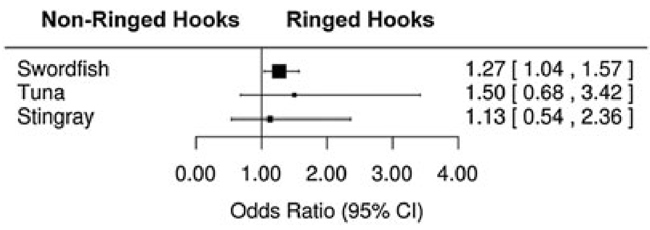

Figure 2. Odds ratio and 95% confidence interval (CI) for swordfish, bluefin tuna and pelagic stingray captures on the two types of hook (ringed and non-ringed).

Size

Lower jaw fork length (LJFL) of swordfish was measured on 363 specimens (i.e. 95% of swordfish captures), and ranged from 59.0 cm to 168.5 cm. More than 80% of the swordfish were in the length categories from 80–89.9 cm to 110–119.9 cm (Figure 3). The greatest percentage of swordfish captures was recorded for the length category 90–99 cm LJFL on both hooks (35.4% for ringed hooks and 38.8% for non-ringed hooks). However, the second greatest percentage of swordfish captured on the two hooks was represented in different categories: 80–89 cm LJFL for ringed hooks (25.8% of swordfish captures) and 100–109.9 cm LJFL for non-ringed hooks (25.5% of swordfish captures) (Figure 3). Thus, ringed circle hooks obtained an overall higher capture rate of small-sized swordfish. In particular, capture of small-sized swordfish by ringed hooks was significantly higher (8%) than on non-ringed hooks (27.7% vs. 19.5%, respectively; χ^2 test $P = 0.014$), although the mean length of swordfish caught on the two hook types did not differ significantly (98.0 cm on ringed hooks and 98.9 cm on non-ringed hooks; one-way ANOVA: $F_{1,361} = 0.364$, $P = 0.547$).

Table 1. Total catch (number of individuals) by species, CPUE (number of animals captured per 1000 hooks) and type of hook

Common name	Species	Total catch	CPUE on ringed hooks	CPUE on non-ringed hooks
Swordfish	*Xiphias gladius*	384	8.465	6.654
Pelagic stingray*	*Pteroplatytrigon violacea*	34	0.709	0.630
Bluefin tuna	*Thunnus thynnus*	30	0.709	0.472
Loggerhead sea turtle*	*Caretta caretta*	6	0.157	0.000
Blue shark*	*Prionace glauca*	4	0.039	0.118
Sunfish*	*Mola mola*	3	0.039	0.079
Little tunny	*Euthynnus alletteratus*	2	0.039	0.039
Dolphinfish / Mahi mahi	*Coryphaena hyppurus*	1	0.000	0.039

*Denotes a bycatch species.

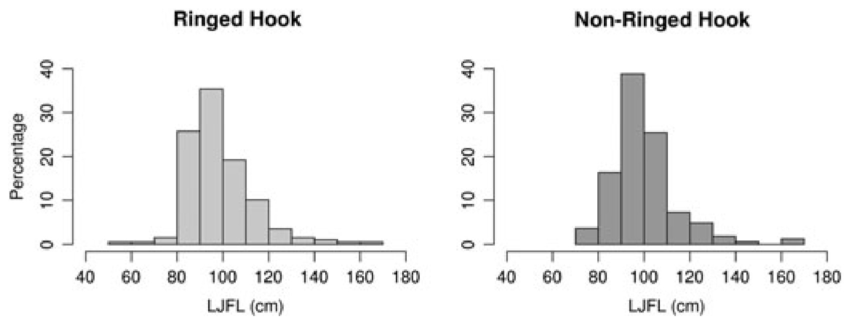

Figure 3. Percentage distribution of swordfish captured and measured (N = 363), by type of hook (ringed and non-ringed) and lower jaw fork length classes (LJFL, 10 cm intervals).

Bycatch species

Catch rate

Four bycatch species were recorded – pelagic stingray *Pteroplatytrigon violacea*, blue shark *Prionace glauca*, sunfish *Mola mola*, and the loggerhead sea turtle *Caretta caretta* (Table 1). The highest bycatch rates (0.709 animals per 1000 ringed hooks and 0.630 animals per 1000 non-ringed hooks) were recorded for the pelagic stingray. Catchability of this species had a non-significant increase in the presence of the ring (OR = 1.13, 95%CI 0.54–2.36; Figure 2). Three of the four blue sharks and all six loggerhead sea turtles hooked were captured on circle hooks with the ring. The small sample sizes prevented meaningful statistical analysis. In sea turtles, hooks were located superficially on the turtles' body – five in the mouth and one in the front flipper.

Size

Mean loggerheads curved carapace length (CCL) was 54.2 cm (SD = 4.2, n = 6). For the other bycatch species, the branchline was cut close to the hook and animals were not boarded on the fishing vessel.

DISCUSSION

Target species

Results from this study suggest that the ring has significant effect on the catch rates of targeted swordfish as well as on the catch rate of small-sized swordfish.

Swordfish is one of the main targeted species of the longline fleet operating in the Mediterranean Sea (De La Serna *et al.*, 1996). In this study, CPUE of swordfish on ringed circle hooks was significantly higher (1.27 times) than that recorded on non-ringed circle hooks. CPUE recorded on both ringed and non-ringed circle hooks in this study are consistent with the range of CPUE recorded on non-ringed circle hooks of the same size (16/0), previously tested by the large- and small-scale Sicilian swordfish longline fisheries (Piovano *et al.*, 2009, 2012b). CPUEs recorded in this study are also within the range recorded for swordfish captures on J hooks for the Sicilian swordfish longline fishery in the central Mediterranean Sea, which varies significantly among years and months (Tserpes *et al.*, 2015).

In the Mediterranean Sea it is estimated that swordfish reach first sexual maturity at 142 cm LJFL (De La Serna *et al.*, 1996). ICCAT (2011) recommendation for stock management is a minimum retaining and landing size of 90 cm LJFL. In Italy, minimum landing size of swordfish has been established at 140 cm TL for commercial fishing (Decreto del Presidente della Repubblica, 1639/68) and at 90 cm LJFL, or 140 cm total length (TL), for recreational/game fishing (Ministero delle Politiche Agricole Alimentari e Forestali, 2012).

Mean LJFLs from this study (98 cm on circle hooks with ring and 99 cm on non-ringed circle hooks) are consistent with the average annual LJFL of swordfish captured on J hooks by the Sicilian fleet between 1986 and 1999, and in 2002 (ranged from 95 cm to 112 cm; in Tserpes *et al.*, 2001; Di Natale *et al.*, 2005), indicating that this fishery is consistently exploiting immature, small-sized individuals.

According to results from this study, the adoption of ringed circle hooks has the potential to increase the incidence of captures of small-sized individuals by the Sicilian fleet, which is among the larger swordfish fleets in the Mediterranean Sea (Tserpes *et al.*, 2011). Such consequences would be contrary to ICCAT recommendations aimed at improving yield-per-recruit and spawning biomass-per-recruit levels of the Mediterranean swordfish stock (ICCAT SCRS, 2012).

Bycatch species

Results from this study suggest that the ring has no significant effect on the catch rates of pelagic stingrays.

Pelagic stingray is subject to high bycatch rates by the Sicilian pelagic longline fishery (Piovano *et al.*, 2010), and a reduction in captures of this non-commercial elasmobranch would reduce the longline fishery footprint. In this study the presence of a ring resulted in higher, though not significant, catch rates. CPUE recorded on both ringed and non-ringed circle hooks are consistent with previous results on non-ringed circle hooks of the same size (Piovano *et al.*, 2009, 2010).

Bycatch of endangered loggerhead sea turtles (IUCN, 2015) was also recorded in the present study. Capture of sea turtles is a rare event in many longline fisheries (Gilman *et al.*, 2006), and becomes even more rare in instances when using BRTs, such as circle hooks. The size of the six loggerhead sea turtles captured on ringed circle hooks (no capture was recorded on non-ringed circle hooks) suggests they were all immature individuals (Margaritoulis *et al.*, 2003), with approximate ages 11 to 18 years old (Piovano *et al.*, 2011). Turtles captured in this study may have derived either from a Mediterranean or an Atlantic rookery, as both are known to be present in the same foraging grounds in Sicilian waters (Clusa *et al.*, 2014, 2016). Loggerhead age at first reproduction in the Mediterranean has been estimated at 24 years on average (Casale *et al.*, 2011; Piovano *et al.*, 2011), assuming an average minimum size of 69 cm CCL for Mediterranean first time nesters (Margaritoulis *et al.*, 2003). Atlantic loggerheads mature at bigger size and older age (Avens *et al.*, 2015).

Results from the present study introduce some concern as adoption of circle hooks has the potential of leading to increased bycatch rates of loggerhead sea turtles if a ring is present. As a precautionary measure, non-ringed circle hooks as opposed to ringed circle hooks should be preferred in order to promote fishing practices that minimize impacts on loggerhead sea turtles.

In general, the presence of a ring may influence the direction and force of pull of a hooked animal (Bigelow *et al.*, 2012) and the way bait moves when in the water. According to Australian tuna longline fishermen, the ring allows for the bait to move more naturally in the water, thereby adding to its appeal to predators (Wellington, 1989). This opinion was similarly expressed by Sicilian fishermen interviewed after completion of this current experiment. Sicilian fishermen also believed that the ring works to increase bluefin tuna catch rates, for two reasons: first, the ring allows the hook to better follow the movements of a fighting fish, such as tunas; and second, because hooks deployed by the local tuna fisheries are Japanese style tuna hooks, which have a ring as a connection point between the hook and the branchline. Despite these claims, however, odds ratio analysis in favour of the ringed circle hooks was not statistically significant in this study.

Previous research in the study area supported the use of large circle hooks as a BRT for sea turtles (Piovano *et al.*, 2009, 2012b) and pelagic stingrays (Piovano *et al.*, 2010). However, as with other components of the longline fishing gear, deployment of ringed or non-ringed hooks is based on fishermen preference.

The need for a detailed description accompanying the recommendation or requirement for using circle hooks has clearly emerged, as this study showed how overlooking technical differences, such as the presence of a ring, can have unexpected results on the captured species.

This is the first study to provide empirical evidence to support claims of increased catchability of targeted species such as swordfish owing to the presence of a ring. However, the ring effect also resulted in increased capture of small-size swordfish, thus igniting potential new concern regarding Mediterranean swordfish stocks. In addition, this study identified a potential additional risk to loggerhead sea turtles by the presence of a ringed hook. It is thus strongly recommended that fisheries policies aimed at shifting toward using circle hooks for conservation purposes clearly indicate avoidance of variables such as a ring that can adversely affect ecosystem-level sustainability of longline fisheries. Despite the use of circle hooks as a conservation tool, the presence of a ring has the potential to negate these conservation benefits.

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