OBSERVATIONS ON THE CATCH-AT-SIZE OF THE SHORTFIN MAKO (*ISURUS OXYRINCHUS*) CAUGHT BY THE PORTUGUESE PELAGIC LONGLINE FISHERY

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SUMMARY

This paper provides an overview of the catch-at-size of shortfin mako (Isurus oxyrinchus) captured by the Portuguese pelagic longline fishery in the Atlantic Ocean. The analysis was based on data collected from fishery observers onboard the commercial vessels, and from skippers logbooks (self sampling). Data series (1997 to 2011) was analyzed in terms of trends and compared between years, seasons and regions. An analysis was also carried out for the size variations with latitude and longitude. The sex-ratios proportions were also compared between region and seasons. In general, a tendency for decreasing sizes in the more recent years was noted, particularly for the Southern Atlantic. Seasonal and regional variability in the catch sizes were also detected and are discussed.

RÉSUMÉ

*Ce document offre un aperçu général de la prise par taille du requin-taupe bleu (*Isurus oxyrinchus*) capturé par la pêcherie palangrière pélagique du Portugal dans l'océan Atlantique. L'analyse reposait sur des données collectées auprès d'observateurs embarqués à bord de navires commerciaux et des carnets de pêche des capitaines (auto-échantillonnage). Les séries de données (1997 à 2011) ont été analysées en termes de tendances et comparées par année, saison et région. Une analyse a également été effectuée afin d'obtenir les variations des tailles en fonction de la latitude et de la longitude. Les proportions des sex-ratios ont été comparées entre les régions et les saisons. De manière générale, une tendance à la baisse des tailles a été observée au cours de ces dernières années, notamment dans l'Atlantique Sud. Une variabilité saisonnière et régionale dans les tailles capturées a également été détectée et fait l'objet de discussions.*

RESUMEN

*Este documento presenta una visión global de la captura por talla del marrajo dientuso (*Isurus oxyrinchus*) capturado por la pesquería de palangre pelágico portuguesa en el Atlántico. El análisis se basó en datos recopilados por los observadores pesqueros embarcados en buques comerciales y en los cuadernos de pesca de los patrones (automuestreo). Se analizó la serie de datos (1997 a 2011) en términos de tendencias, y se realizó una comparación entre años, temporadas y regiones. Igualmente, se realizó un análisis de las variaciones de talla en función de la latitud y longitud. También se compararon las proporciones de sexos entre regiones y temporadas. En general se observó una tendencia descendente en las tallas en los años más recientes, especialmente para el Atlántico meridional. También se detectó y debatió la variabilidad estacional y regional en las tallas de la captura.*

KEYWORDS

By-catch, catch-at-size, size distribution, Isurus oxyrinchus, pelagic longlines, sex-ratios

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1. Introduction

Pelagic sharks are commonly by-catch in pelagic longline fisheries (e.g. Buencuerpo *et al*. 1998; Simpfendorfer *et al.* 2002) but still, information on their life history, population parameters and the effects of fisheries is limited. Elasmobranchs in general have K-strategy life cycles, characterized by slow growth rates and long lives, and reduced reproductive potential with few offspring and late maturity. The natural mortality rates are usually low, and increased fishing mortality may have severe consequences on these populations (Smith *et al.* 1998).

The Portuguese pelagic longline fishery started in the late 1970's. In the North Atlantic area the fishery started to develop mainly after 1986, while in the South Atlantic it gained importance after 1989 (Santos et al. 2002). The Portuguese fleet usually deploys a pelagic drift longline for targeting mainly swordfish (*Xiphias gladius*). Still, this is a multi-species fishery, where some other bony fishes as well as pelagic sharks (mainly blue shark *Prionace glauca*, and shortfin mako *Isurus oxyrinchus*) are frequently captured.

The general aims of this paper are to present information on the catch-at-size distribution of the shortfin mako shark (SMA) captured by the Portuguese pelagic longline fishery in the Atlantic Ocean. Specific objectives were to present and compare catch-at-size and sex ratio information in terms of hemispheres, years, seasons and major fishing areas for this fleet.

2. Materials and methods

The data used for this study was collected by two sources, namely 1) fishery observers onboard Portuguese pelagic longline vessels, and 2) skippers logbooks (self sampling) voluntarily provided to IPIMAR. The fishery observer data is usually the most complete and detailed, as apart from set data, it collects individual information on the catch sizes and sex for all specimens caught. The skippers' logbooks have the data recorded and reported voluntarily by the vessel skippers, and usually also have detailed information regarding the catch, effort and location of the fishing sets. For some species, including the major fishery species (i.e. swordfish, tunas) and some sharks (i.e. blue and shortfin mako) detailed individual specimen information is also recorded, including individual specimen sizes or weights.

The data analyzed refers to data from the fishery between the years of 1997 to 2011. A total of 13,253 SMA specimens were either measured (FL, fork length in cm) and/or weighted (total weight in Kg). For this paper the analysis was carried out in terms of size, and so for the specimens with only weight information available a conversion between W-FL was used:

$W = (a)*FL^{(b)}$; a = 5.2*10-6; b = 3.141 (Kohler *et al*. 1995).

Histograms of the yearly SMA catch-at-size frequency distributions were created for the southern and northern hemispheres. The mean sizes and boxplots were plotted by year, month and FAO major fishing areas, and were compared with Kruskal-Wallis non-parametric rank sum tests. This test was chosen instead of the parametric approaches (e.g. ANOVA) because the data was not normally distributed (tested with Kolmogorov Smirnov tests with Lilliefors correction), and was heterogeneous between groups (tested with Levene tests). Univariate Generalized Additive Models (GAMs) were created to analyze and plot the non-linear effects of latitude and longitude in the sizes of the captured specimens. For these models the response variable considered was the fork length and the explanatory variables were the latitude and longitude. The error distribution was assumed to follow a gamma distribution, and the link function used was the log.

The proportions of the sex-ratios were compared between hemispheres, FAO fishing regions, and seasons within each hemisphere. These analyses were carried out with contingency tables, and the differences tested with chi-square statistical tests, comparing the observed versus expected proportions in each cell of the contingency tables.

Separate analyses were carried out the North and South Atlantic. For the purpose of this study the 5ºN parallel was used to separate the two hemispheres, as recommended in the ICCAT Manual for shark species (ICCAT 2006-2009).

All statistical analysis for this paper was carried out with the R Project for Statistical Computing version 2.14.1 (R Development Core Team 2012). All plots and analysis were build with function in the core R program, except the Levene tests for homogeneity of variances that used library "car" (Fox & Weisberg 2011), and the GAM plots that were created with library "mgcv" (Wood 2011). Contingency table analysis was carried out using functions from library "gmodels" (Warnes 2011).

3. Results and Discussion

3.1 Yearly size distribution

Significant variations in the size distributions of the SMA captured by the Portuguese fleet along the years were detected, with a tendency for capturing smaller sized specimens towards the more recent years (**Figure 1**). These observed differences were significant (Kruskal-Wallis chi-square = 3261, df = 14, p-value < 0.001). Currently, mean catch-at-size is below 150 cm of fork length.

When the yearly size distribution was analyzed for the two hemispheres separately, it was noticeable that in general the SMA mean sizes for the North Atlantic tended to be smaller than in the South Atlantic. However, the major changes in mean size seem to have occurred mainly in the South Atlantic, with a decreasing tendency in the mean sizes during in recent years, whereas in the northern hemisphere the mean size has been stable during the last decade. These trends were also evident in the catch-at-size frequency distributions, with a decreasing tendency especially for the Southern Atlantic (**Figure 2**). The size frequency distributions for the study period showed a general narrower size range in the Northern hemisphere (**Figure 3, Figure 4**).

When hypothesis tests are carried out for the two hemispheres separately, changes in the yearly size distribution were detected both for the North (Kruskal-Wallis chi-square = 204, df = 14, p-value < 0.001) and the South Atlantic (Kruskal-Wallis chi-square = 2948, df = 13, p-value < 0.001).

3.2. Seasonal size distribution

In terms of seasonal variations, the size distribution along the months of the year was relatively similar for the Northern Atlantic, with a very slight increase in sizes during the summer months. For the South Atlantic the differences were more noticeable, with smaller sizes also captured during the months of May and June that is this hemisphere corresponds to the austral late autumn and early winter (**Figure 5**). These differences were significant both for the North (Kruskal-Wallis chi-square = 110, df = 11, p-value < 0.001) and South Atlantic (Kruskal-Wallis chi-square = 2144, df = 11, p-value < 0.001).

3.3 Regional size distribution

When considering the FAO major fishing areas, differences in the SMA catch sizes were also detected. Specifically, there was a tendency for smaller sizes in the northern areas (e.g. ICES and NAFO), slightly larger sizes in the more tropical areas of the Western-Central Atlantic and CECAF, and larger specimens in the South West Atlantic region (**Figure 6**). These differences in sizes between regions were significantly different (Kruskal-Wallis chi-square = 2555, df = 5, p-value < 0.001).

When the latitude and longitude coordinates were considered instead of the FAO fishing areas, some interesting tendencies were found. For the North Atlantic, a clear tendency of decreasing sizes with latitude was found, as well as the existence of an area in the middle of the longitude range where larger specimen tend to be captured (**Figure 7**). For the South Atlantic, there were more oscillations in the effect of latitude in the catch sizes, while with regards to the longitude the effects were for a tendency of smaller specimens towards the eastern longitudes (**Figure 7**).

3.4 Sex-ratios

No differences in the sex-ratios proportions were detected between the two hemispheres (chi-square = 0.49, p-value = 0.483) (**Table 1**). However, when a analysis was carried out geographically for the FAO major fishing areas, significant differences were found (chi-square = 43.5, p-value < 0.001). Specifically, higher proportions of males were found in the NE Atlantic (ICES) and SW Atlantic regions, while higher proportions of females were found in the eastern tropical and southeastern Atlantic (CECAF and SEAFO areas) (**Table 2**).

In terms of seasonal changes, and within each hemisphere separately, no differences were found in the sex-ratio proportions between season for the North Atlantic (chi-square = 4.87, p-value < 0.181), but significant differences were found for the South Atlantic (chi-square = 46.92, p-value < 0.001). In the southern Atlantic, the differences were mainly noticeable in the 1st and 2nd quarters of the year, with a much higher proportion of males in the 1st quarter, and a much higher proportion of females on the 2nd quarter (**Table 3**).

3.5 Final remarks

This paper presents some of the first information on the catch-at-size trends for the shortfin mako shark captured by the Portuguese pelagic longline fishery in the Atlantic Ocean. While the information presented is important, it should be noted that it represents only part of the catch by this fleet, specifically the data collected by fishery observers and self reported voluntarily in the skippers' logbooks. An effort is currently being carried out to collect, compile and further analyze these data. We hope, in the near future, to incorporate more data from other trips not yet included, and eventually expand the analysis to the earlier years of the fishery.

Even though still preliminary, the results presented provide important information that may be considered for future management and conservation initiatives of this elasmobranch species. By determining the areas and periods of the year when smaller sized specimens tend to be more captured, it might be possible to determine particular areas of impact of the fishery on particularly vulnerable components of the populations, such as for example the juveniles.

For example, if we consider the estimated sizes at maturity for the species for the species of 185 cm FL for males and 275 cm FL for females (estimated by Natanson *et al*. 2006), then it seems that most of the catch (at least for the Northern Atlantic) is possibly composed by juveniles, which is a cause of concern for the species conservation and sustainability. If eventual minimum landing sizes are established for the species, the type of spatial and seasonal catch-at-size analysis presented may provide some information on where and when such captures are more likely to occur. Additionally, if eventual spatial-temporal closure areas are to be considered, this analysis may also contribute to establish priority areas and periods for the Atlantic Ocean.

Acknowledgments

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Table 1. Contingency table with the *sex-ratios* for SMA in the northern and southern hemispheres. The contingency table chi-square analysis is presented, with indication of the chi-square statistic, the degrees of freedom and the corresponding p-value.

Stock	*% observed*		*Proportion test*		
	Females	*Males*	*Chi-square*	*Df*	*p-value*
North	52.4	47.6	0.49	1	0.483
South	50.3	49.7			

Table 2. Contingency table with the *sex-ratios* for SMA in the FAO major fishing areas. The contingency table chi-square analysis is presented, with indication of the chi-square statistic, the degrees of freedom and the corresponding p-value.

FAO Area	*% observed*		*Chi-square test*		
	Females	*Males*	*Chi-square*	*Df*	*p-value*
27.ICES	33.8	66.2	43.05	3	< 0.001
34.CECAF	56.6	43.4			
41.SWAtl	36.5	63.5			
47.SEAFO	53.9	46.1			

Table 3. Contingency table with the sex-ratios for SMA per quarter for each hemisphere. The contingency table chi-square analysis is presented, with indication of the chi-square statistic, the degrees of freedom and the corresponding p-value.

North Atlantic

FAO Area	*% observed*		*Chi-square test*		
	Females	*Males*	*Chi-square*	*Df*	*p-value*
Q1	52.3	47.7	4.87	3	0.181
Q2	42.5	57.5			
Q3	52.3	47.7			
Q4	56.7	43.3			

South Atlantic

FAO Area	% observed		Chi-square test		
	Females	Males	Chi-square	Df	p-value
Q1	27.5	72.5	46.92	3	<0.001
Q2	77.3	22.7			
Q3	59.7	40.3			
Q4	51.4	48.6			

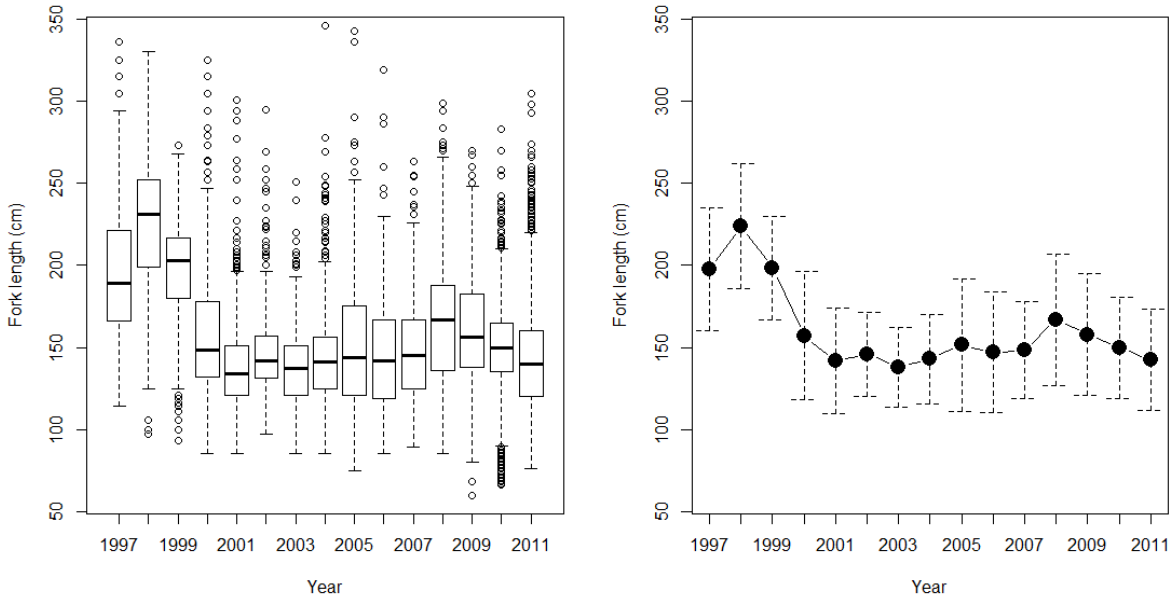

Figure 1. Catch-at-size variations along the years for SMA captured by the Portuguese pelagic longline fleet in the Atlantic Ocean. The graphic on the left represents the boxplots, and the graphic on the right represents the mean annual sizes with the standard deviations.

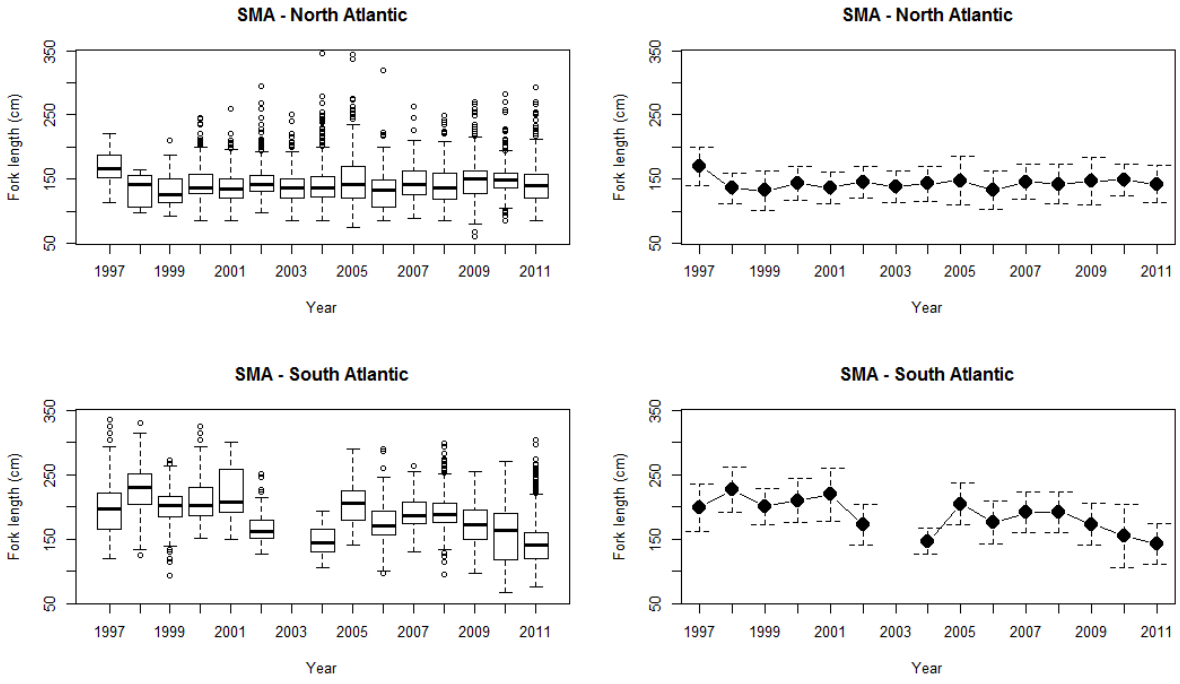

Figure 2. Catch-at-size variations for SMA captured by the Portuguese pelagic longline fleet in the North and South Atlantic. The graphic on the left represents the boxplots, and the graphic on the right represents the mean annual sizes with the standard deviations.

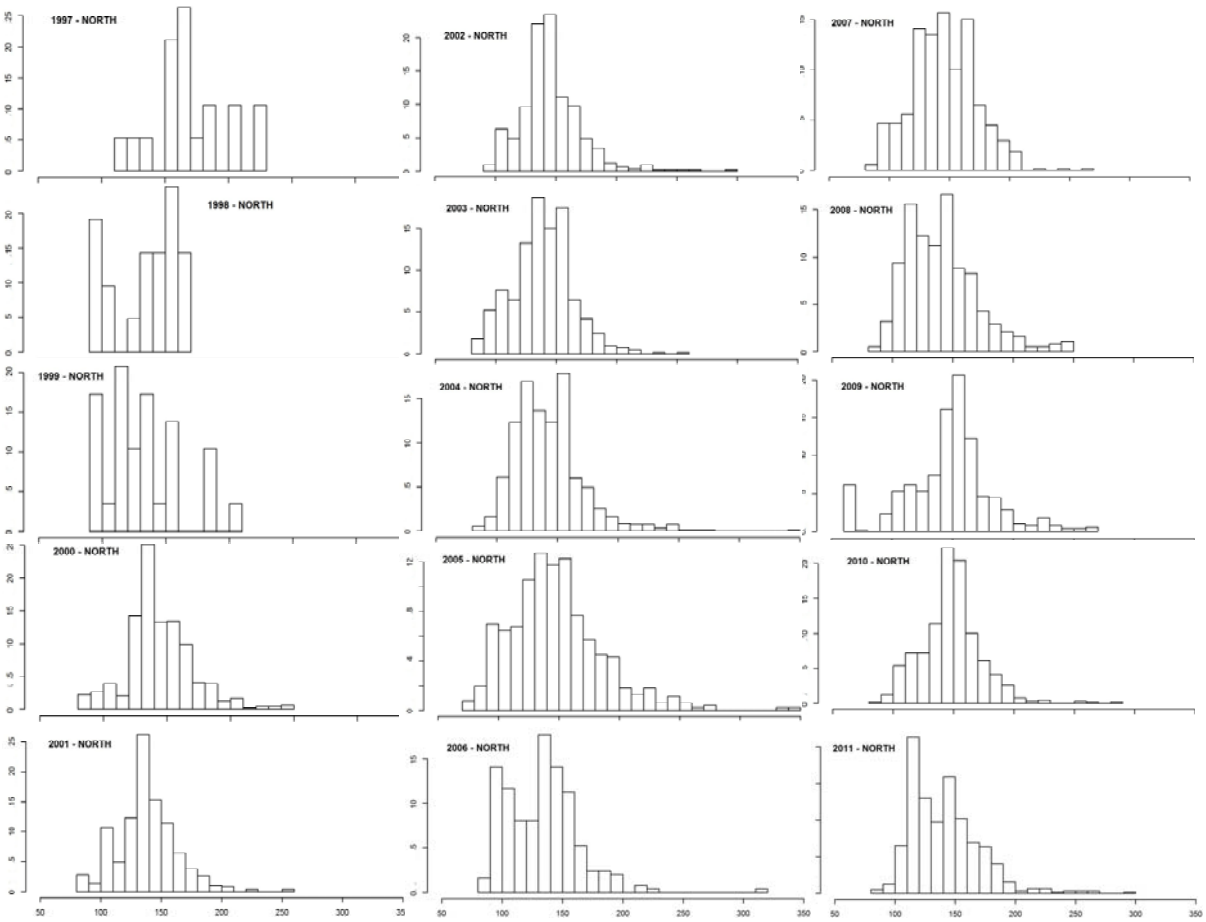

Figure 3. Relative size (fork length cm) frequency distribution of SMA captured by the Portuguese longline fleet in the Northern Atlantic Ocean, between 1997 and 2011.

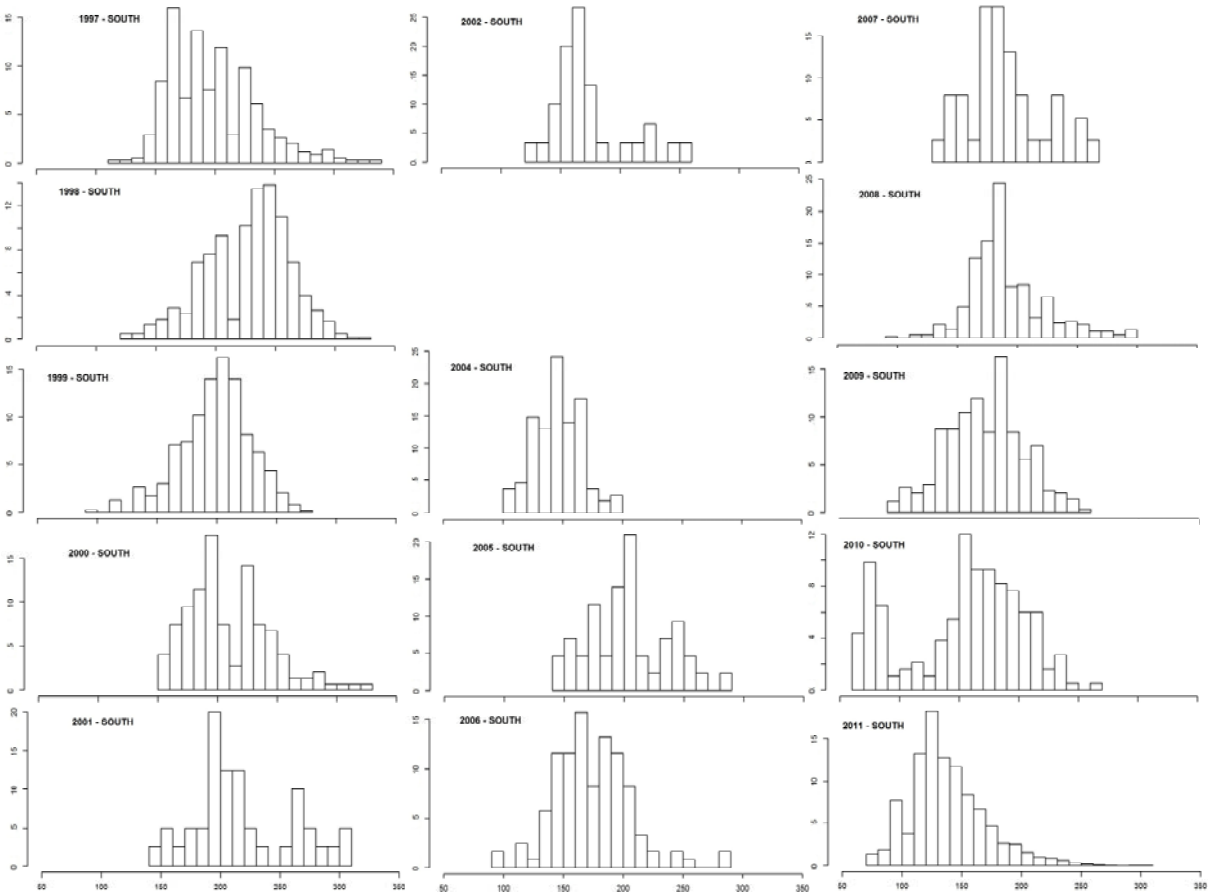

Figure 4. Relative size (fork length cm) frequency distribution of SMA captured by the Portuguese longline fleet in the Southern Atlantic Ocean, between 1997 and 2011.

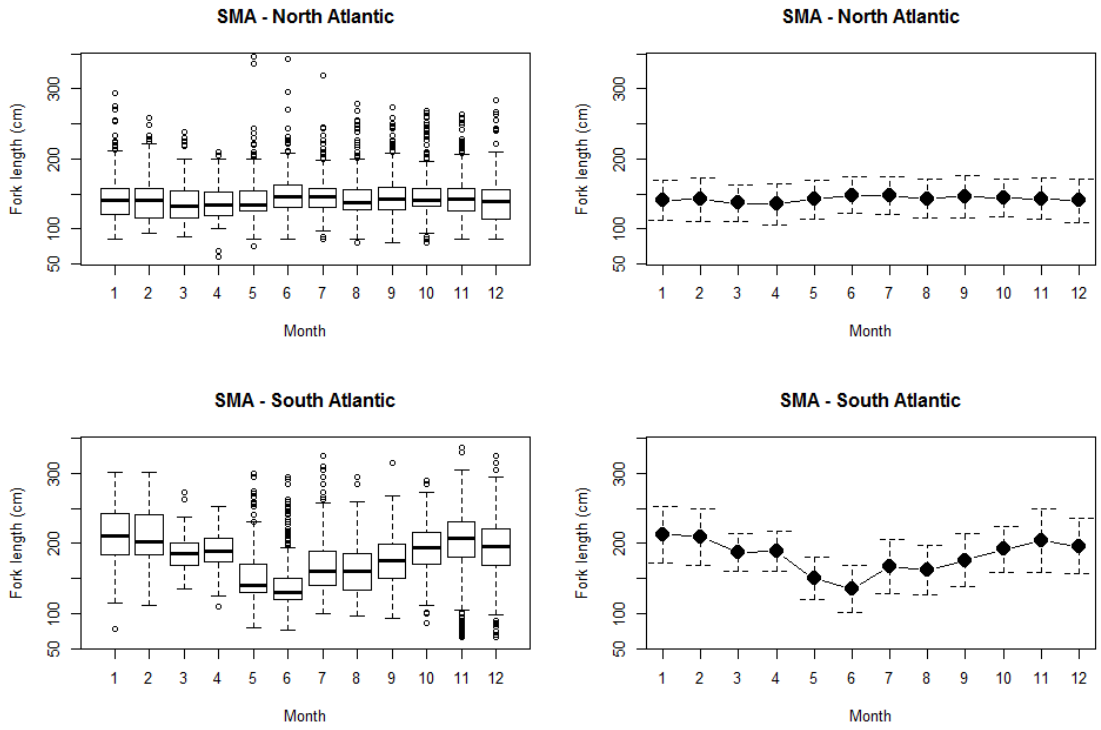

Figure 5. Monthly catch-at-size variations for SMA captured by the Portuguese pelagic longline fleet in the North and South Atlantic. The graphic on the left represents the boxplots, and the graphic on the right represents the mean annual sizes with the standard deviations.

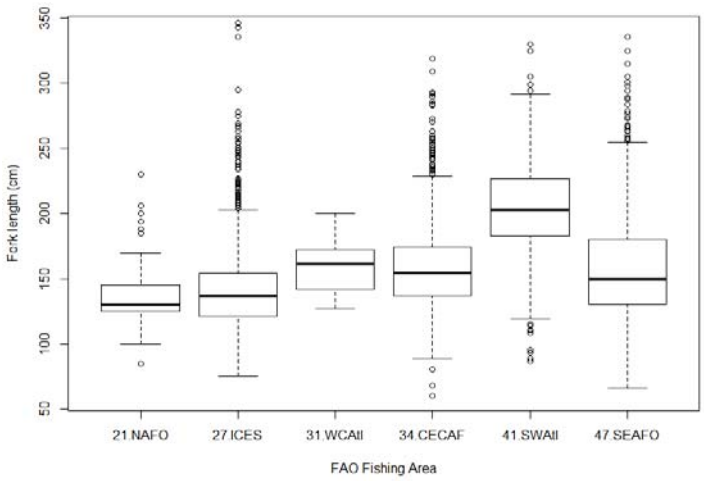

Figure 6. Catch-at-size of SMA captured by the Portuguese pelagic longline fleet in various FAO major fishing areas.

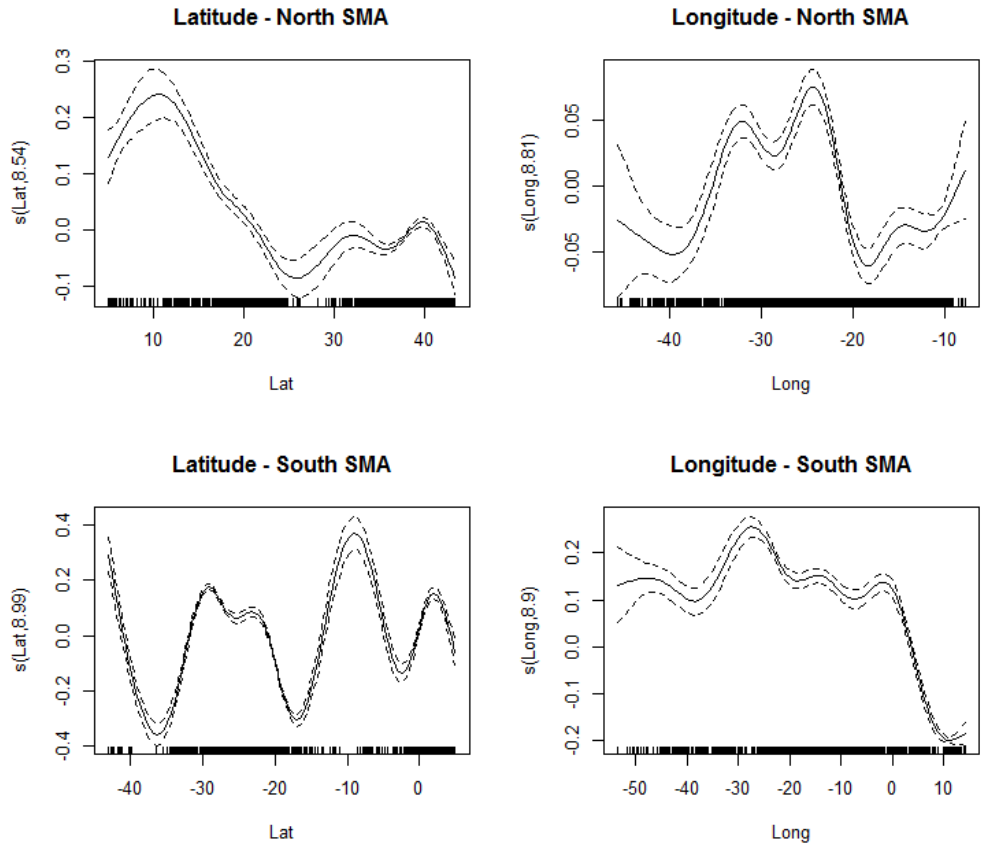

Figure 7. GAM plots with the univariate effects of latitude and longitude on the North and South Atlantic SMA catch sizes. The dashed lines represent the standard errors and the vertical bars in the bottom represent numbers of observations.