# DEPREDATION IN THE PORTUGUESE PELAGIC LONGLINE FLEET IN THE INDIAN OCEAN

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*SUMMARY*

*Depredation has aroused great interest over the last few decades due to the expansion of distant fishing, in particular pelagic and bottom longlines. As part of the monitoring of the Portuguese pelagic longline fleet, catches and depredation records were taken by scientific observers on board commercial vessels from Portugal. Data were compiled and analyzed for the periods 2011-2015 in the southern area of the Indian Ocean. A total of 445 fishing sets were monitored in the period, with a total of 26,366 fish catches, including 778 depredation events. The percentage of depredation increasing yearly along the time series. The two main predated species were swordfish and escolar, with significant differences in prey size for swordfish, but not for escolar. However, the highest proportions of depredation were observed on tuna and small pelagic fishes. For swordfish specimens, the effects of spatial variables (latitude and longitude) were significant on the rate of depredation events. The results presented in this study provide a first overview of the depredation patterns in the Portuguese pelagic longline fishery in the Indian Ocean that can help to promote more informed management and conservation measures.*

*KEYWORDS: Depredation, longline fisheries, swordfish, sharks, Portuguese fleet, Indian Ocean.*

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## 1. Introduction

Depredation has aroused increasing interest over the last few decades due to the expansion of distant fisheries, in particular pelagic longlines. Depredation is usually defined as *'the partial or complete removal of hooked fish or bait from fishing gear... by predators likes cetaceans, sharks, bone fish, birds, squids, crustaceans and others*' distinguishing it from predation, i.e. *'the taking of free swimming fish (or others organism)* ...' (Donoghue *et al*., 2003; Gilman *et al*., 2007; Romanov *et al.*, 2013). The complete and partial removal of the catch and bite off of the gear leads to significant financial loss to the fishermen (Nishida and Shiba, 2005; Rabearisoa *et al.*, 2012; Kumar *et al*., 2016)

Depredation events have been documented largely in the tropical Indian Ocean. However, detailed information collected systematically is still rare for the area. Therefore, there is a real need for the development of specific indicators to assess the degree of depredation, which remains a poorly understood phenomenon, especially in poorly studied areas of the Indian Ocean (Mutombene, 2015; Rabearisoa *et al.*, 2015b).

Several depredation mitigation measures have been or are being tested worldwide to mitigate this issue, including physical protection of the catch or acoustic devices, but this remains a challenging work (Tixier *et al*., 2010; Løkkeborg, 2011; Hamer *et al*., 2012; O’Connell *et al.*, 2015; Rabearisoa *et al.*, 2015; Straley *et a*l., 2015; Tixier *et al*., 2014; Werner *et al.*, 2015)

The main objective of this paper is to provide a first overview on the depredation in the Portuguese pelagic longline fishery in the Indian Ocean. The specific objectives are to 1) analyze depredation event related to total catches, 2) evaluate species-specific depredation events, and 3) provide information on the predators.

## 2. Material and methods

### *2.1. Data collection*

Depredation records were taken by scientific observers on board Portuguese commercial pelagic longline vessels. Data were compiled for the period between 2011-2015. Data were collected in the southern Indian Ocean, mostly in the SW region, between 23ºS to 34ºS and 36ºE to 96ºE.

For analysis purposes, the Indian Ocean region was separated into 2 areas, specifically west and east. For the purposes of this analysis, the east-west separation was made at 80ºE based on the FAO separation between areas 51 and 57.

Data on specimen size (fork length, FL), location, depredation episodes and date was recorded. In some cases the observer recorded the suspected predator or predators species responsible for depredation, based on fish damage (e.g., bite shape) and predator-prey interactions during gear hauling.

### *2.2. Data analysis*

Catch data was tested for normality with Shapiro-Wilk normality tests (Shapiro and Wilk, 1965) and for homogeneity of variances with Levene tests (Levene, 1960). The annual trends of total and depredated catches were plotted and analyzed, as well as, the proportions of depredated catches by species. The overall catch-at-size was compared with the depredated catch-at-size for the most depredated species, specifically *Xiphias gladius* (swordfish - SWO) and *Lepidocybium flavobrunneum* (escolar – LEC).

A binomial GAM model with logit link function was created to determine the effects of spatial variables (latitude and longitude) on the depredation rates of swordfish. The response variable was the swordfish catches, with each specimen coded as: 1=depredation event occurred and 0=depredation event did not occur. The model also accounted for the year effect, as a fixed categorical factor. Other variables, such as SST were also tested in the model, but were not used due to collinearity with the spatial effects, particularly with latitude.

The analysis for this paper was carried out using the R language for statistical computing version 3.3.1. (R Core Team, 2016). Additional packages that were used included “car” (Fox and Weisberg, 2011), “descr” (Aquino *et al.*, 2016), “ggmap” (Kahle and Wickham, 2013), “ggplot2” (Wickham, 2009), “lattice” (Sarkar, 2008), “mgcv” (Wood, 2011), “nortest” (Gross and Ligges, 2015), “perm” (Fay and Shaw, 2010), “plyr” (Wickham, 2011), “Rmisc” (Hope, 2013).

## 3. Results

### *3.1. Spatial distribution of catches and depredation events*

A total of 26,366 catches were recorded and considered within the scope of this study. The sample covered a wide geographical area of the south Indian Ocean, with most sets taking place in the SW region (**Figure 1**).

The total number of depredated catches were 778, representing about 3% of the total catch. These depredations events occurred in 334 of the 445 sets during the study period and area, representing depredation occurrences in 75% of total sets (**Figure 2**).

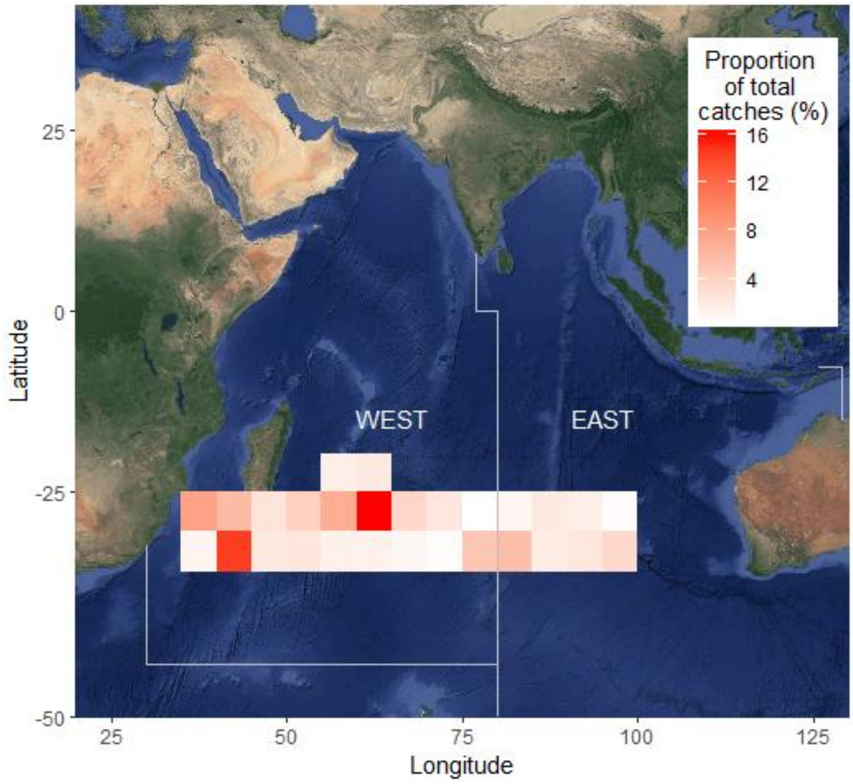


**Figure 1**. Distribution in 5*5 degrees of total catches recorded for this study in the Indian Ocean (2011-2015).

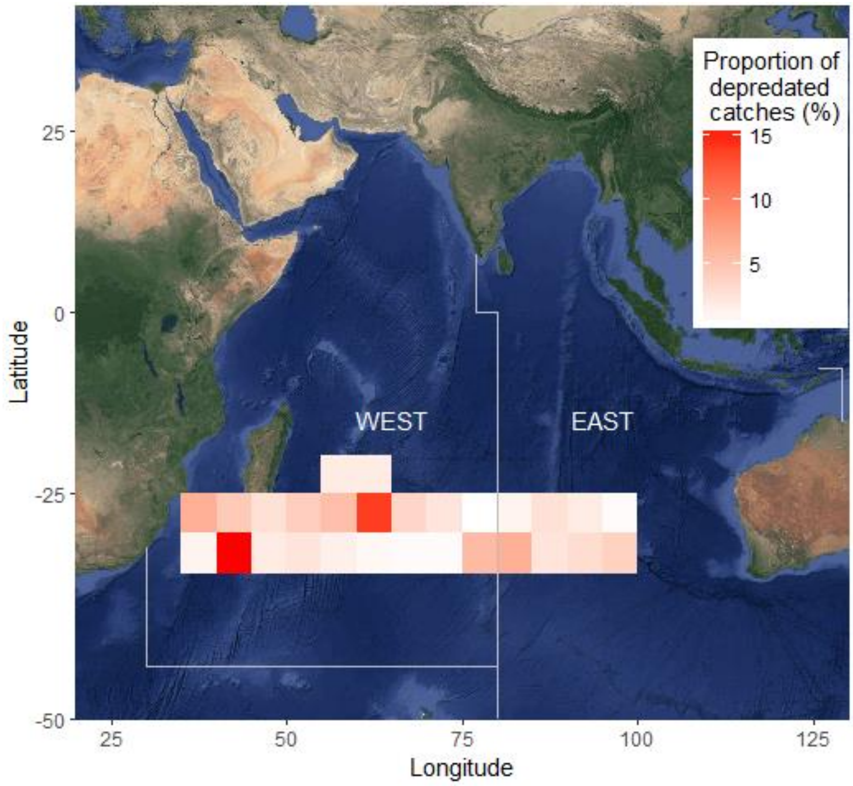


**Figure 2**. Distribution in 5*5 degrees of depredated catches recorded for this study in the Indian Ocean (2011-2015).

Total and depredated catches per set data were not normally distributed (Shapiro-Wilk test: $W = 0.9798$, p-value $< 0.001$ and $W = 0.8564$, p-value $< 0.001$), but variances were homogeneous between regions (Levene test: $F = 0.2825$, df = 1, p-value = 0.5953 and $F = 2.9896$, df = 1, p-value = 0.0845). Using univariate non-parametric statistical tests revealed that total and depredated catches per set were significantly different between regions (Permutation test: chi-squared = 5.64, df = 1, p-value = 0.0176 and chi-squared = 24.246, df = 1, p-value $< 0.001$) respectively.

### *3.2. Depredated species*

In the Portuguese longline fishery the catch composition is mostly composed of 6 species, *Xiphias gladius*, *Prionace glauca* (blue shark – BSH), *Coryphaena hippurus* (common dolphinfish – DOL), *Lepidocybium flavobrunneum*, *Isurus oxyrinchus* (shortfin mako - SMA) and *Thunnus obesus* (bigeye tuna - BET) (**Figure 3**). These species represent 90% of the fish catch in numbers, highlighting to swordfish and blue shark with 35,5 and 28,9% of total catches respectively (**Figure 3**).

A total of 24 species were depredated, *Xiphias gladius* representing 56% of depredated captures, followed by *Lepidocybium flavobrunneum*, *Coryphaena hippurus*, *Prionace glauca*, *Thunnus obesus*, *Acanthocybium solandri* (wahoo – WAH), *Alepisaurus ferox* (long snouted lancetfish – ALX), *Isurus oxyrinchus*, *Gempylus serpens* (snake mackerel - GES) and *Thunnus alalunga* (albacore – ALB) (**Figure 3**).

The percentage of depredated indivuals against total catch by species is represented in **Figure 4**, tuna and small pelagic fishes have the highest percentages of depredation in relation to total catches. *Acanthocybium solandri* and *Gempylus serpens* stand out as the most depredated species, with 10% of individuals captured depredated (**Figure 4**).

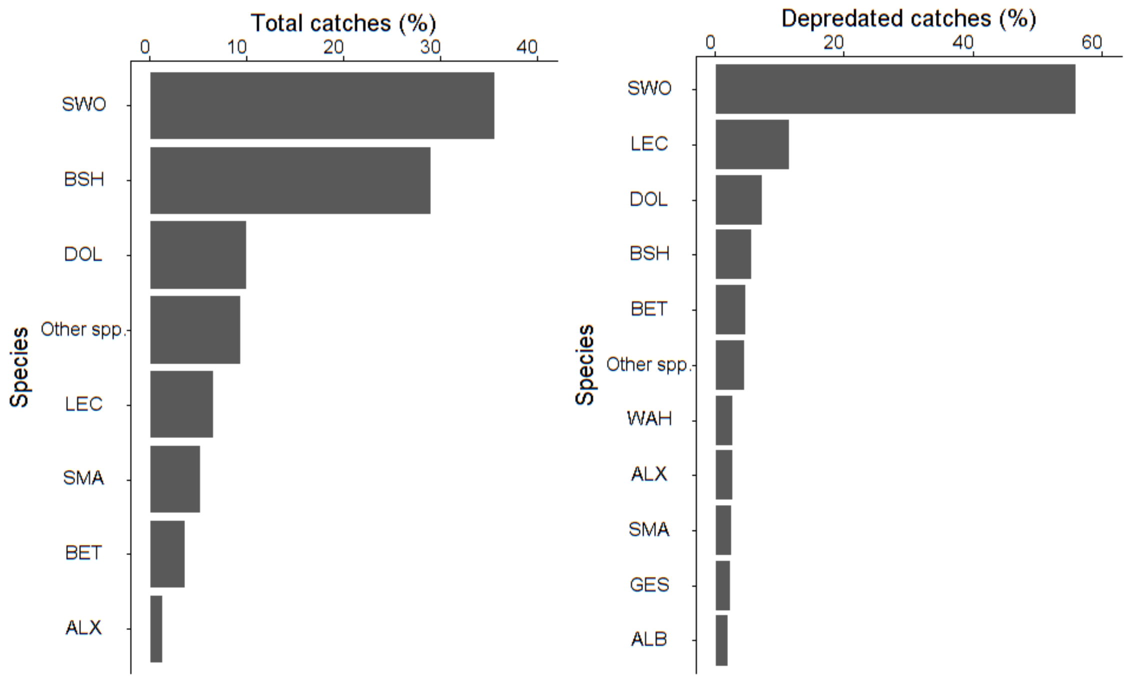


**Figure 3**. Left graph: Percentage of total catches recorded for this study in the Indian Ocean (2011-2015) (n=26366). Right graph: Contributions of species to depredated catches of longline fishery in percentage (n=778).

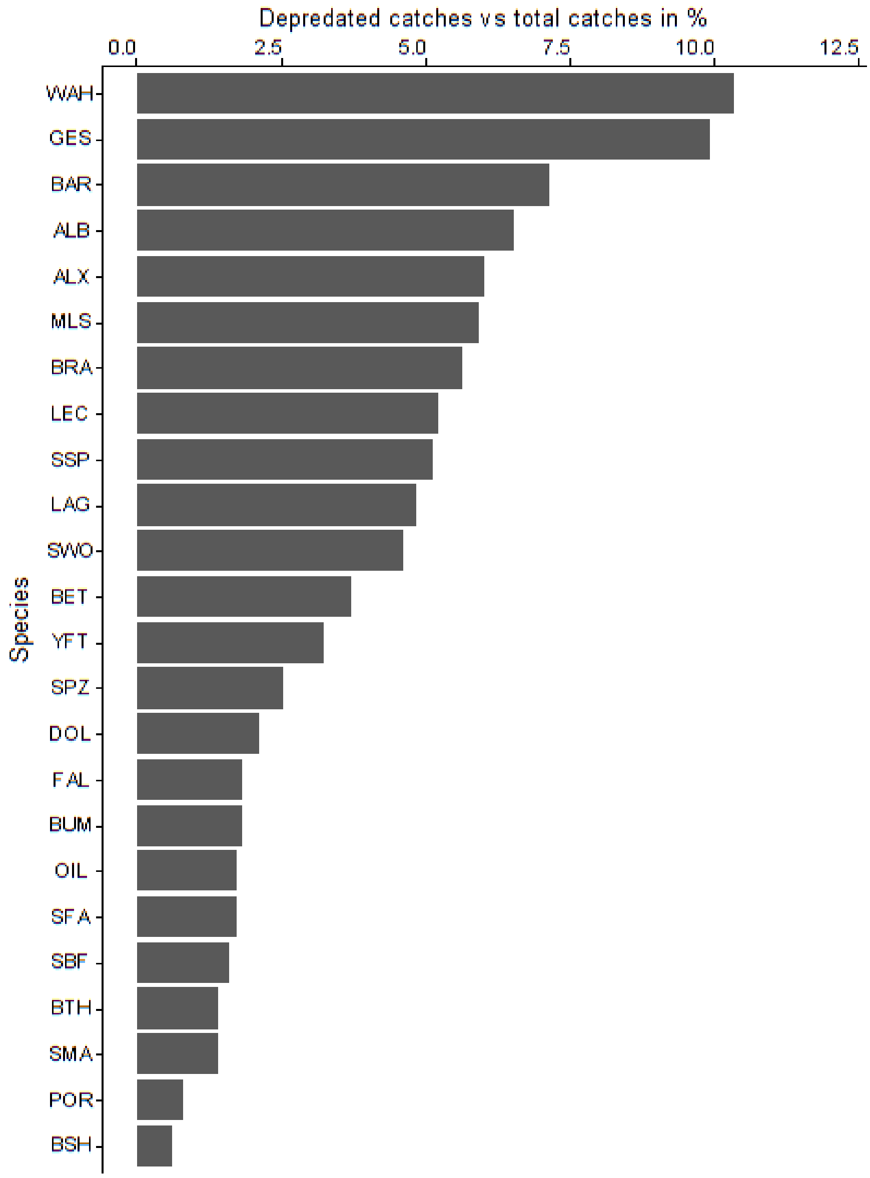


**Figure 4**. Percentage of depredated catches against total catches by species for the Portuguese pelagic longline fishery in the Indian Ocean.

It was not possible to identify the predator in 61% of depredated individuals. For the ones that the predator could be identified, 21% of the depredation was from sharks species, as *Prionace glauca*, *Isurus oxyrinchus*, *Lamna nasus* (porbeagle - POR) and the small *Isistius brasiliensis* (cookie cutter shark - ISB). Small pelagic fish preyed on about 13% of the depredated individuals. Marine mammals and seabirds were responsible for 1.9 and 0.3% respectively of the depredations. Only 2.4% of the depredated catches were targeted by more than one predator.

### *3.3. Annual trends of depredated catches*

Total and depredated catches variances were heterogeneous between years (Levene test: F = 3.267, df = 4, p-value = 0.). Using univariate non-parametric statistical tests revealed that total and depredated catches were significantly different between years (Permutation test: chi-squared = 105.25, df = 4, p-value < 0.001 and chi-squared = 59.519, df = 4, p-value < 0.001). The fraction of depredated catches had an increasing annual trend of 0.85 % on average, being 1.5 % in 2011 and reaching 4.9 % in 2015 (**Figure 5**).

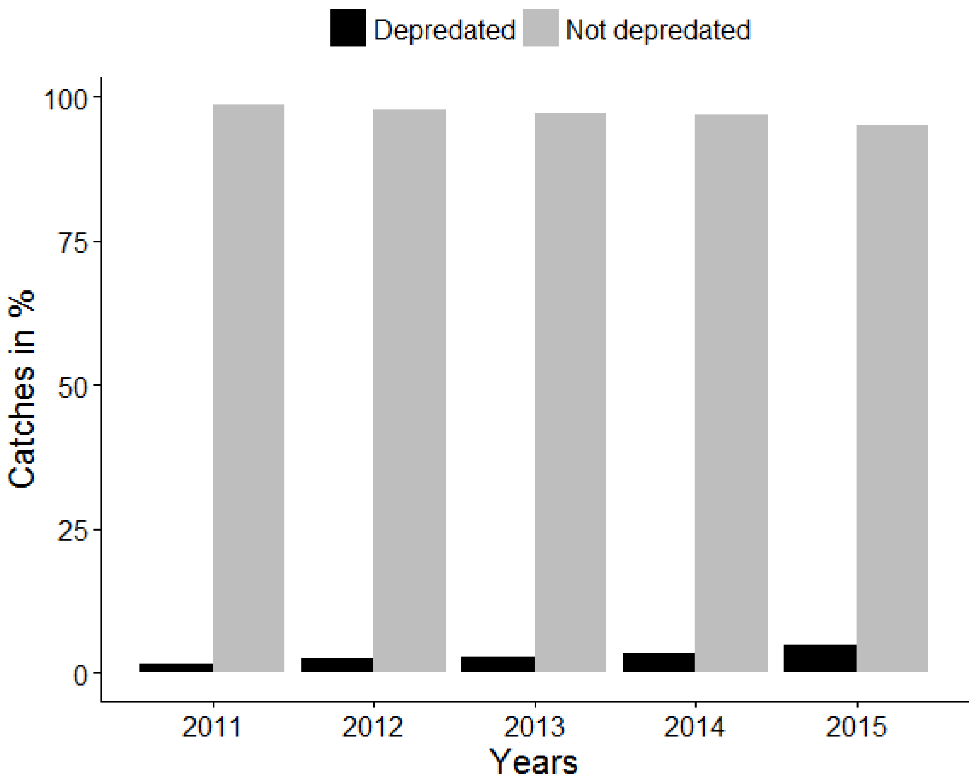


**Figure 5**. Annual catches, in %, for depredated and non-depredated individuals, during the period 2011-2015.

### *3.4. Comparison of catch-at-size of depredated and total catch*

It is possible to see a small variability in sizes between depredated catches and total catches of swordfish (Proportion test: chi-squared = 29.365, df = 17, p-value = 0.0313) (**Figure 6**). However, this variability is not shown for escolar (Proportion test: chi-squared = 4.0118, df = 8, p-value = 0.8561) (**Figure 7**). Both species showed unimodal distributions. It was not possible to compare the sizes of other species due to the limited number of preyed individuals.

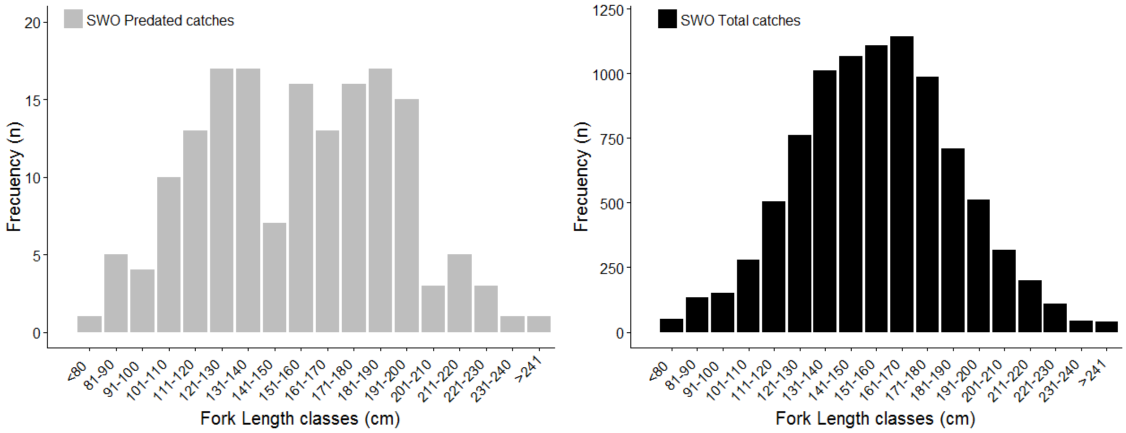


**Figure 6**. Size-frequency distributions of depredated (n=164) and total (n=9137) catches of *Xiphias gladius* (swordfish - SWO) in the Indian Ocean for the Portuguese pelagic longline fishery. Sizes are grouped in 10 cm fork length classes.

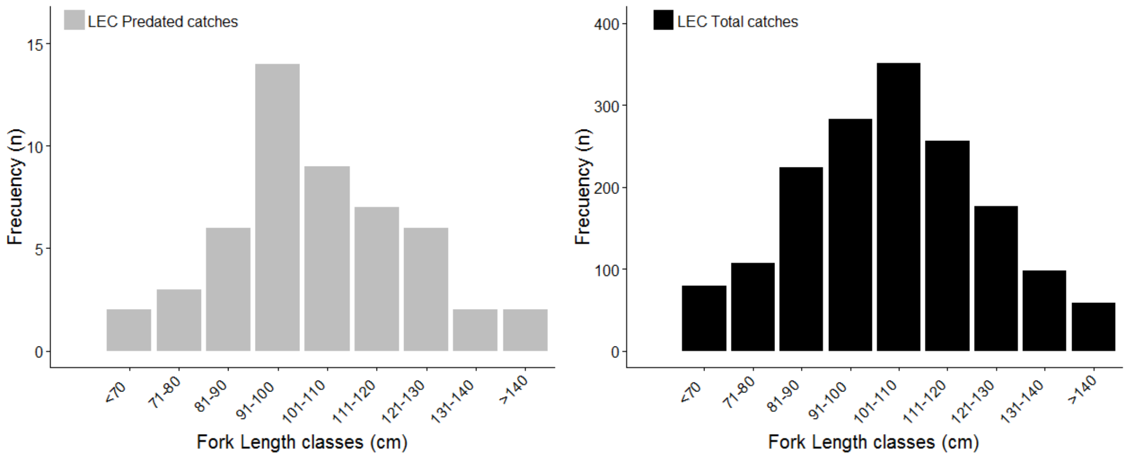


**Figure 7**. Size-frequency distributions of depredated (n=51) and total catches (n=1633) of *Lepidocybium flavobrunneum* (escolar – LEC) in the Indian Ocean for the Portuguese pelagic longline fishery. Sizes are grouped in 10 cm fork length classes.

### *3.5. Models for the depredation rates on swordfish*

The effects of continuous spatial variables (latitude and longitude) were significant on the rate of depredation events in swordfish specimens, and are shown in **Figure 8**. It is possible to see that in general there are higher depredation rates towards western longitudes, closer to the African continent. In terms of latitude the higher rates are in the extremes (higher and lower latitudes) of the areas of operation of the Portuguese fleet. In term of the year effects, there were no differences between 2011, 2012 and 2013 (p-values > 0.05 on all cases), but the depredation rates increased for 2014 and 2015 (p-values < 0.01).

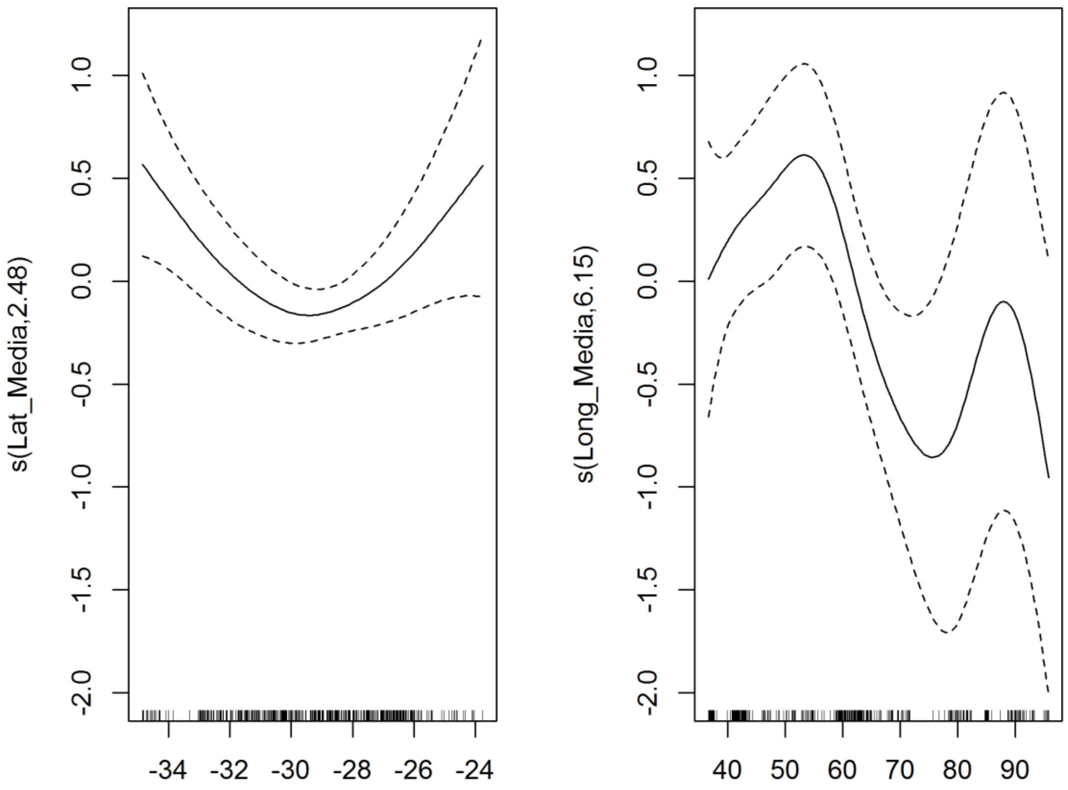


**Figure 8**. GAM plot with the non-linear effects of latitude and longitude in the depredation events on swordfish specimens, in the pelagic longline fishery operating in the Indian Ocean.

## 4. Discussion

This work provides the first study of depredation in the Portuguese pelagic longline fleet in the southern of Indian Ocean, compiled by fisheries observers on board commercial longline vessels. The results presented are an important contribution to the study of depredation events in the Indian Ocean.

It is important to note that the data used in this study comes from various vessels in different periods. Therefore, the size ranges, abundance and distribution reported are affected by the availability of the area and the selectivity of the vessels. With respect to the spatial distribution of the data, while the observations reported in part reflect the spatial dynamics of catches, there is also a large influence of the seasonal and spatial patterns of the fishing effort of the fleet.

A higher proportion of depredation catches was observed for some species, like tuna and small pelagic fishes, possibly showing that there is a depredation preference for some species by predators. Depredation, especially when the captures are discarded, can cause significant economic losses to the fishing industry (Gilman *et al.*, 2008). Significant differences in the choice of size of prey by predators in swordfish were observed. For escolar, depredation events seem to be size independent. Caution should be taken when interpreting these results as the depredated catches sample size is small. For swordfish specimens, the effects of continuous spatial variables (latitude and longitude) were significant on the rate of depredation events.

In the future such studies should be continued as more data is being continuously collected.

## 5. Acknowledgments

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