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Effects of leader material on catches of shallow pelagic longline fisheries in the southwest Indian Ocean

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Abstract—Catches from a commercial longline fishery targeting swordfish (*Xiphias gladius*) on monofilament nylon leaders were compared with catches on wire leaders in the Indian Ocean. More taxa were caught on wire leaders, which also showed higher catch rates (13% and 56%, in number and weight, respectively) of blue shark (*Prionace glauca*). In contrast, catch rates of swordfish were not significantly affected by leader material. Nylon leaders showed lower at-haulback mortality for most bony fishes, except swordfish. Higher bite-off rates were observed on nylon monofilament, likely owing to the escape of species with sharp teeth, such as sharks. Both leader types caught most species within similar size ranges, but larger mean sizes of blue shark were recorded on wire leaders. The value per unit of effort (VPUE) of the retained catch did not differ between leader materials; however, VPUEs are highly dependent on market fluctuations. Banning wire leaders could be an effective way of reducing shark catches, particularly blue shark catches, in the southwest Indian Ocean.

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Pelagic longlines have historically been used by distant water fleets to catch large tunas (*Thunnus* spp.) and swordfish (*Xiphias gladius*) on the high seas. However, there has been considerable concern over the ecological effects of these fisheries because longline gears also catch other species, particularly billfish (Istiophoridae) and pelagic sharks (Elasmobranchii), and, to a less extent, marine-turtles, sea-birds and marine-mammals (Lewison et al., 2004; Watson and Kerstetter, 2006; Huang, 2011). This range of species is due to the fact that these groups of animals occupy broad geographic ranges spanning geopolitical boundaries and oceanographic regions that support different fisheries (Wallace et al., 2010). Fisheries bycatch—the unintended capture of nontarget organisms during fisheries operations—is therefore a major problem worldwide because it occurs with virtually all fishing fleets and is a global issue for management of marine resources (Hall et al., 2000; Soykan et al., 2008). Despite the existence of extensive differences in bycatch species and the magnitude of these differences from one fishery to another, bycatch can be a driver of declines in marine megafauna populations (Lewison et al., 2004; Read, 2007; Wallace et al., 2010). Such declines can be particularly important in the case of bycatch species that have long life cycles and low productivity, and therefore low potential for population recovery, as is the case for several pelagic sharks.

The large pelagic longline fisheries in the Indian Ocean date back to the 1950s, when the Asian fleets targeted mainly tropical tunas (Lee et al., 2005) and caught billfishes and sharks as bycatch. During the early 1990s, the shallow-setting pelagic longliners (mostly European) expanded the range of their swordfish fishery from the Atlantic Ocean to the Indian Ocean. A few changes were incorporated into the fishing gear in the early 2000s, specifically a shift from traditional to modern gear (Watson and Kerstetter, 2006), making use of mainlines and branch lines of monofilament leader and using lightsticks or flashlights. Moreover, in the same period, the landings of pelagic sharks increased as a result of the increasing interest in the international markets for shark products. Between the mid-2000s and early 2010s, owing to increasing costs (mostly related to the oil prices) and taking advantage of the high abundance of sharks in particular areas or seasons (or both), the fisheries targeting swordfish started replacing the traditional monofilament leaders with multifilament steel leaders, and baiting the hooks with fish, mostly mackerel (*Scomber* spp.), instead of squid (*Illex* spp.). These gear changes raised concerns about their effects, particularly on shark stocks, because those gear changes were occurring on an ocean-wide scale.

A number of research initiatives have focused on the mitigation of longline bycatch by making several technological and methodological changes, all aiming at increasing the selectivity of fishing gear and reducing mortality. With regard to shark bycatch, particular attention has been given to the use of different hook styles (Watson et al., 2005; Yokota et al., 2006; Coelho et al., 2012a; Amorim et al., 2015) and bait types (Watson et al., 2005; Coelho et al., 2012a; Amorim et al., 2015). However, there are few published studies on the effects of wire leaders on longline catches, despite the general concern regarding increasing catches of sharks. Moreover, a number of these previous studies have reported some contradictory results: Branstetter and Musick (1993) conducted 71 longline sets (using 50 branchlines with nylon leaders and 100 branchlines with wire leaders) and reported higher catch rates of sharks on nylon leaders in inshore waters, but found the opposite in offshore waters; Berkeley and Campos (1988), on the basis of 13 longline sets (about 25% using wire leaders), reported lower catches of sharks on wire leaders than on nylon, but the difference was not statistically significant; Stone and Dixon (2001) completed 10 sets with alternately spaced monofilament and tarred multifilament nylon leaders and reported lower catches for the tarred multifilament nylon leaders; Afonso et al. (2012) completed 17 longline shallow sets, using nylon and wire leaders, and reported higher catches of blue shark (*Prionace glauca*), and all sharks combined on wire leaders; Vega and Licandeo (2009) conducted 37 fishing sets using polyamide monofilament (hooks baited with squid or mackerel) and steel multifilament 3-strand wire (hooks baited with mackerel) and showed marginal differences in shark catch rates, but no differences for the blue shark; and finally, Ward et al. (2008) conducted the largest experiment involving 5 commercial vessels (177 longline sets) targeting tuna (with deep setting), using wire (6 strands) and nylon leaders and reported a higher shark catch rate on wire leaders but did not report any data for the blue shark (the most common species caught on pelagic longlines). Most of these studies were conducted in the northwestern Atlantic Ocean (Branstetter and Musick, 1993; Stone and Dixon, 2001) and the southwestern equatorial regions (Afonso et al., 2012); whereas the remaining studies were conducted in the southwest Pacific Ocean off northeastern Australia (Ward et al., 2008), and in the southeast Pacific Ocean off Easter Island and Salas y Gómez Island (Vega and Licandeo, 2009).

There is a lack of information specific to the Indian Ocean on longlining despite the global landings of sharks on the order of 90,000 metric tons (t) (Indian Ocean Tuna Commission [IOTC] Online Data Querying Service, website). Interestingly, a recent European Union funded research project estimated potential shark catches for the Indian Ocean alone to be on the order of 160,000 t (Murua et al.[1]). In 2015, the Scientific Committee of the IOTC completed its first stock assessment for the blue shark, concluding that the uncertainties in the data and model structure were high, and as such the stock status was uncertain; however, the possibility of the stock being currently overfished was not ruled out (IOTC[2]).

Our study was designed to test the effect of different combinations of the material used on the terminal tackle of the branch lines (monofilament nylon and multifilament wire) on the catches of the shallow pelagic longline fishery targeting swordfish in the southwest Indian Ocean, an area of significant pelagic shark catches. We provide, for the first time for the Indian Ocean and on the basis of a large experimental study, a comparison between the catch composition, catch and yield rates, mortality rates, bite-off rates, and catch-at-size for both target and bycatch species caught by the 2 types of leader materials currently used on pelagic longline fisheries traditionally targeting swordfish.

Materials and methods

Experimental design and data collection

A total of 82 longline sets were carried out during 2 trips in the southwest Indian Ocean, over wide latitudinal (23–32°S) and longitudinal (56–71°E) ranges (Fig. 1) between November 2013 and March 2014. The experiments were conducted by a commercial fishing vessel from the Portuguese pelagic longline fleet. The fishing gear consisted of a standard monofilament polyamide mainline (3.6 mm in diameter), with 6 branch lines between floats (82 m from each other). The branch lines were approximately 18.6 m in length, and were attached to the main line by a 12.5-cm snap. Each branch line had 4 sections: 1) the first section consisted of 2.5-mm nylon monofilament (11.85 m long) connected by a swivel (4.5 cm) to the next section; 2) the second section consisted of a 0.7-m weighed rope (weighing 50 g), connected by a loop to the following section; 3) the third section consisted of 2.2-mm nylon monofilament (5.4 m in length), connected by a loop to the following

[1] Murua, H., F. J. Abascal, J. Amande, J. Ariz, P. Bach, P. Chavance, R. Coelho, M. Korta, F. Poisson, M. N. Santos, et al. 2013. Provision of scientific advice for the purpose of the implementation of the EUPOA sharks. Final report. European Commission Studies for Carrying out the Common Fisheries Policy (MARE/2010/11-LOT 2), 336 p. [Available from website.]

[2] IOTC (Indian Ocean Tuna Commission). 2015. Report of the 18th Session of the IOTC Scientific Committee. Indian Ocean Tuna Commission. Bali, Indonesia, 23–27 November. IOTC-2015-SC18-R[E], 175 p. [Available from website.]

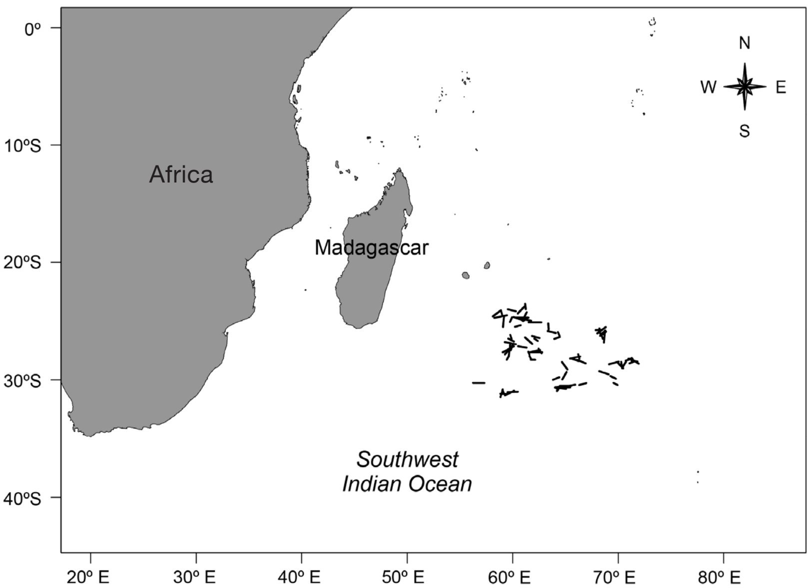

Figure 1

Map of the locations, indicated with black lines, of the experimental longline sets conducted in the southwest Indian Ocean between November 2013 and March 2014 to determine possible effects of leader material on catches of pelagic longline fisheries.

section; in the case of the control; 4) the fourth section consisted of a 2.5-mm nylon monofilament leader (0.65 m in length) with a hook in the terminal tackle, whereas in the case of the treatment (the wire leader), the fourth section consisted of a 1.2-mm multifilament stainless steel leader (3 strands, 0.65 m long) with a hook in the terminal tackle. A battery flashlight (green color) was attached to the loop connecting the second and third sections of the branch lines. Only one hook type was used, specifically a stainless steel 10° offset J hook (model EC-9/0-R[3], Won Yang Fishing Tackle Co. Ltd., Pusan, Korea) that corresponds with the traditional J hook used by the fishery, whose characteristics are summarized in Figure 2. Only one bait type, squid (*Illex* spp.), was used throughout the experiments. Standardized bait was used in all longline sets (squid 24.5 cm [standard deviation (SD) 1.64]). All characteristics of the fishing gear and fishing practices (e.g., gear section placement, setting time, light color, bait size, and hook) were standardized along the 2 trips. The total number of hooks was constant in each set and was the same for each leader type in every set (504 hooks for each leader type material in each set) and fishing occurred at depths of approximately 20–50 m. Gear deployment began traditionally at 1730 h, and haulback started the next day at about 0600 h. Leader type was alternated section by section along the longline, and each section had 84 hooks that were stored in individual "baskets." This alternating of leader types minimized potential confounding effects specific within each set: for example, location, water temperature, fish density, or other factors. Moreover, the branch line type of the first section was changed every set, according to a fixed scheme (i.e., mono:wire:mono:wire, and so on).

Following Watson et al. (2005), we carried out power tests in order to estimate the experimental fishing effort required to detect a fishing method that has different degrees of effectiveness in catching swordfish and blue shark in comparison with the control fishing method. The control fishing method was assumed to be the combination of gear and bait most commonly used in the fishery, specifically J hooks baited with squid, and the power calculations were based on the necessary number of hooks required to detect a 25% and 50% change in the number of swordfish and blue shark caught. A trained observer from the Instituto Português do Mar e da Atmosfera monitored the experimental trials and collected the data on the vessel. Whenever a specimen was caught in the longline, the observer identified the species, recorded the leader line material, the fate (retained or discarded) of a specimen, condition at haulback (alive or dead) and if discarded (alive or dead) and the type of interaction (i.e., hooking location: *mouth* or *jaw*, when the hook was visible; and hooking mode: *deeply ingested*, hook ingested and located in the throat or gut; *externally hooked* when the hook was located externally). The condition of the leaders (bitten-off or not) was recorded. In the case of marine turtles, when possible, they were netted with a large dip net and, whenever possible, the observer and crew attempted to remove fishing gear with long-handled de-hookers and line cutters. The sex of the specimens, both turtles and fish, was determined and size was measured to the nearest lower 1 cm (lower-jaw fork length for billfishes; fork length [FL] for other fishes; carapace curved length for turtles). However, because of the size or weight of some species (i.e., manta rays [*Manta* spp.]) and to increase their survivorship, some specimens were immediately released by cutting off the line.

In the study area, the fleet is currently using mainly monofilament leaders and hooks baited with squid, therefore we considered that the main target species was swordfish. The catch was assigned to 1 of 5 groupings: billfish, which included swordfish and marlins, the latter of which were considered a bycatch; tuna (*Thunnus* spp.), considered bycatch; sharks, which included all elasmobranchs, considered bycatch; other bony fishes, which were assigned exclusively to bycatch species; and turtles. Finally, all the species that were

[3] Mention of trade names or commercial companies is for identification purposes only and does not imply endorsement by the National Marine Fisheries Service, NOAA.

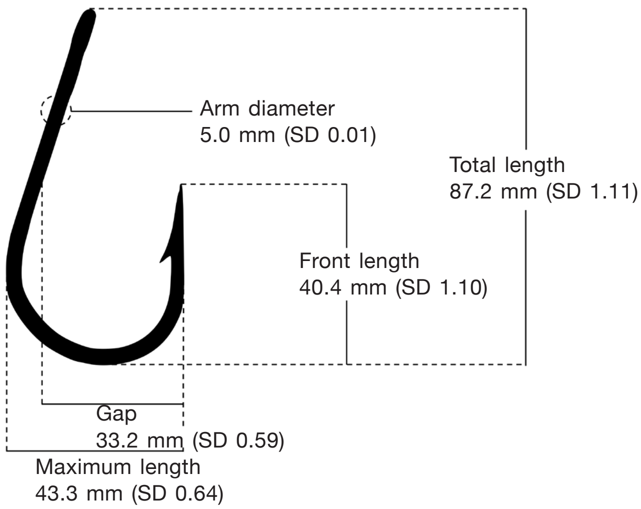

Figure 2

Details of the J hook used in this study on the possible effects of leader material on catches of pelagic longline fisheries in the southwest Indian Ocean. Standard deviations (SDs) are given in parentheses. Hook measurements are shown in the illustration. The offset angle is 10° and refers to the angle of sideways bending of the end of the hook inward in relation to the hook shank.

accidentally caught but not retained were considered discards, consisting mostly of teleost and elasmobranch species with low commercial value or shark species whose retention is currently forbidden by the IOTC, or a combination of both (i.e., bigeye thresher [*Alopias superciliosus*] and oceanic whitetip shark [*Carcharhinus longimanus*]). Other more occasional discards were small specimens of commercial species (e.g., occasional captures of small swordfish) or depredated individuals.

Data analysis

Catch rates were expressed as catch per unit of effort in number of specimens (no. of specimens /1000 hooks ($CPUE_N$). Mortality per unit of effort (MPUE) was also calculated as the number of dead specimens (at haulback) per 1000 hooks (see, for example, Afonso et al., 2012, who used this measure). For the retained species, catch per unit of effort in weight ($CPUE_b$) was also estimated as the weight (in kilograms) per 1000 hooks. Conversion equations were used because the retained catches were processed and frozen onboard and therefore weighing was difficult. For billfishes and tunas, these rates were calculated with the IOTC conversion equations. However, in the case of the remaining species, conversion equations from the Instituto Português do Mar e da Atmosfera (IPMA[4]) were used. The value of the catch per unit of effort (VPUE), measured in euros per 1000 hooks (and given in both U.S. dollars and euros per 1000 hooks), was estimated for the retained species. The reference (price) values used for each species for the VPUE calculations, were those registered for frozen products at the Vigo (Spain) auction in April 2014. The U.S. dollars-to-euro exchange rates were also considered for April 2014. These values were chosen because most European flagged pelagic longliners ship their frozen products to the Vigo market (Amorim et al., 2015).

Kolmogorov–Smirnov tests with Lilliefors correction (Lilliefors, 1969) were used for testing the $CPUE_N$, $CPUE_b$, and MPUE for normality, whereas Levene tests (Levene, 1960) were used for testing the homogeneity of variances. Because of the general lack of normality and homogeneity of variances, the differences between different leader types were tested with randomization tests to determine whether the observed differences between different leader types were significant or whether they were occurring owing to randomness in the sampling (Manly, 2007). For the randomization tests, a Monte Carlo approach was used; the data were randomized and resampled 9999 times to build the expected distribution of the differences under a random distribution and the result was then compared and used to determine the significance of the differences observed in the sample.

For all captured species, the mean length and respective SDs were calculated and for the 2 most abundant species caught (swordfish and blue shark), the size frequency distributions were plotted with histograms. For those 2 species, the mean sizes for the 2 leader types were compared with randomization tests.

The bite-off rates were calculated for each fishing set as the number of missing hooks owing to a cut in the gangion line, per 1000 hooks, within each leader type. The mean and SDs were calculated and plotted, and the differences between leader types were tested with randomization tests.

The relationship between hooking location (mouth or jaw) and hooking mode (deeply ingested, and externally hooked) with leader type material was assessed with plots and with contingency table analysis and chi-square proportion tests. This analysis was performed only for species that numbered >30. In some cases, because of the small sample sizes, particularly for the externally hooked, the analysis was simplified to compare only mouth or jaw and deeply ingested hooking locations.

Generalized linear models with a binomial error distribution and a logit link function were created for determining the influence of changing between the 2 different leader types in the various species or combined taxonomic groups. This was tested both for the catches in number and for the mortalities caused by hooking and was applied only to species or other taxa

[4] IPMA (Instituto Português do Mar e da Atmosfera). 2014. Unpubl. data. Instituto Português do Mar e da Atmosfera, Rua C do Aeroporto, 1749-077 Lisboa, Portugal.

for catches with greater than 30 individuals. The response variable of the models was the proportion of the catches (or dead specimens in the mortality models) in each longline set, calculated as the number of animals (or dead specimens in the mortality models) given the number of hooks used in each set. The odds-ratios of the parameters with their respective 95% confidence intervals (CIs) were calculated and used for interpretation. For this purpose, the monofilament leader was considered the baseline (control) configuration, and the odds-ratios were calculated for changing to the alternative wire (experimental) leader.

Data analysis for this study was carried out with R statistical software, vers. 3.2.0 (R Core Team, 2015). Most analyses were performed with functions available in the core R program. Additional libraries were used for the Levene tests to compare homogeneity of variances (library car; Fox and Weisberg, 2011) and for the permutation tests (library perm; Fay and Shaw, 2010). Plots were built by using ggplot2 (Wickham, 2009), and the map was built by using mapplots (Gerritsen, 2014), shapefiles (Stabler, 2013), and a function for the north arrow created by Tanimura et al. (2007).

Results

Power tests

Overall, a total of 82,656 hooks were used during the experimental fishing sets (82 sets), corresponding to 41,328 hooks of each leader type. According to the conducted power analysis, the number of hooks deployed is larger than that necessary to detect a 50% (5904 hooks) or 25% (23,613 hooks) change in the catch rates (in number) of the blue shark, the most captured shark species in Indian Ocean pelagic longline fisheries. The same was also true for detecting such a change in swordfish catch rates (5088 and 20,346 hooks, respectively).

Catch composition

A total of 33 taxa were caught during this study, specifically 11 species of sharks (2 species belonging to Mobulidae), 6 species of billfish, 3 species of tuna, 12 species of other bony fishes and a single species of marine turtle (Table 1). For the species composition of the catch, the highest number of species was recorded for wire leaders (31 out of the 32), compared with 24 taxa caught with monofilament leaders. For the different groups of species, monofilament leaders in contrast to wire leaders resulted in the catch of an equal number of billfish and tuna species, but a lower number of sharks (7 *vs.* 9) and other bony fishes (8 *vs.* 12, respectively)

A total of 2385 specimens were caught during this study, of which 329 were discarded either because they were noncommercial species, belonged to species whose retention is prohibited by the IOTC, or they were damaged by depredation**.** Among the overall catch there were 1077 billfishes, 845 sharks, 412 other bony fishes, 50 tuna, and a single marine turtle, as summarized in Table 1. A total of 15 taxa were retained in the experiments, the swordfish and blue shark being the most abundant species, representing 50.1% and 37.3% of the retained catches in number, respectively. All the remaining species represented less than 1.5% of the total retained catch in number, the exceptions being 2 other bony species, the dolphinfish (*Coryphaena hippurus*) and the escolar (*Lepidocybium flavobrunneum*), which represented 6.7% and 3.0%, respectively (Table 1). In addition, 18 taxa were systematically discarded, specifically 9 sharks, 8 other bony fishes and a marine turtle, the loggerhead turtle (*Caretta caretta*). Amongst the discarded groups of species, other bony fishes and sharks accounted for 64.7% and 15.8% of the discarded specimens, whereas commercial species such as billfishes (10.3%) and tunas (0.9%) were also discarded owing to predation or the small size of specimens. The most commonly discarded bony fishes were the longnose lancetfish (*Alepisaurus ferox*) and snake mackerel (*Gempylus serpens*), accounting for 28.6% and 26.7% of discards, respectively. In the case of elasmobranchs, the pelagic stingray (*Pteroplatytrygon violacea*) was the most commonly discarded species (7.6%), followed by the 2 shark species prohibited to be fished: the bigeye thresher (3.0%) and the oceanic whitetip shark (2.4%). The frequency of occurrence varied greatly among species, with the swordfish being the most frequently caught species (present in 100% of the sets), followed by the blue shark (91.5%), dolphinfish (37.8%), longnose lancetfish (36.6%), and snake mackerel (29.3%) (see details in Table 1).

Catch rates

The effects of the leader type on the $CPUE_N$ were group and taxon specific. The values of $CPUE_N$ were higher when wire leaders were used for other bony fishes and sharks, as well as for the overall catch (on average 32%, 30% and 13%, with 95% CIs of 8–60%, 13–49% and 5–23%, respectively). At the species level, only $CPUE_N$ for blue sharks showed a significant increase on wire leaders, which was on the order of 31%, with 95% CIs varying between 14% and 52% (Fig. 3). Swordfish and billfishes showed lower $CPUE_N$ on wire leaders, but the detected differences were not significant. The effects of the leader type on the $CPUE_b$ of retained species were again group and taxon specific. However, in the $CPUE_b$, higher catch rates on wire were noted only for the shark group, blue shark in particular and the overall retained catch (on average 53%, 56% and 15%, respectively). In the case of the target species (swordfish), although the wire leaders had a negative effect (decrease of 11%) on the mean $CPUE_b$, this effect was not statistically significant (Tables 1 and 2).

In terms of the VPUE, no significant differences were detected in changes from monofilament to wire leaders (permutation test: difference in means= −$44.99 (−€32.62), P=0.874) because the decrease of swordfish

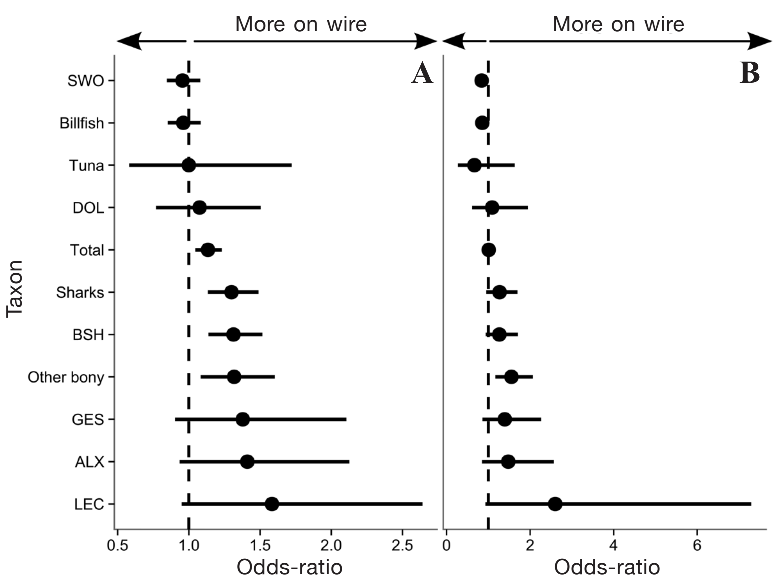

Figure 3

Odds-ratios of the (**A**) catch rates in number and (**B**) hooking mortality for the change from the leader material from monofilament to wire for species and species groups caught during longline sets conducted during November 2013–March 2014 in the southwest Indian Ocean. Food and Agriculture Organization of the United Nations species codes are used: SWO=swordfish (*Xiphias gladius*); DOL=dolphinfish (*Coryphaena hippurus*); BSH=blue shark (*Prionace glauca*); GES=snake mackerel (*Gempylus serpens*); ALX=longnose lancetfish (*Alepisaurus ferox*); and LEC=escolar (*Lepidocybium flavobrunneum*). The models and odds-ratios were calculated only for species or combined taxa with 30 or more individuals. The error bars indicate the 95% confidence intervals of the odds-ratios. The vertical dashed line indicates the reference of the odds-ratios (1=no change). The top arrow represents the increase in the odds-ratios when changing from 2.5-mm monofilament nylon to 1.2-mm multifilament stainless wire leaders.

catch rates was compensated by the increase of blue shark retention (Table 1).

The mean bite-off rates for wire and monofilament leaders were 1.38/1000 hooks and 5.37/1000 hooks, respectively. These differences were found to be significant (permutation test: difference in means=3.99, $P<0.001$). Regarding hooking location, most shark species were deeply hooked (58% overall, 60% for the blue shark and 50% for the shortfin mako (*Isurus oxyrinchus*), respectively). The pelagic stingray was an exception, where specimens were mostly hooked by the mouth or jaw (83%). In contrast, most tunas and billfish species were retained, having been hooked in the mouth, except for the swordfish, which was predominantly deeply hooked (85%, and 12% and 2% were retained, having been hooked in the mouth and externally, respectively). No differences were detected when comparing hooking location between the 2 different types of leader material, for the main species, the swordfish (contingency table analysis: $P>0.05$ for all cases; Fig. 4)

Mortality rates

The effects of the leader type in terms of mortality rates (in number) at haulback varied among the different species groups and taxa. The mortality models detected significantly less mortality from hooking for the swordfish when wire leaders were used, showing a 16% decrease in the mortalities (95% CI varying between 2% and 28%) and also for the billfishes group with a 15% decrease in the mortalities (95% CI varying between 1% and 26%). In contrast, for the other bony fishes there was an increase in hooking mortality of 55% when wire leaders were used (95% CI varying between 17% and 100%). For the blue shark the hooking mortality also increased when wire leaders were used (26% in the point estimate) but this increase was not statistically significant because the 95% CIs varied between a decrease of 6.5% and an increase of 71% with the use of wire. The same was observed for the shark group combined; the point estimate showed a decrease in hooking mortality of 27% when wire leaders were used, but the 95% CI varied between a decrease of 5% and an increase of 70%, indicating that the effects were not statistically significant (Tables 1 and 2, Fig. 3).

Size distribution of retained species

Statistics of the size structure of the species caught on the different leader materials tested during this study are summarized in Table 3. For most species caught, there were no major differences in size range and mean size for the different leader types tested (Table 3). However, for the blue shark, a wider size range was recorded and significant differences in the mean size were detected, and slightly larger sizes were captured with wire leaders (mean size: 198.2 cm FL [SD 38.15] vs. than with monofilament leaders (mean size 190.6 cm FL [SD 35.32]). For swordfish, very similar size ranges were observed and no significant differences were detected in the mean size captured for the 2 leader materials (Fig. 5, Table 3).

Discussion

The results from this study show that leader material had an effect on the catch composition of a longline fishery and that wire leaders caught more species. This result contrasts with those reported by Ward et al.

Table 1

Means and standard deviations (SDs) for catch in number ($CPUE_N$) and weight ($CPUE_b$) per unit of effort (per 1000 hooks), mortality (MPUE) per unit of effort (1000 hooks) by species and species groups caught by using 2 different leader materials, 2.5-mm monofilament nylon and 1.2-mm multifilament stainless wire, during experimental longline sets conducted in the southwest Indian Ocean between November 2013 and March 2014. Other values given are number of specimens caught (no.); frequency of occurrence (FO), measured as a percentage; discards (Disc), measured as a percentage; dead discards (DD), measured as a percentage; and the value per unit of effort (per 1000 hooks) of the retained catch (VPUE), given in U.S. dollars ($) and euros (€).

		Monofilament									Wire								
Group and Species	No.	FO	Disc	DD	$CPUE_N$	SD	MPUE	SD	$CPUE_b$	SD	FO	Disc	DD	$CPUE_N$	SD	MPUE	SD	$CPUE_b$	SD
Billfish																			
Istiompax indica	2	1.2	0.0	0.0	0.0	0.2	0.0	0.2	2.7	24.8	1.2	0.0	0.0	0.0	0.2	0.0	0.0	3.0	27.6
Makaira nigricans	7	4.9	0.0	0.0	0.1	0.4	0.0	0.2	16.8	75.2	3.7	0.0	0.0	0.1	0.4	0.0	0.3	9.9	51.5
Kajikia audax	22	12.2	7.7	7.7	0.3	1.0	0.2	0.7	10.6	31.0	9.8	22.2	22.2	0.2	0.7	0.1	0.4	5.8	21.9
Istiophorus platypterus	7	2.4	0.0	0.0	0.0	0.3	0.0	0.0	2.1	13.7	6.1	0.0	0.0	0.1	0.5	0.1	0.4	5.0	20.2
Tetrapturus angustirostris	8	2.4	0.0	0.0	0.0	0.3	0.0	0.2	6.9	44.0	7.3	16.7	16.7	0.1	0.5	0.1	0.5	15.8	63.2
Xiphias gladius	1031	100.0	2.7	1.9	12.8	6.1	9.1	5.3	648.5	357.6	98.8	3.2	3.0	12.2	6.2	7.7	4.2	583.2	348.5
Total billfish	1077				13.3	6.2	9.4	5.3	687.6	372.2	–	–	–	12.8	6.4	8.0	4.4	622.8	373.9
Tuna																			
Thunnus alalunga	9	6.1	0.0	0.0	0.2	0.8	0.1	0.4	4.0	18.4	2.4	0.0	0.0	0.1	0.4	0.0	0.2	1.5	7.6
Thunnus obesus	22	8.5	14.3	14.3	0.2	0.6	0.1	0.4	6.7	29.9	15.9	6.7	6.7	0.4	0.9	0.1	0.5	15.6	42.2
Thunnus albacares	19	12.2	9.1	9.1	0.3	0.7	0.1	0.4	13.1	44.9	8.5	0.0	0.0	0.2	0.7	0.0	0.4	12.5	43.5
Total tuna	50				0.6	1.3	0.3	0.8	23.9	61.9	–	–	–	0.6	1.2	0.2	0.7	29.5	66.8
Other bony fishes																			
Alepisaurus brevirostris	6	3.7	100.0	33.3	0.1	0.4	0.0	0.2	–	–	3.7	100.0	100.0	0.1	0.4	0.1	0.4	–	–
Alepisaurus ferox	94	36.6	100.0	64.1	0.9	1.4	0.5	1.0	–	–	46.3	100.0	61.8	1.3	1.8	0.8	1.5	–	–
Sphyraena spp.	5	–	–	–	–	–	–	–	–	–	4.9	100.0	100.0	0.1	0.6	0.1	0.4	–	–
Centrolophidae	1	–	–	–	–	–	–	–	–	–	1.2	100.0	100.0	0.0	0.2	0.0	0.2	–	–
Coryphaena hippurus	137	37.8	4.5	4.5	1.6	2.9	0.5	1.4	12.5	24.4	39.0	9.9	9.9	1.7	3.1	0.6	1.5	10.9	21.2
Gempylus serpens	88	29.3	100.0	89.2	0.9	1.7	0.7	1.4	–	–	39.0	100.0	82.4	1.2	2.2	0.9	2.0	–	–
Lampris guttatus	1	–	–	–	–	–	–	–	–	–	1.2	100.0	100.0	0.0	0.2	0.0	0.2	–	–
Lepidocybium flavobrunneum	62	20.7	0.0	0.0	0.6	1.3	0.1	0.5	7.3	18.9	36.6	10.5	7.9	0.9	1.4	0.3	0.7	9.5	17.6
Mola spp.	3	2.4	100.0	0.0	0.0	0.3	0.0	0.0	–	–	1.2	100.0	0.0	0.0	0.2	0.0	0.0	–	–
Ruvettus pretiosus	6	4.9	50.0	25.0	0.1	0.4	0.0	0.0	0.1	0.4	2.4	100.0	100.0	0.0	0.3	0.0	0.2	–	–
Regalecidae	1	–	–	–	–	–	–	–	–	–	1.2	100.0	100.0	0.0	0.2	0.0	0.0	–	–
Acanthocybium solandri	7	2.4	50.0	50.0	0.0	0.3	0.0	0.2	0.2	2.0	6.1	40.0	40.0	0.1	0.5	0.1	0.4	0.4	2.1
Total other bony fishes	412	–	–	–	4.3	3.6	1.9	2.5	20.1	28.6	–	–	–	5.7	4.8	2.9	3.6	20.7	26.6
Sharks																			
Prionace glauca	767	91.5	4.2	0.3	8.0	6.3	1.8	2.7	416.6	305.9	96.3	0.5	0.2	10.5	7.9	2.3	3.0	650.1	474.4
Alopias superciliosus	10	8.5	100.0	55.6	0.2	0.8	0.1	0.5	–	–	1.2	100.0	100.0	0.0	0.2	0.0	0.2	–	–
Manta sp.	1	–	–	–	–	–	–	–	–	–	1.2	100.0	0.0	0.0	0.2	0.0	0.0	–	–
Carcharhinus longimanus	8	1.2	100.0	0.0	0.0	0.2	0.0	0.0	–	–	8.5	100.0	28.6	0.2	0.6	0.0	0.3	–	–
Pteroplatytrygon violacea	25	11.0	100.0	0.0	0.3	0.9	0.0	0.0	–	–	14.6	100.0	0.0	0.3	0.8	0.0	0.0	–	–
Lamna nasus	2	–	–	–	–	–	–	–	–	–	2.4	100.0	0.0	0.0	0.3	0.0	0.0	–	–
Pseudocarcharias kamoharai	1	–	–	–	–	–	–	–	–	–	1.2	100.0	0.0	0.0	0.2	0.0	0.0	–	–
Mobula sp.	1	1.2	16.7	0.0	0.0	0.2	0.0	0.0	–	–	–	–	–	–	–	–	–	–	–
Isurus oxyrinchus	26	14.6	16.7	0.0	0.3	0.7	0.0	0.2	23.6	66.5	15.9	0.0	0.0	0.3	0.8	0.0	0.3	25.4	68.5
Sphyrna sp.	1	1.2	100.0	0.0	0.0	0.2	0.0	0.0	–	–	–	–	–	–	–	–	–	–	–
Sphyrna zygaena	3	–	–	–	–	–	–	–	–	–	3.7	100.0	100.0	0.1	0.4	0.1	0.4	–	–
Total sharks	845	–	–	–	8.9	6.5	2.0	2.8	440.1	323.3	–	–	–	11.5	8.0	2.5	3.3	675.5	475.6
Turtles																			
Caretta caretta	1	–	–	–	–	–	–	–	–	–	1.2	100.0	0.0	0.0	0.2	0.0	0.0	–	–
Total turtles	1	–	–	–	–	–	–	–	–	–		–	–	0.0	0.2	0.0	0.0	–	–
Total overall	2385	–	–	–	27.1	9.6	13.6	6.5	1167.7	525.9	–	–	–	30.6	10.8	13.7	6.7	1347.1	588.7
VPUE of retained catch		$3869.9 (SD 1870.3) (€2805.5 [SD 1355.9])									$3902.9 (SD 1803.2) (€2829.4 [SD 1307.2])								

Table 2

Results of the permutation (perm) tests for statistical comparison between catch in number ($CPUE_N$) and weight ($CPUE_b$) per unit of effort (per 1000 hooks) and mortality (MPUE) per unit of effort (per 1000 hooks) by species and species groups caught by 2 different leader materials, 2.5-mm monofilament nylon and 1.2-mm multifilament stainless wire, during experimental longline sets conducted in the southwest Indian Ocean between November 2013 and March 2014.

	$CPUE_N$		MPUE		$CPUE_b$	
Group and species	Perm test	*P*	Perm test	*P*	Perm test	*P*
Billfish						
Istiompax indica	0.00	1.00	0.02	1.00	–0.31	1.00
Makaira nigricans	0.02	1.00	–0.02	0.99	6.87	0.48
Kajikia audax	0.10	0.58	0.10	0.46	4.85	0.24
Istiophorus platypterus	–0.07	0.44	–0.10	0.12	–2.88	0.32
Tetrapturus angustirostris	–0.10	0.29	–0.10	0.22	–8.94	0.36
Xiphias gladius	0.56	0.57	1.45	0.05	65.26	0.24
Total billfish	0.51	0.62	1.36	0.08	64.85	0.27
Tuna						
Thunnus alalunga	0.12	0.35	0.07	0.37	2.57	0.25
Thunnus obesus	–0.19	0.15	–0.02	1.00	–8.90	0.13
Thunnus albacares	0.07	0.66	0.05	0.73	0.69	0.90
Total tuna	0.00	1.00	0.10	0.51	–5.64	0.59
Other bony fishes						
Alepisaurus brevirostris	0.00	1.00	–0.05	0.62	–	–
Alepisaurus ferox	–0.39	0.13	–0.24	0.27	–	–
Sphyraena spp	–0.12	0.12	–0.10	0.12	–	–
Centrolophidae	–0.02	1.00	–0.02	1.00	–	–
Coryphaena hippurus	–0.12	0.79	–0.05	0.86	1.60	0.65
Gempylus serpens	–0.34	0.30	–0.27	0.35	–	–
Lampris guttatus	–0.02	0.99	–0.02	0.99	–	–
Lepidocybium flavobrunneum	–0.34	0.15	–0.19	0.08	–2.18	0.45
Mola spp.	0.02	1.00	–	–	–	–
Ruvettus pretiosus	0.05	0.68	–0.02	1.00	–	–
Regalecidae	–0.02	1.00	–	–	–	–
Acanthocybium solandri	–0.07	0.44	–0.07	0.36	–0.14	0.75
Total other bony fishes	–1.36	0.04	–1.04	0.03	–0.65	0.88
Sharks						
Prionace glauca	–2.49	0.03	–0.48	0.28	–233.52	0.00
Alopias superciliosus	0.19	0.05	0.10	0.21	–	–
Manta sp.	–0.02	0.99	–	–	–	–
Carcharhinus longimanus	–0.15	0.07	–0.05	0.50	–	–
Pteroplatytrygon violacea	–0.02	1.00	–	–	–	–
Lamna nasus	–0.05	0.51	–	–	–	–
Pseudocarcharias kamoharai	–0.02	1.00	–	–	–	–
Mobula sp.	0.02	0.99	–	–	–	–
Isurus oxyrinchus	–0.05	0.82	–0.02	1.00	–1.84	0.85
Sphyrna sp.	0.02	1.00	–	–	–	–
Sphyrna zygaena	–0.07	0.23	–0.07	0.23	–	–
Total sharks	–2.64	0.02	–0.53	0.27	–235.37	0.00
Turtles						
Caretta caretta	–0.02	0.99	–	–	–	–
Total turtles	–0.02	0.99	–	–	–	–
Total overall	–3.53	0.03	–0.12	0.92	–179.38	0.04

(2008), who found the same number of species caught with both leader types, and those observed by Vega and Licandeo (2009), who found that monofilament gear caught more species. Theoretically, monofilament nylon leaders may be more difficult than wire leaders of the same diameter to be visually detected, but are also more easily severed than wire leaders. One possible reason for the different results may be related to differences in availability of species in the study areas, as well as their relative ability to bite through a leader. However, it should also be noted that other gear characteristics, such as hook style and size can also influ-

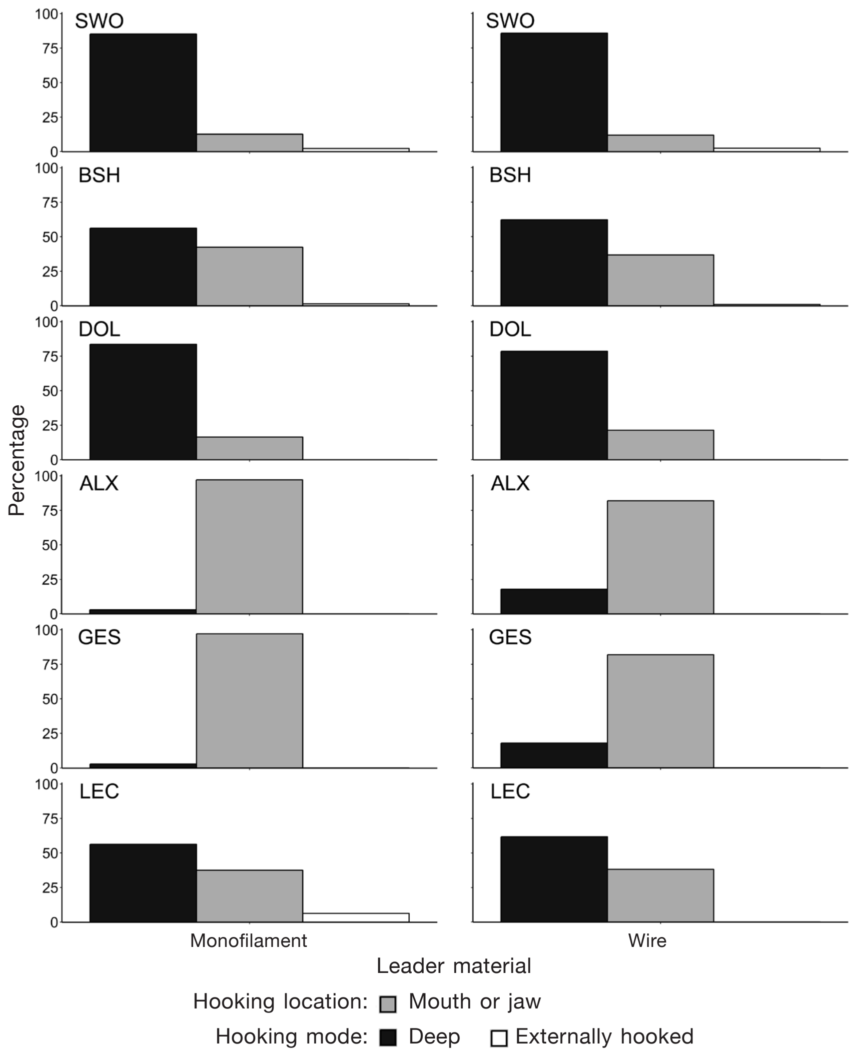

Figure 4

Hooking location by leader material for the main species (no. >30) captured in 2013–2014 in the southwest Indian Ocean. Food and Agriculture Organization of the United Nations species codes are used: SWO=swordfish (*Xiphias gladius*); BSH=blue shark (*Prionace glauca*); DOL=dolphinfish (*Coryphaena hippurus*); ALX=longnose lancetfish (*Alepisaurus ferox*); GES=snake mackerel (*Gempylus serpens*); and LEC=escolar (*Lepidocybium flavobrunneum*). The bars refer to the percentage of each hooking location for each leader material: 2.5-mm monofilament nylon and 1.2-mm multifilament stainless wire.

ence the catch and could contribute to the differences between studies. Specifically, Vega and Licandeo (2009) used J hooks similar to those used in our study and as such the results are more directly comparable, whereas Ward et al. (2008) used Japanese tuna hooks with 10° offset. Another factor causing differing results may be related to the bait. Vega and Licandeo (2009) used a mix of squid and mackerel as bait on sets with nylon leaders and just mackerel on sets with wire leaders, whereas we used squid bait exclusively, which is the most commonly used bait in this fishery for targeting swordfish. Finally, it should also be noted that there was a difference in effort in terms of the number of sets conducted in each study, specifically 82 sets in our study, 37 sets in Vega and Licandeo (2009) and 177 sets in Ward et al. (2008).

Leader type also had a significant effect in terms of relative catchability in both number and weight for some of the species or species groups (or combination of both) in this pelagic longline fishery. The use of monofilament leaders trended toward higher catch rates of swordfish (although not statistically significant) and

Table 3

Statistics of the size structure of the species caught during longline sets conducted in the southwest Indian Ocean between November 2013 and March 2014 and results of the permutation (perm) tests for statistical comparison of mean sizes (in cm) for the 2 leader materials tested, 2.5-mm monofilament nylon and 1.2-mm multifilament stainless wire. Also provided are the number of specimens measured (no.) as well as the range and mean, with standard deviation (SD), of the sizes in the catch for each species or species group. Size measurements refer to the length (in centimeters): lower-jaw fork length for billfishes, fork length for all other fishes, and total carapace curve length for marine turtles.

	Monofilament				Wire					
Group and species	No.	Range	Mean	SD	No.	Range	Mean	SD	Perm test	*P*
Billfish										
Istiompax indica	1	227–227	227.0	0.0	1	235–235	235.0	0.0	–	–
Makaira nigricans	4	245–277	264.5	13.9	3	236–258	245.7	11.2	18.83	0.11
Kajikia audax	13	175–228	194.2	18.4	8	175–217	192.3	13.9	1.90	0.83
Istiophorus platypterus	2	210–211	210.5	0.7	5	184–219	205.6	13.4	–	–
Tetrapturus angustirostris	2	155–165	160.0	7.1	6	146–163	155.3	7.2	–	–
Xiphias gladius	519	64–249	151.9	30.6	499	67–251	149.9	29.3	2.00	0.28
Tuna										
Thunnus alalunga	7	98–109	103.3	3.7	3	98–102	100.0	2.0	3.29	0.25
Thunnus obesus	6	76–162	121.3	38.2	14	76–164	127.2	22.9	–5.88	0.67
Thunnus albacares	11	80–165	137.8	22.6	8	132–172	148.5	15.7	–10.68	0.29
Other bony fishes										
Alepisaurus brevirostris	3	68–92	77.3	12.9	3	64–100	81.3	18.0	–4.00	0.78
Alepisaurus ferox	37	71–139	102.3	18.2	54	45–152	102.5	23.5	–0.24	0.97
Sphyraena spp	–	–	–	–	4	94–132	118.8	17.7	–	–
Centrolophidae	–	–	–	–	1	76–76	76.0	0.0	–	–
Coryphaena hippurus	66	67–130	101.7	13.5	71	65–121	96.9	12.4	4.77	0.03
Gempylus serpens	37	78–155	105.9	15.0	51	77–149	107.6	14.1	–1.78	0.58
Lampris guttatus	–	–	–	–	1	106–106	106.0	0.0	–	–
Lepidocybium flavobrunneum	24	64–132	104.1	17.5	36	51–136	97.6	21.7	6.49	0.23
Ruvettus pretiosus	4	49–60	55.5	4.8	2	54–55	54.5	0.7	–	–
Regalecidae	–	–	–	–	1	171–1	171.0	0.0	–	–
Acanthocybium solandri	1	141–141	141.0	0.0	5	100–140	119.2	17.3	–	–
Sharks										
Prionace glauca	318	127–281	190.6	35.3	433	108–279	198.2	38.1	–7.64	0.00
Alopias superciliosus	5	115–192	171.0	31.6	1	162–162	162.0	0.0	–	–
Carcharhinus longimanus	–	–	–	–	3	88–148	108.3	34.4	–	–
Lamna nasus	–	–	–	–	1	247–247	247.0	0.0	–	–
Pseudocarcharias kamoharai	–	–	–	–	1	88–88	88.0	0.0	–	–
Isurus oxyrinchus	10	152–228	204.3	23.1	14	138–227	186.4	26.9	17.87	0.10
Sphyrna zygaena	–	–	–	–	3	169–179	173.3	5.1	–	–
Turtles										
Caretta caretta	–	–	–	–	1	65–65	65.0	0.00	–	–

lower catch rates of sharks, particularly blue shark. Other authors have reported similar results in the Atlantic (Afonso et al., 2012) and Pacific oceans (Ward et al., 2008; Vega and Licandeo, 2009). However, earlier studies in the Atlantic Ocean, by Branstetter and Musick (1993) and Stone and Dixon (2001), showed the opposite result for the blue shark. Differences in the length of wire leaders, diameter of monofilament leaders and target species may account for the differences in catches rates among studies. For example, in the Stone and Dixon (2001) study the lower section (leader) of both gangion types was monofilament nylon and the upper section varied between tarred and no-tarred nylon material. Additionally, in our study the wire leaders were 2 to 3 times longer than those used in earlier studies and this change could have contributed to some of the observed differences.

As with our study, other authors have also reported similar trends in rates of bite-offs and that most of these events occurred when the use of nylon leaders (e.g., Ward et al., 2008; Afonso et al., 2012). However, the level of bite-off rates varies considerably between the fishing grounds and fisheries. We found rates similar to those reported by Afonso et al. (2012) for a Brazilian swordfish fishery in the Atlantic Ocean (about 30% of shark catches), but much lower rates (by one order of magnitude) than those reported by observers on a tuna longline off northeastern Australia (Ward et al., 2008). Among the captured species, sharks are most likely to be responsible for the majority of bite-

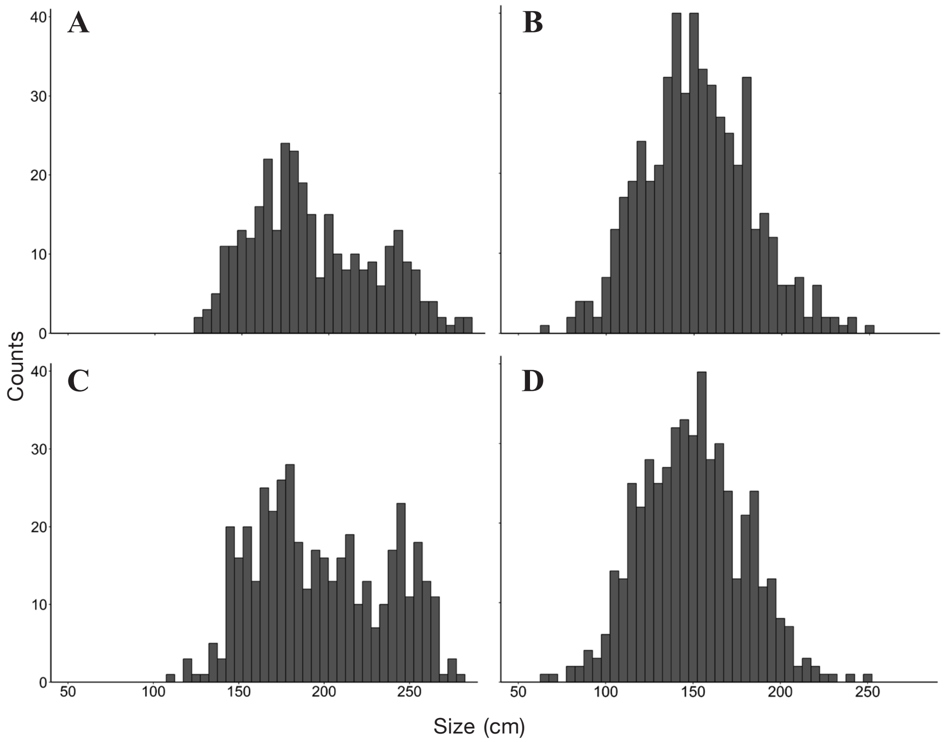

Figure 5

Size distributions for the 2 major species caught during 2013–2014 in the southwest Indian Ocean. (**A**) blue shark (*Prionace glauca*) caught with 2.5-mm monofilament nylon: (**B**) swordfish (*Xiphias gladius*) caught with 2.5-mm monofilament nylon; (**C**) blue shark (*Prionace glauca*) caught with 1.2-mm multifilament stainless wire; (**D**) swordfish (*Xiphias gladius*) caught with 1.2-mm multifilament stainless wire. Size measurements are given in centimeters: lower-jaw fork length for swordfish and fork length for blue shark.

offs because these bite-offs were more frequent on sets with the highest shark catch rates. Moreover, several shark bite-offs were observed during the fishing experiments by the fishery observers. However, other species that also have sharp teeth, such as the snake mackerel or the dolphinfish, could also escape the longline by severing the leaders. Other important aspects related to bite-off rates are the hook styles used and hooking location**.** Circle hooks primarily embed in the corner of the jaw (Prince et al., 2002; Skomal et al., 2002) and J hooks are more likely to be swallowed, causing deep hooking in the throat or gut. Deep hooking, which was the most common retention mode recorded in our study with the J hook, can result in leaders becoming more exposed to abrasion against teeth.

Very few authors have discussed the effects of gear material on mortality at haulback. As in our study, Afonso et al. (2012) also did not find significant differences when comparing shark MPUE between leader types, although the mortalities were slightly higher when using wire leaders. On the other hand, we recorded higher swordfish MPUE on wire. We cannot explain such a result, particularly as the mean $CPUE_N$ and $CPUE_b$ were similar for both leader materials. In addition, the size selectivity of gear material has been poorly studied. Although it would appear that leader material has no effect on size selectivity for most species, in the case of blue shark, a wider size range and a larger mean size were observed with the use of wire leaders, which reinforces the previously reported observation (Afonso et al., 2012) that wire leaders retain the more resilient and larger blue shark specimens.

Although a relatively small number of specimens of other shark species were caught during our experiment, the dead *versus* alive ratios (mortality at haulback) observed were consistent with those reported by Coelho et al. (2012b) for a similar fishery in the Atlantic Ocean. The exception was the shortfin mako, which in this case showed a much lower mortality ratio at haulback (7–15%). Coelho et al (2012b) reported a relationship between hooking mortality and specimen size for the shortfin mako in the Atlantic Ocean, with larger specimens having a lower probability of being dead at haulback. Because the size distribution in this region of the Indian Ocean tends to be composed of larger specimens than those in the Atlantic Ocean, as reported by the Coelho et al. (2012b) study (Atlantic Ocean: mean size=168.8 cm FL [SD 35.4], range=66–305 cm FL; Indian Ocean: mean size=193.9 cm FL [SD 24.6], range=138–228 cm FL), such differences could be a reason for the lower hooking mortality of the shortfin mako in the Indian Ocean.

According to our results, there was not a significant difference in the VPUE, but it should be noted that our estimates were based on the average market price for a single month. A range of prices would, perhaps, better reflect market fluctuations. On the other hand, current perceptions of fishermen are that changing the bait from the more expensive squid to cheaper mackerel, is worthwhile in areas or seasons of high shark abundance (representing over 50% of the retained catch), as reported by Amorim et al. (2015) in a similar fishery in the southern Atlantic Ocean. Therefore, a thorough assessment (including the cost of replacing and repairing damaged gear) of the economic impact of banning wire leaders will be required if fisheries managers wish to consider such a measure to reduce unwanted bycatch in longline fisheries.

The interaction of bycatch species with longlining gear raises a number of other concerns, namely their postrelease mortality (Gilman et al., 2008). Moyes et al. (2006), using a scientific crew, investigated postrelease survival of blue shark in longline fisheries in the Pacific Ocean, whereas Campana et al. (2009) conducted a similar experiment in the Atlantic Ocean but on commercial vessels. These authors used pop-up satellite archival tags that recorded postrelease survival rates of blue shark of 100% (Moyes et al.) and 81%, (Campana et al.); the differences were attributed to the different study design, gear configuration (e.g., hook style and size, quantity of hooks and soaking time) and handling practices by the scientific crew in Moyes et al. (2006). It is known that the blue shark is a hardy shark species, and individuals are often recovered with one or more hooks in their bodies or mouth from previous captures (senior author, personal observ.). However, it is not common to find reports of protected shark species or small sharks (or both), or commonly discarded bony fishes, with hooks embedded in their jaws from past interactions with longline gear. Therefore, we may assume that postrelease mortality rates are likely higher for those species. Campana et al. (2015) showed that porbeagles (*Lamna nasus*) and shortfin makos experienced much greater mortality than blue sharks in the Canadian pelagic longline fishery, and about one-half of the hooked porbeagles and shortfin makos died during or after fishing owing to hooking or postrelease mortality. Additionally, we should note that Campana et al. (2015) used mainly circle hooks, whereas in our study we used J hooks that can affect the hooking location (mouth or jaw *vs.* deeply hooked) and consequently on the injuries of the discarded specimens. Apart from high mortality at haulback for many shark species (Coelho et al., 2012b), we also found high mortality rates at haulback with the use of nylon monofilament and wire leaders for commonly discarded species such as the longnose lancetfish (60% and 61%), and the snake mackerel (88% and 81%, respectively),

The results of our work support banning wire leaders as an effective way of reducing shark bycatch in general, of lowering the number of sharks landed and, consequently, is an effective way of decreasing shark mortality in a fishery where the blue shark and the shortfin mako are currently the only shark species retained. At least some sharks are able to escape and survive by severing the nylon leaders, although their fate (delayed mortality) is still poorly known. The introduction of wire leaders in the southwest Indian Ocean swordfish longline fishery was a consequence of lower catch rates of the target species and a response to the increase in exploitation costs, with the objective of increasing the revenues of fishermen. Fishery managers considering the banning of wire leaders in this swordfish fishery need to balance the potential beneficial effects on shark populations (particularly blue shark and shortfin mako) with the potential adverse effects on other species (particularly swordfish, as catches could increase). A reduction in the current catch levels of sharks should have a positive impact on the stocks, even though the current status of the shark stocks is unknown. According to the IOTC[2], in the case of blue sharks, maintaining or increasing fishing effort will result in further declines in biomass, productivity, and catch rates in a stock whose current status is unknown but where the possibility of overfishing cannot be ruled out. For the swordfish, the most recent maximum sustainable yield (MSY)-based reference points are uncertain for the Indian Ocean population as a whole, whereas the resource in the southwest Indian Ocean is overfished (IOTC[2]). Therefore an increase in effort or catch rates (or both) on swordfish target fisheries may exacerbate the problem because local depletion has been observed in the past decade and biomass still remains below the level that would produce MSY. Additionally, the human dimension (i.e., socioeconomics) should also be considered, because both species (i.e., swordfish and blue shark) are important to fishermen and represent over 90% of the overall retained catch. A combination of management measures (e.g., spatial or seasonal protection of critical habitats and good practices in handling specimens to be released) may represent a more appropriate solution to efficiently mitigate the incidental bycatch and mortality of species (namely sharks) captured in pelagic longline fisheries.

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