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STANDARDIZED CPUE AND SIZE DISTRIBUTION OF SWORDFISH IN THE PORTUGUESE PELAGIC LONGLINE FISHERY IN THE ATLANTIC

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SUMMARY

This document provides indicators for swordfish captured by the Portuguese pelagic longline fishery in the Atlantic (standardized CPUEs and size distribution trends). The analysis was based on data collected from fishery observers, port sampling and skippers logbooks (self sampling), collected between 1995 and 2016. The mean sizes were compared between years, seasons (quarters), stocks (North and South) and areas. The CPUEs were analyzed for the North Atlantic and compared between years, and were modeled with GLM tweedie, GLM Delta lognormal, GLM and GLMM lognormal (adding a constant). In general the nominal CPUE trends increased during the period with some inter-annual variability. The standardized CPUEs showed similar trends with an overall increase during the period, with some oscillations. For the size distribution there were increasing trends in the North Atlantic and no major trends in the South. The data presented in this working document can be considered for use in the upcoming 2017 Atlantic swordfish assessment specifically the standardized CPUE for the North Atlantic and the size distribution for both hemispheres.

RÉSUMÉ

Le présent document fournit des indicateurs de l'espadon capturé par la pêcherie palangrière pélagique portugaise opérant dans l'Atlantique (CPUE standardisées et tendances de la distribution des tailles). L'analyse se basait sur les données collectées par les observateurs des pêcheries, l'échantillonnage au port et les carnets de pêche des capitaines (auto-échantillonnage), compilées entre 1995 et 2016. Les tailles moyennes ont été comparée entre les années, saisons (trimestres), stocks (Nord et Sud) et les zones. Les CPUE ont été analysées pour l'Atlantique Nord et comparées par année et ont ensuite été modélisées au moyen de méthodes GLM tweedie, GLM delta lognormale, GLM et GLMM lognormale (en ajoutant une valeur constante). En général, les tendances de CPUE nominale ont augmenté au cours de la période, affichant une certaine variabilité interannuelle. Les CPUE standardisées montraient des tendances similaires, soit une augmentation générale au cours de la période s'accompagnant d'oscillations. La distribution des tailles montrait des tendances croissantes dans l'Atlantique Nord et aucune tendance principale dans le Sud. On peut envisager l'utilisation des données présentées dans ce document de travail dans la prochaine évaluation du stock d'espadon de l'Atlantique de 2017, plus précisément la CPUE standardisée pour l'Atlantique Nord et la distribution des tailles pour les deux hémisphères.

RESUMEN

En este documento se presentan los indicadores para el pez espada capturado por la pesquería de palangre pelágico portuguesa en el Atlántico (CPUE estandarizadas y tendencias de distribución de tallas). El análisis se basó en datos recopilados por los observadores pesqueros, en los muestreos en puerto y en los cuadernos de pesca de los patrones (automuestreo), recopilados entre 1995 y 2016. Las tallas medias se compararon entre años, temporadas (trimestres), stocks (norte y sur) y zonas. Se analizaron las CPUE para el Atlántico norte y se compararon entre los años, y se modelaron con GLM Tweedie, GLM Delta lognormal, GLM y GLMM lognormal (añadiendo una constante). En general, las tendencias de CPUE nominal se incrementaron durante el periodo, con alguna variabilidad interanual. Las CPUE estandarizadas mostraban tendencias similares bien con un incremento global durante el periodo, bien con algunas oscilaciones. Respecto a la distribución por tallas, existía alguna tendencia creciente en el Atlántico norte y ninguna tendencia importante en el sur. Los datos

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presentados en este documento pueden ser considerados para su uso en la próxima evaluación de pez espada del Atlántico de 2017, específicamente la CPUE estandarizada para el Atlántico norte y la distribución por tallas para ambos hemisferios.

KEYWORDS

Fishery indicators, standardized CPUE, pelagic longline fisheries, swordfish, size distribution.

1. Introduction

Fisheries management is usually based on stock assessment models that require data on the abundance of the species under assessment. Ideally, data for such models should be fishery-independent but, when assessing pelagic and migratory species that cover wide geographical areas (e.g. tunas, billfishes and pelagic sharks) this type of fisheries-independent data is usually not available. Therefore, most stock assessments currently carried out for pelagic species are based on fishery-dependant data, available from the commercial fisheries that capture those species.

The data usually gathered from the commercial fisheries and analyzed is the Catch per Unit of Effort (CPUE, either in number or biomass), and it is important to standardize those CPUEs to account for effects (consequence of the fishery-dependence) other than the annual abundance effects that are being analyzed. By standardizing the CPUEs, the effects of the covariates considered are removed from the annual CPUE values, and those standardized CPUEs can be used as annual indexes of abundance.

The ICCAT SCRS is carrying a stock assessment of Atlantic swordfish in 2017. The first standardized CPUE series for swordfish from the Portuguese fleet was presented to the SCRS in 2013 (Santos et al., 2013) to be used in the previous assessment. Following that previous work, this paper now presents updated indicators including standardized CPUE series and size distributions from the Portuguese pelagic longline fleet, to be considered for use in the 2017 assessment.

2. Materials and methods

2.1. Data collection

The data used for this study was collected by IPMA (*Portuguese Institute for the Ocean and Atmosphere*) from several different sources, namely 1) fishery observers onboard Portuguese pelagic longline vessels, 2) landings on Portuguese ports, and 3) skippers logbooks (self sampling) voluntarily provided to IPMA.

The fishery observer data is usually the most complete and detailed, apart from set data there is also the collection of individual information on the catch sizes and sex for all specimens. During the landings, detailed information is also collected, although due to some procedure logistics sometimes it is difficult to collect individual size and/or sex data for the major species caught (e.g. blue shark). 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 sharks as blue and shortfin mako) detailed individual specimen information is usually recorded, including individual specimen sizes or weights.

2.2. Data analysis

The data analyzed in this work refers to data from the fishery between 1995 and 2016 for the Atlantic Ocean.

The CPUE standardization analysis was restricted to the North Atlantic (separated by the 5ºN, as used in the ICCAT SWO stock delimitation), as most of the effort and data from the fishery comes from that area. Data from a total of 1,931 trips or sub-trip (consecutive sets in the same trip, area and month) is available for the entire Atlantic. For the CPUE standardization only data from the North Atlantic was used, and only for the years from, 1999-2016 (the initial years were excluded due to low coverage). Therefore, the data available for the CPUE standardization represented 1,614 trips of sub-trips, that represented 12,363 fishing sets and 14,184,646 hooks (**Table 1**). The coverage of the sample used in the CPUE standardization, in terms of swordfish total catch, varied between minimums of 21.4% and maximums of 78.8%, with an average coverage of 41.8% (**Table 1**).

The CPUEs were calculated as Kg (live weight) / 1000 hooks, and were mapped in 5*5 degrees to provide an overview of the catch locations of swordfish by the fleet. The yearly nominal CPUEs were calculated and the time series plotted.

For the CPUE standardization, the data from the first years of the series (1995-1998) was excluded from the model runs due to low number of observations and effort covered. The final CPUE time series was therefore analyzed for the period 1999 to 2016. For the CPUE standardization, the response variable considered was CPUE measured as biomass of live fish (kg) per 1000 hooks deployed. The standardized CPUE series was estimated with Generalized Linear Models (GLM) and Generalized Linear Mixed Models (GLMM).

Swordfish is the main target species of the fishery and therefore there are very few sets with zero catches. Still those few zeros can cause mathematical problems for fitting the models, and as such several alternative approaches were tested, specifically a GLM tweedie model, a GLM Delta lognormal approach, and GLM and GLMM lognormal models (adding a constant).

With the delta-method two separate models are estimated. For our study the first model assumed a binomial error distribution with a logit link function, and was used to model the proportion of fishing sets with positive catches. For this model, the binomial response variable was coded with 1 = set with positive catches of SWO and 0 = set with zero catches of SWO. The second model was used to estimate the expected CPUE of the positive sets of SWO, assuming that those positive sets follow a normal error distribution after a log-transformation of the nominal CPUE data.

The tweedie model uses a different approach in which only one model is fitted to the data, with that model handling this mixture of continuous positive values with a discrete mass of zeros. The tweedie distribution is part of the exponential family of distributions, and is defined by a mean (μ) and a variance ($\varphi\mu p$), in which φ is the dispersion parameter and p is an index parameter. In this study, the index parameter (p-index) was calculated by maximum likelihood estimation (MLE).

For the lognormal models, the response variable was defined as the nominal CPUE + constant (c), with c set to 10% of the overall mean catch rate. The value of c=10% of the mean has been recommended by Campbell (2004), as it seems to minimize the bias for this type of adjustments. Further, and in a comparative study, Shono (2008) showed that when the percentage of zeros in the dataset is low (<10%, which is the case of this study), the method of adding a constant to the response variable performs relatively well.

The covariates considered and tested in the models were:

- Year: analyzed between 1999 and 2016;
- Quarter of the year: 4 categories: 1 = January to March, 2 = April to June, 3 = July to September, 4 = October to December;
- Area: using the areas represented in **Figure 1** and considering the aggregations mentioned below;
- Targeting: based on the SWO/SWO+BSH ratio of captures; see explanations below.

Interactions were considered and tested in the analysis. Specifically, interactions not involving the year factor were considered as fixed factors in the GLM, while interactions involving the year factor were considered as random variables within GLMMs.

In terms of targeting effects, the differences in fishing strategy reflect the increased economic importance of sharks among the Portuguese pelagic longline fleets which traditionally targeted swordfish almost exclusively. These changes in target species were incorporated into the model by a proxy based on the ratio of the swordfish retained catch and the combined swordfish + blue shark retained catches by trip (or sub-trip). This ratio is in general considered a good proxy indicator of target criteria more clearly directed at swordfish vs. a more diffuse fishing strategy aimed at the two main species (SWO and BSH). Moreover, it has been consistently applied both to the Portuguese and other fleets that have a similar method of operation, such as the Spanish fleet, with applications both to the Atlantic and the Indian Ocean longline fisheries (e.g., Ramos-Cartelle et al., 2011; Mejuto et al., 2012; Santos et al., 2013b; Coelho et al., 2014). This ratio factor used as proxy for targeting was calculated by trip or sub-trips and categorized into ten levels using the 0.1 quantiles.

Other approaches to include targeting effects into the CPUE standardization process for the Portuguese pelagic longline fishery have been tested in the past. Coelho et al. (2015a) tested a cluster analysis based on the catch composition of the 10 major species or species-groups, in an analysis as suggested by He et al. (1997) and that has been successfully applied for CPUE standardization of other fleets (e.g. Wang and Nishida, 2014, for the

Taiwanese fleet in the Indian Ocean). Coelho et al. (2015a) demonstrated that for the Portuguese pelagic longline fleet, given that the catches are largely dominated by the two major species, specifically swordfish and the blue shark, the use of ratios or clusters resulted in very similar results.

The catches were assigned to fishing areas according to **Figure 1**, which were defined by Ortiz et al. (2010) for swordfish and used before for other CPUE standardizations of the Portuguese fleet, as Santos et al. (2013b) and Coelho et al. (2015a) for swordfish and blue shark, respectively. In this specific study some of these areas were aggregated into larger zones due to the low number of trips or sub-trips with positive swordfish catches in some of the areas. Even though those areas were defined originally for swordfish and tested for blue shark, they reflect the activity of the fleet that is mainly catching those two species.

The significance of the explanatory variables in the CPUE standardization models was assessed with likelihood ratio tests comparing each univariate model to the null model (considering a significance level of 5%), and by analyzing the deviance explained by each covariate. Goodness-of-fit and model comparison was carried out with the Akaike Information Criteria (AIC) and the pseudo coefficient of determination (R^2). Model validation was carried out with a residual analysis. The final estimated indexes of abundance were calculated by least square means (LSMeans or Marginal Means), that for comparison purposes were scaled by the mean standardized CPUE in the time series.

In terms of sizes, data from both hemispheres was analyzed. The size data was analyzed with exploratory size frequency plots and time series of the mean sizes in each stock. Size data was tested for normality with Kolmogorov-Smirnov tests with Lilliefors correction (Lilliefors, 1967) and for homogeneity of variances with Levene tests (Levene, 1960). Catch sizes were compared between years, quarters, sampling areas and stocks using non-parametric k-sample permutation tests (Manly, 2007) given that the data was not normally distributed and the variances were heterogeneous.

Data analysis for this paper was carried out in the R language for statistical computing 3.2.0 (R Core Team, 2015). The plots were designed using library "ggplot2" (Wickham, 2009) and the maps using libraries "maps" (Richard et al., 2014), "maptools" (Bivand and Lewin-Koh, 2013), "mapplots" (Gerritsen, 2014) and "shapefiles" (Stabler, 2013). Additional libraries used in the analysis included "classInt " (Bivand, 2013), "nortest" (Gross and Ligges, 2012), "car" (Fox and Weisberg, 2011), "perm" (Fay and Shaw, 2010), "doBy" (Højsgaard et al., 2014), "tweedie" (Dunn, 2014), "statmod" (Smyth et al., 2015) and "lsmeans" (Lenth, 2015).

3. Results and Discussion

3.1. Distribution and trends in the size distribution

Size data for SWO was available for 53,411 specimens, specifically 34,337 from the North Atlantic stock and 19,074 from he South. The sizes ranged from 45-312 cm LJFL in the North and from 52-312 cm LJFL in the South.

Mapping the catch by size classes seems to indicate that the smaller specimens occur mostly in more tropilca waters closer to areax such as the Azores and Cabo Verde Islands, while the larger specimens occur in the South Atlantic and also in temperate waters off mainland Portugal (**Figure 2**).

There was some variability observed in the size frequency distribution of SWO in the Atlantic regions. In some areas such as the BIL94B, BIL96 and BIL97, while BIL94A and BIL94C were bimodal (**Figure 3**). This could be an issue that might need further investigation in the future and a possible revision of the sampling areas, in order to define areas with more unimodal distributions of the size classes that can more easily be used in integrated stock assessment models.

The time series of the catch at size distribution for the Portuguese fleet showed some increasing trends in the North Atlantic especially after 2010, and was mostly stable in the South Atlantic over the entire period (**Figure 4**. In terms of size frequencies distribution, there was some inter-annual variability and also some evidence of increasing size frequency distributions mainly in the North Atlantic (**Figure 5**).

3.2. Distribution of the catch and effort in the North Atlantic

The SWO nominal CPUEs in the North Atlantic were mainly concentrated in temperate waters of the central north region between the Azores and mainland Portugal, with some peaks in other areas such as the equatorial region (**Figure 6**). Such spatial distribution of the nominal CPUEs might be related with the species spatial and seasonal trends, but also with the spatial and seasonal dynamics of the fleet.

Regarding the fishery, most of the effort that was sampled took place in the temperate northeast area, as that is a major area of operation of the Portuguese pelagic longline fleet in the Atlantic (**Figure 7**). However, the effort is also distributed along a wide spatial distribution, including both temperate and tropical waters mainly along the eastern Atlantic (**Figure 7**).

3.3. CPUE data characteristics

The swordfish is the main target species of the fishery. Only 1.9% of the trips or sub-trips considered in this study had zero swordfish catches in the North Atlantic, ranging annually from 0% to 10.1%. There were some trends in the proportion of zeros along the study period, with most years having no sets with 0 SWO catches, especially in the earlier years, then more years with no SWO catches especially in 2008-2009, and then again less % of 0 SWO catches in the more recent years (**Figure 8**). Those patterns might again be related with the spatial/seasonal distribution of the fleet that in some sets in some years might change slightly the practices to target mainly sharks.

For the nominal CPUE time series there was a general and clear overall increase in the series between the entire period, even though there were some oscillations and variability between year (**Figure 9**). The nominal swordfish CPUE distribution was skewed to the right due to the presence of the a main proportion of data points in the left size of the distribution, that progressively decreased to the right (**Figure 10**). Once log-transformed (positives only) the distribution became more normal shaped (**Figure 10**).

In terms of seasonality of the SWO CPUEs, it was noticeable that higher catch rates tended to occur in the autumn and winter months, while lower catches are recorded in the summer (**Figure 11**).

3.4. Standardized CPUE for the North Atlantic

All the explanatory variables tested for the SWO CPUE standardization were significant and contributed significantly for explaining part of the deviance (**Table 2**). In general, the factors that contributed most for the deviance explanation were the targeting, year, quarter and area. The interactions in the tweedie and lognormal models also contributed significantly (**Table 2**). The interactions Quarter:Area and Area:TargetingRatio were also significant and included (**Table 2**).

In terms of model fit the following is noted:
- GLM Delta lognormal: Good fit of the lognormal model (positives only) but problems in the Binomial model due to the low % of zeros (only 1.9% of zeros, and therefore lack of data in some 0/1s combinations).
- GLM tweedie: good fit of the model and no major problems in the residuals. The model can account for 2.6% of zeros, very similar to the 1.9% observed in the data;
- GLM lognormal (adding a constant): In general good model fit and no problems in the residuals.
- GLMM lognormal (adding a constant): In general good model fit and better fit of the residuals (compared to the GLM lognormal). Advantage of including year factor interaction as a random effect.

The residuals of the several tested models are shown in **Figure 12**. In terms of model validation, the residual analysis, including the residuals distribution along the fitted values, the QQ plots and the residuals histograms, showed that the models were in general adequate with no major outliers or trends in the residuals (**Figure 12**). However, the residuals of the GLMM lognormal seemed to have the best fit.

In terms of comparisons between the various model approaches tested, most options were very similar, specifically the tweedie and lognormals adding a constant. By the contrary, the Delta method had similar overall increasing trends, but was more variable and had more differences than the others, and also showed a drop in the end that was not accompanying the nominal series (**Figure 13**). As such, and considering the fits and the residual analysis, the GLMM using a lognormal (adding a constant) seemed the better fitted model.

For this final model, a sensitivity analysis to the targeting factor was carried out, as this is a variable that still raises some questions on its use. The sensitivity is shown in **Figure 14** and shows that even thought there was some variability in the series the overall trends were very similar when using or not using the targeting ratios. As such, we recommend using this variable as it improves model fit.

The final standardized SWO CPUE index (kg/1000 hooks) for the Portuguese pelagic longline fishery in the North Atlantic stock area between 1999-2016 shows a general increase of the series with some annual oscillations (**Figure 16**). The final standardized CPUE series suggested to be used in the 2017 SWO stock assessment (north Atlantic) for this fleet is presented in **Table 3**.

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Table 1. Annual swordfish catch (tones, MT) by the Portuguese pelagic longline fishery in the North Atlantic stock area (>5ºN), with a summary of the data coverage for the analysis: Catch (MT), relative percentage of the catch covered in the analysis, and effort (in sets and hooks) covered in the analysis. Only data below the dotted line was used in the CPUE standardization models.

Year	Total catch (t)	Covered in the analysis				
		Catch (t)	%	Trips/Sub-trips	Effort (sets)	Effort (hooks)
1995	1,116.0	35.7	3.2	8	47	75,200
1996	999.0	26.3	2.6	4	52	83,200
1997	586.0	74.4	12.7	28	181	367,500
1998	558.0	128.0	22.9	42	257	494,400
1999	507.0	254.3	50.2	66	512	918,800
2000	503.6	329.7	65.5	142	928	1,418,610
2001	476.4	375.3	78.8	139	802	1,034,908
2002	511.6	202.0	39.5	92	647	783,850
2003	701.7	287.0	40.9	113	734	851,102
2004	1,090.4	426.4	39.1	125	792	876,482
2005	567.8	380.7	67.0	109	902	1,048,178
2006	638.5	202.0	31.6	72	464	522,917
2007	575.9	247.2	42.9	95	562	567,790
2008	659.0	259.5	39.4	92	619	640,946
2009	775.1	328.1	42.3	89	695	730,782
2010	736.5	349.6	47.5	94	783	817,542
2011	1,020.2	218.4	21.4	50	470	482,839
2012	649.4	420.8	64.8	69	663	712,567
2013	1,314.8	610.7	46.4	81	958	973,168
2014	1,115.1	266.8	23.9	46	489	515,191
2015	1355.14	352.7	26.0	59	558	541,854
2016		456.7		81	785	747,120

Table 2. Deviance tables of the parameters used for the SWO CPUE standardization models in the North Atlantic, using the various model analysis: GLM tweedie, GLM Delta lognormal, GLM lognormal adding a constant and GLMM lognormal adding a constant. For each parameter it is indicated the degrees of freedom (Df), the deviance (Dev), the residual degrees of freedom (Resid Df), the residual deviance (Resid. Dev), the F-test statistic and the significance (*p-value*).

Model	**Df**	**Dev**	**Resid. Df**	**Resid. Dev.**	**Stat. (F/Chisq)**	***p-value***
GLM Tweedie						
(Intersept only)			1613	29380		
Year	17	4603.0	1596	24777	30.95	< 0.001
Quarter	3	2390.4	1593	22386	91.09	< 0.001
Area	3	374.1	1590	22012	14.26	< 0.001
TargetingRatio	8	6578.0	1582	15434	94.00	< 0.001
Quarter:Area	9	274.1	1573	15160	3.4819	< 0.001
Area:TargetingRatio	24	446.7	1549	14714	2.1278	0.001
GLM Delta - lognormal model						
(Intersept only)			1583	856.62		
Year	17	138.8	1566	717.81	28.48	< 0.001
Quarter	3	80.1	1563	637.75	93.09	< 0.001
Area	3	24.1	1560	613.62	28.06	< 0.001
TargetingRatio	3	167.3	1557	446.34	194.50	< 0.001
GLM Delta - binomial model						
(Intersept only)			1613	298.56		
Year	17	65.913	1596	232.64	76.91	< 0.001
Quarter	3	0.28	1593	232.36	0.59	0.96
Area	3	9.524	1590	222.84	20.05	0.02
TargetingRatio	3	58.656	1587	164.18	58.66	< 0.001
GLM Lognormal						
(Intersept only)			1613	731.8		
Year	17	91.03	1596	640.7	23.69	< 0.001
Quarter	3	60.54	1593	580.2	89.29	< 0.001
Area	3	9.81	1590	570.4	14.47	< 0.001
TargetingRatio	8	201.69	1582	368.7	111.55	< 0.001
Quarter:Area	9	5.92	1573	362.8	2.91	< 0.001
Area:TargetingRatio	24	12.68	1549	350.1	2.34	< 0.001

Table 3. Nominal and standardized CPUEs (kg/1000 hooks) for SWO captured by the Portuguese pelagic longline fishery in the North Atlantic. The point estimates, 95% confidence intervals and the CV of the standardized index are presented.

Year	Nominal CPUE	Standardized CPUE index			
		Estimate	Lower CI (95%)	Upper CI (95%)	CV
1999	270.3	217.6	170.7	274.8	0.13
2000	385.5	308.5	254.4	372.5	0.16
2001	372.1	323.3	266.2	390.8	0.16
2002	264.0	281.9	228.4	345.8	0.14
2003	339.8	328.9	271.0	397.4	0.14
2004	508.9	395.9	332.5	469.8	0.14
2005	350.2	305.2	258.3	359.4	0.12
2006	377.5	301.2	248.6	363.2	0.12
2007	426.2	329.4	277.9	389.1	0.12
2008	380.9	305.1	255.3	363.1	0.12
2009	476.4	365.6	307.9	432.8	0.12
2010	460.4	416.4	351.6	491.8	0.12
2011	456.1	357.0	290.1	437.4	0.11
2012	623.2	487.2	404.4	585.3	0.12
2013	641.2	457.2	375.1	555.4	0.13
2014	563.9	426.2	341.2	530.0	0.11
2015	709.0	583.3	474.2	715.3	0.12
2016	649.1	551.6	445.5	680.6	0.14

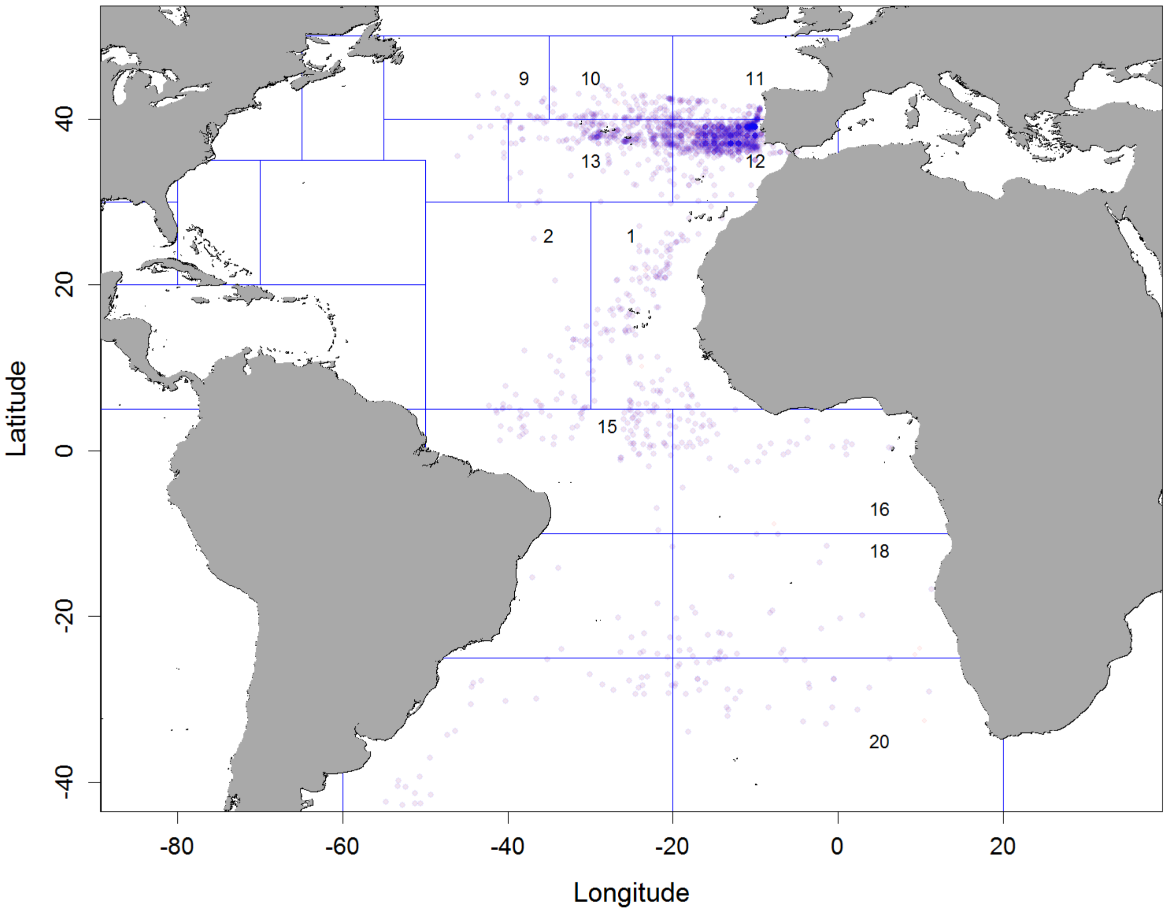


Figure 1. Sampling locations with the definition of fishing areas of the Atlantic for the swordfish used in this study (according to the area definitions by Ortiz et al., 2010). The red dots represent sampling locations (trips or sub-trips) and the violet dots represent trips or sub-trips with positive shortfin mako catches. Due to small sample sizes, the areas "1+2", "13+14" and "9+10+11", "15+16" and "18+20" were joined for the models, creating latitudinal gradients in the area definitions.

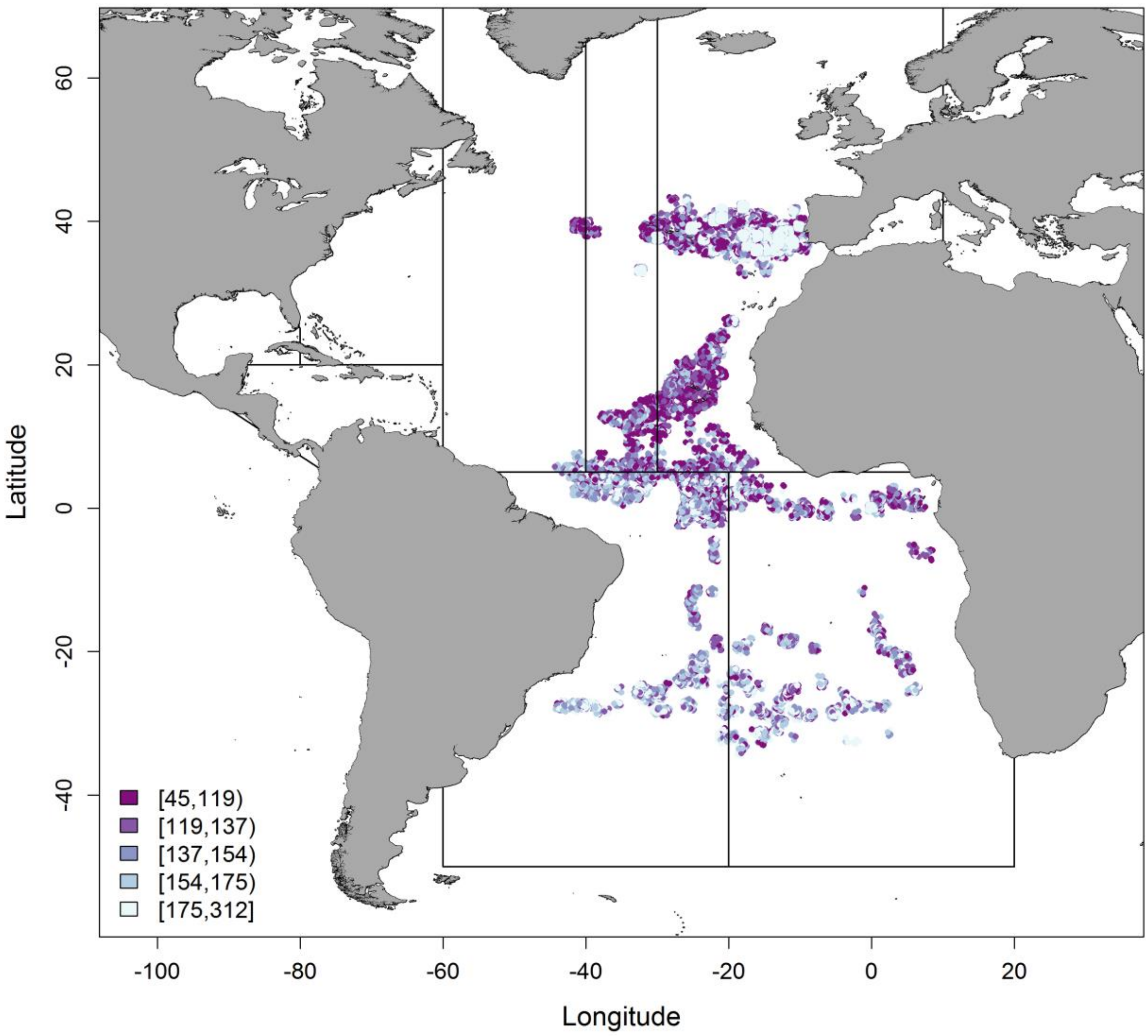


Figure 2. Location and size (LJFL, cm) of the SWO recorded by the Portuguese pelagic longline fleet in the Atlantic until 2016. The size classes are categorized by the 0.2 quantiles and colour coded. The ICCAT sampling areas for sharks (BIL areas) are represented. For visualization purposes, the data points are jittered by 1º * 1º degrees so the positions shown are approximate within each 1º *1º square degree.

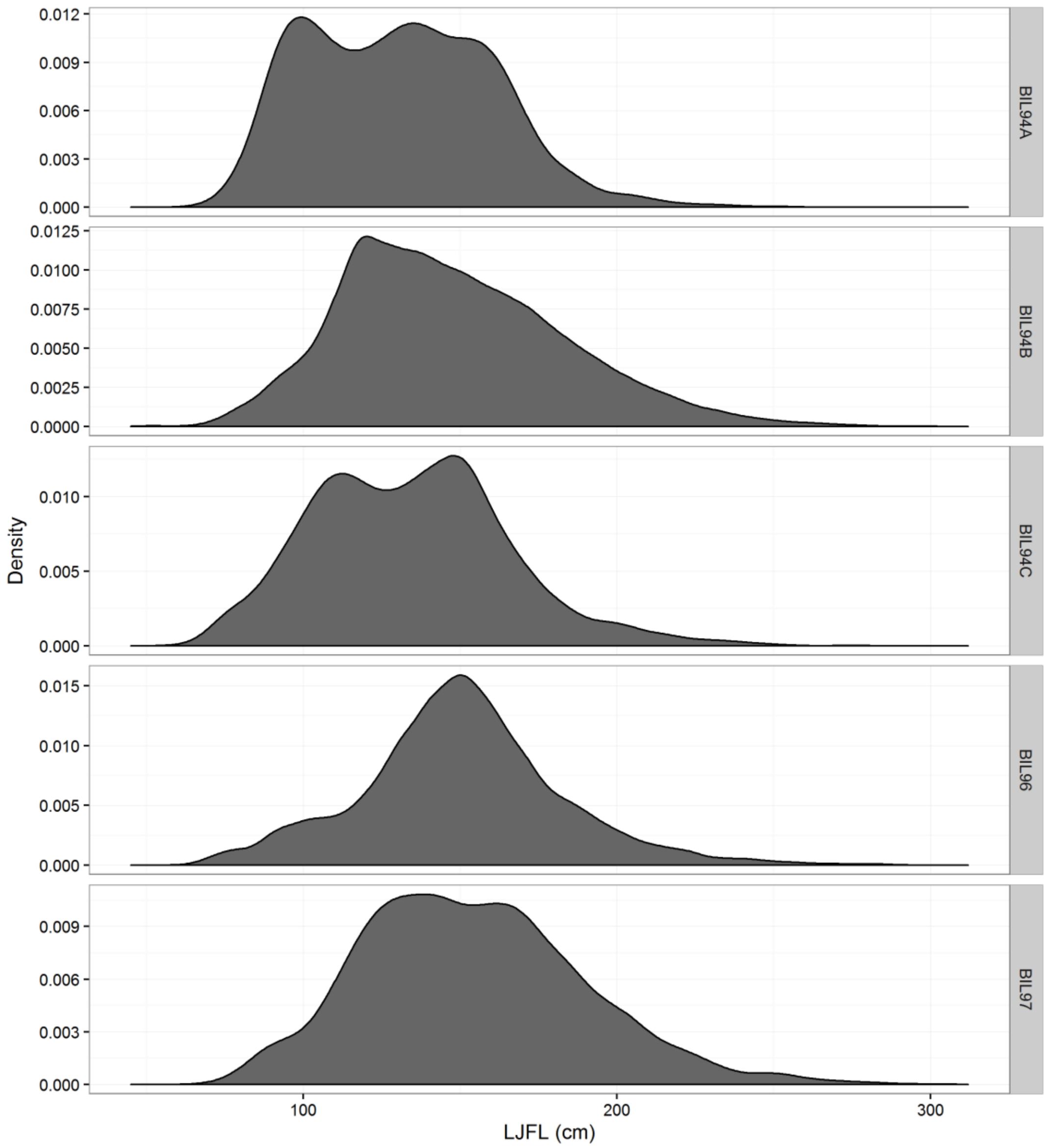


Figure 3. Size-frequency distributions of SWO caught in the ICCAT sampling areas of the Atlantic Ocean by the Portuguese pelagic longline fleet, until 2016.

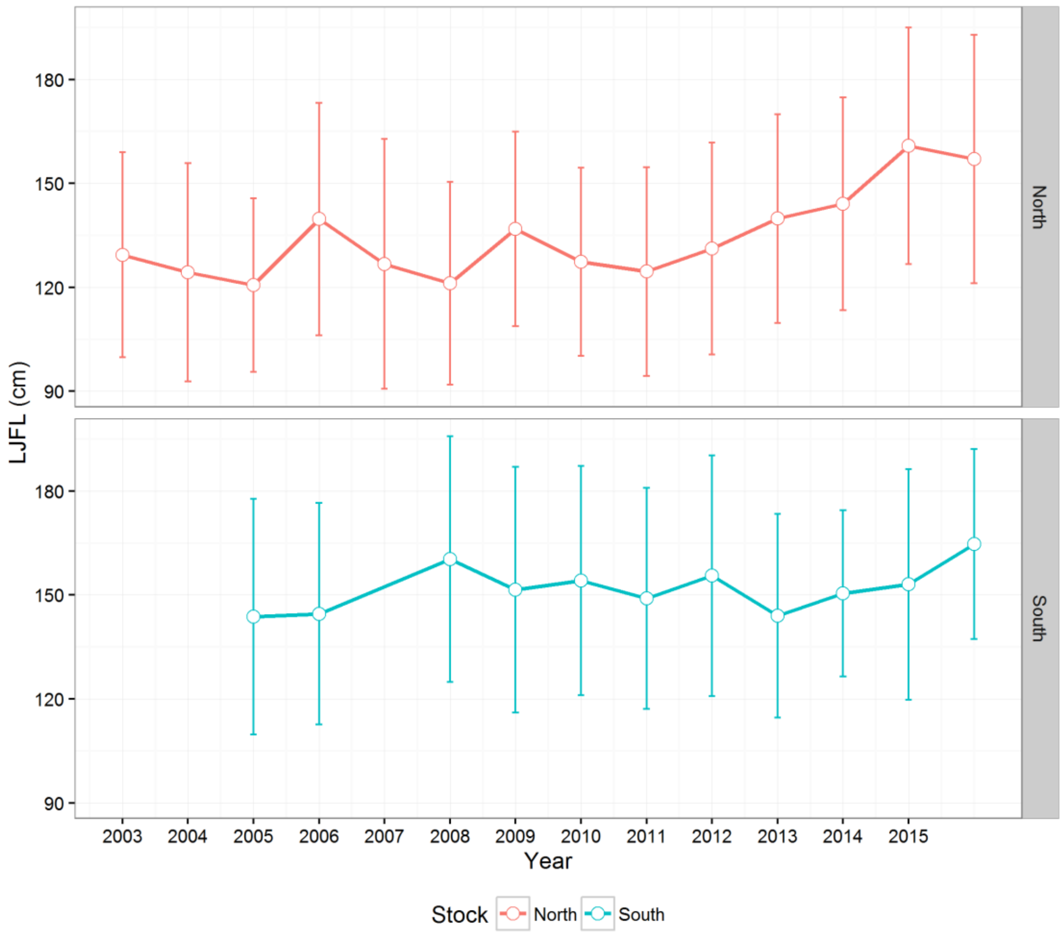


Figure 4. Time series of the mean sizes of SWO caught by the Portuguese pelagic longline fleet in each of the Atlantic stocks. The error bars are ± 1 standard deviations.

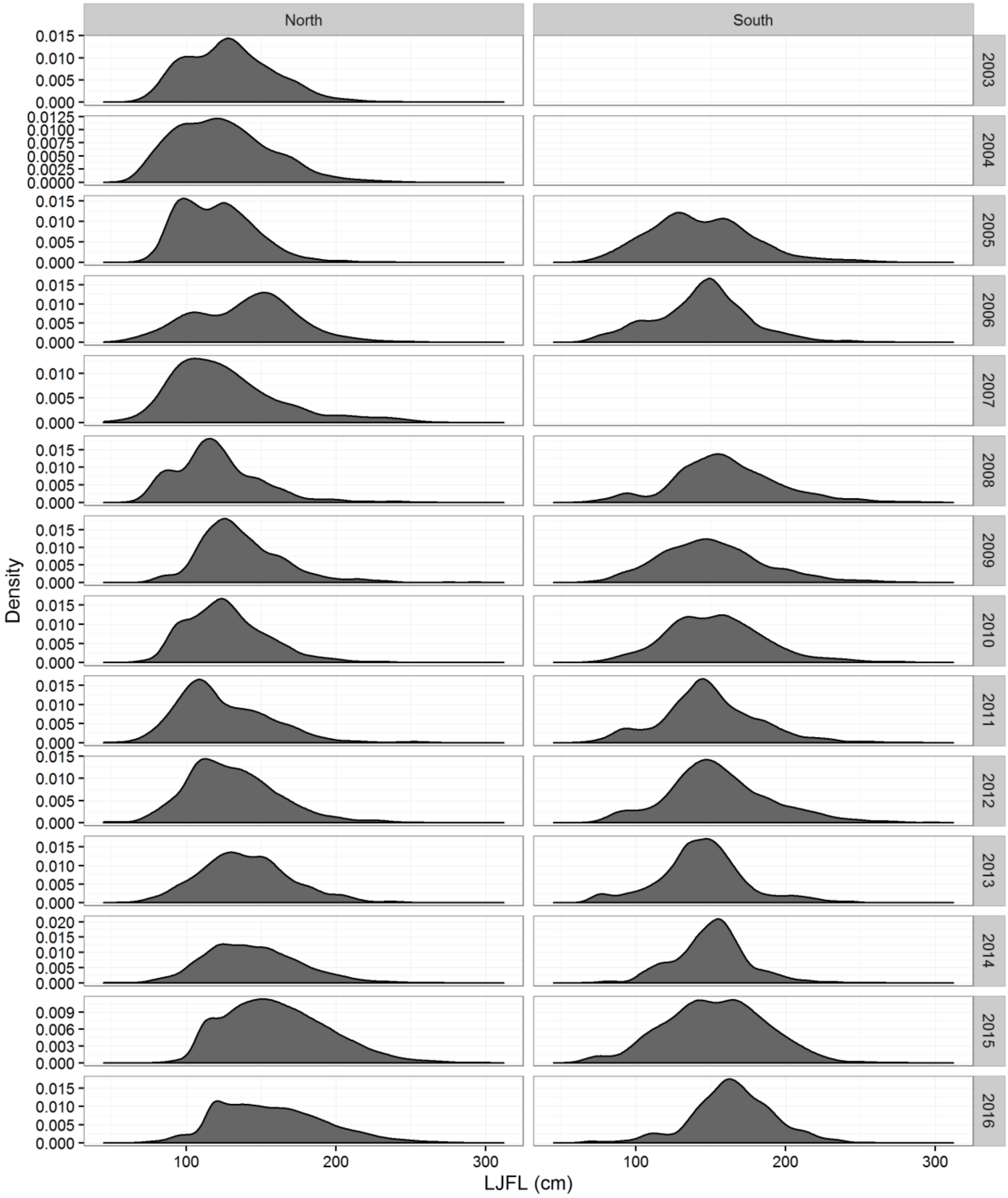


Figure 5. Variation of the yearly size-frequency distributions of SWO caught in each Atlantic stocks by the Portuguese pelagic longline fleet.

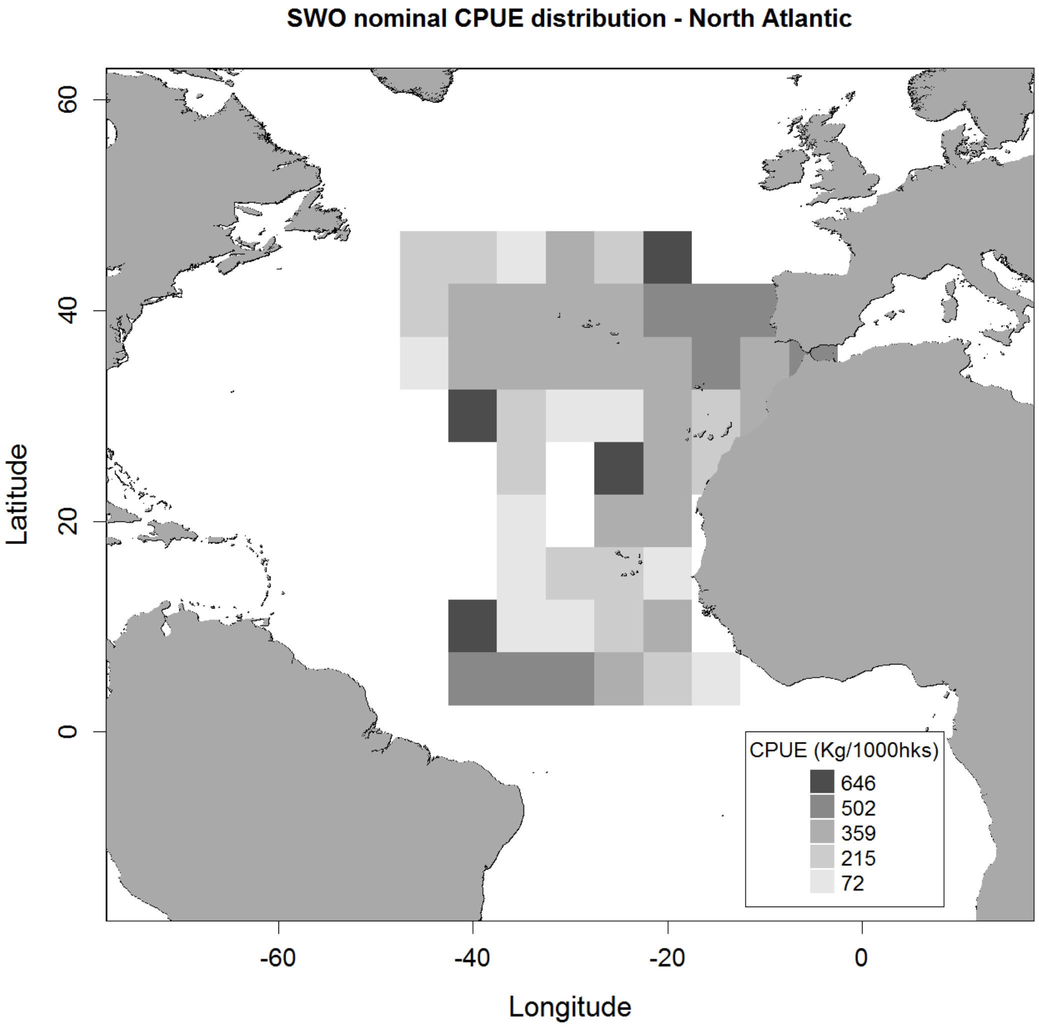


Figure 6. Map of the North Atlantic swordfish nominal CPUEs (all years combined, data between 1999 and 2016) in areas of operation of the Portuguese pelagic longline fleet. The squares are in 5*5º and the average CPUEs are in Kg/1000 hooks.

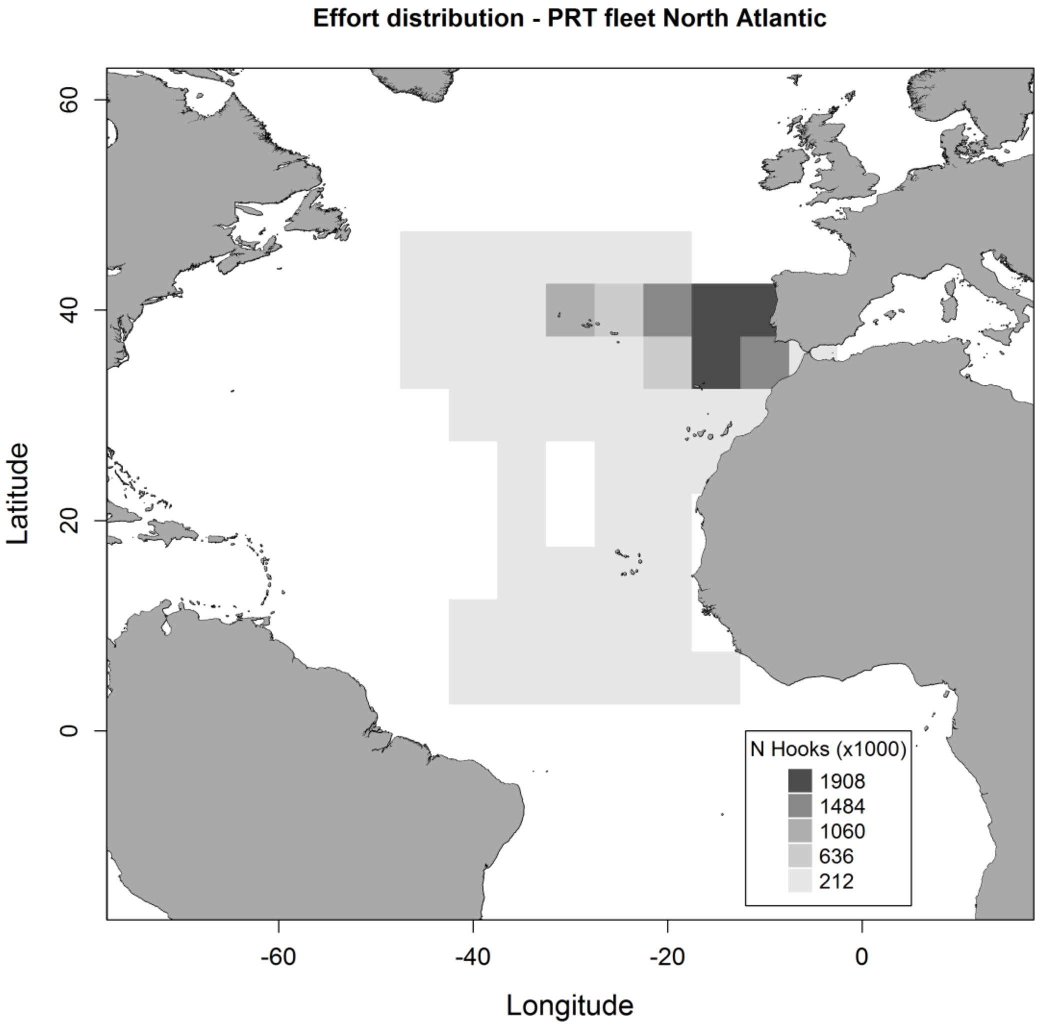


Figure 7. Effort distribution of the Portuguese pelagic longline fleet sampled in the North Atlantic used in this study, for the period 1999-2016. The effort is represented in number of hooks (x1000) in 5x5 degree grids.

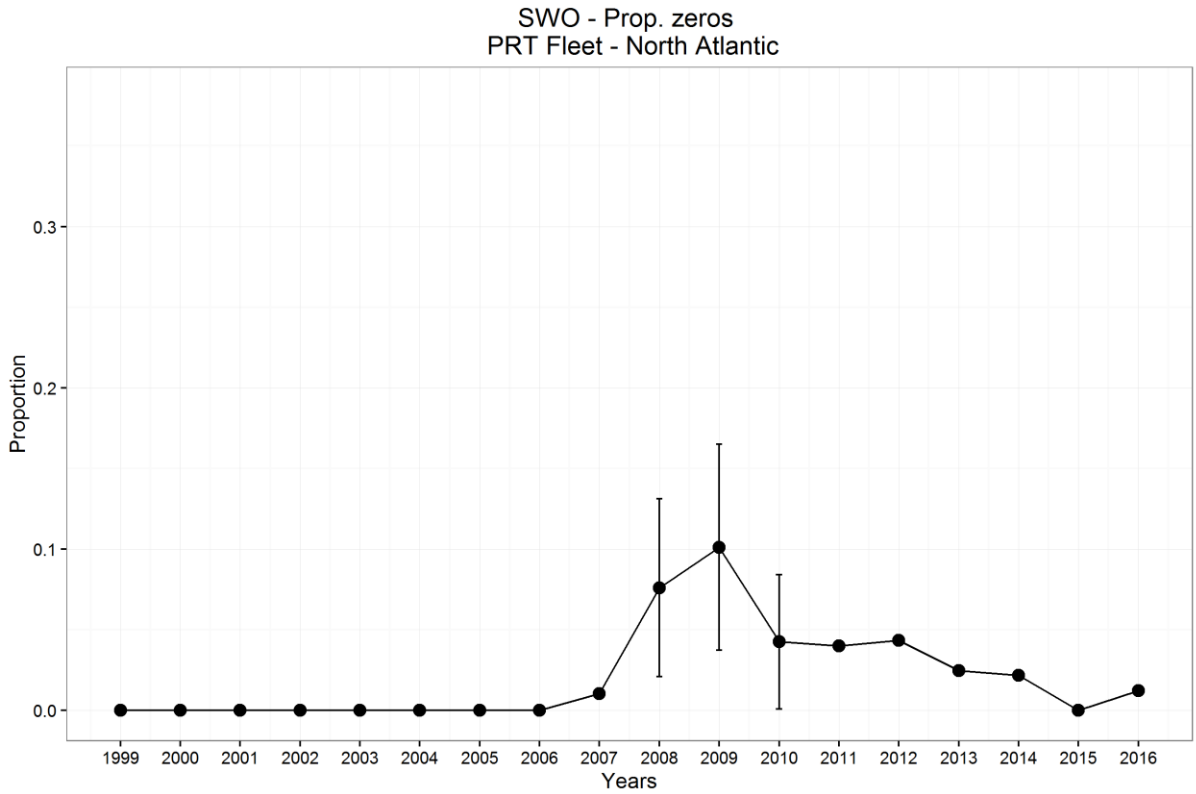


Figure 8. Proportion of trips or sub-trips with zero swordfish catches in the Portuguese pelagic longline fishery targeting swordfish in the North Atlantic between 1999 and 2016. The error bars represent 95% confidence intervals.

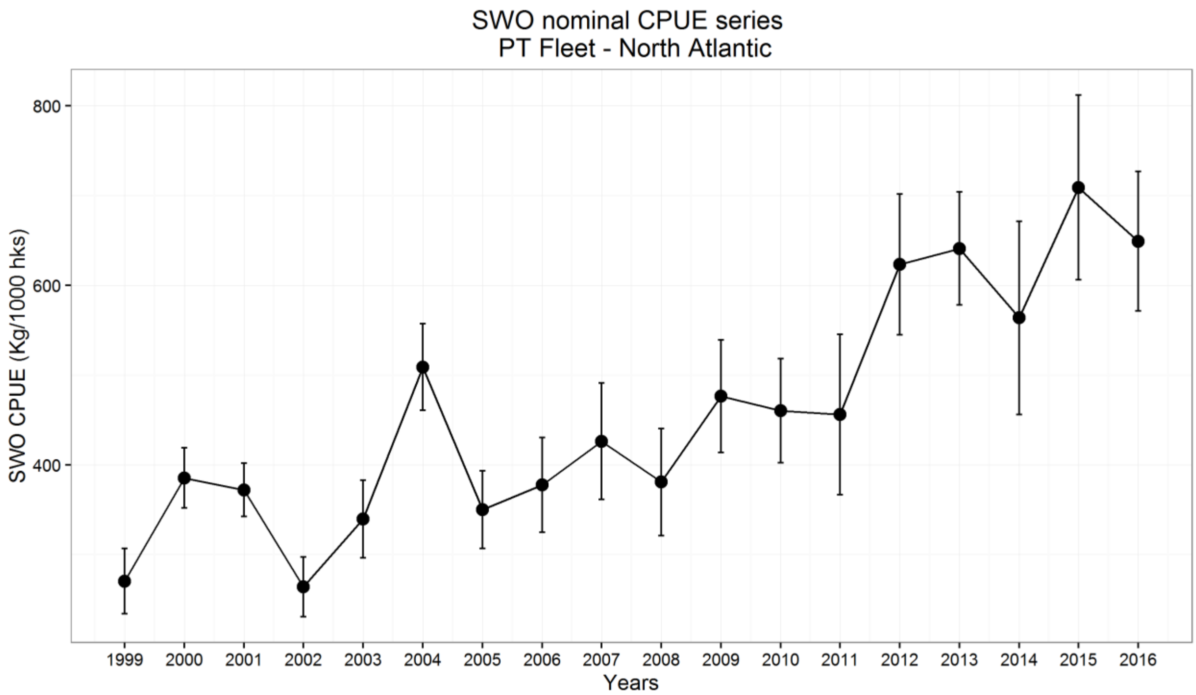


Figure 9. Nominal CPUE series (Kg/1000 hooks) for swordfish caught by the Portuguese pelagic longline fishery in the North Atlantic Ocean, between 1999 and 2016. The error bars represent 95% confidence intervals.

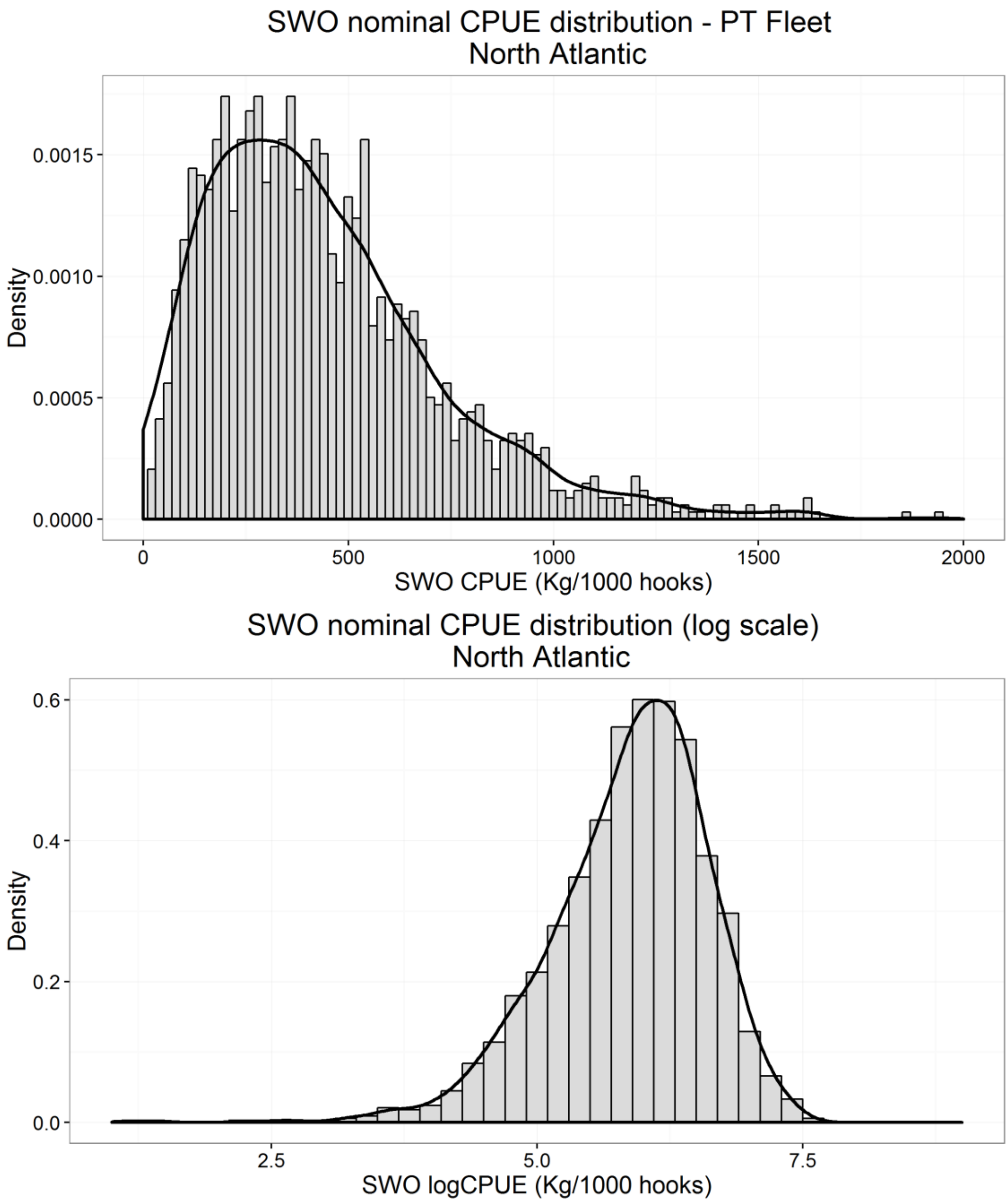
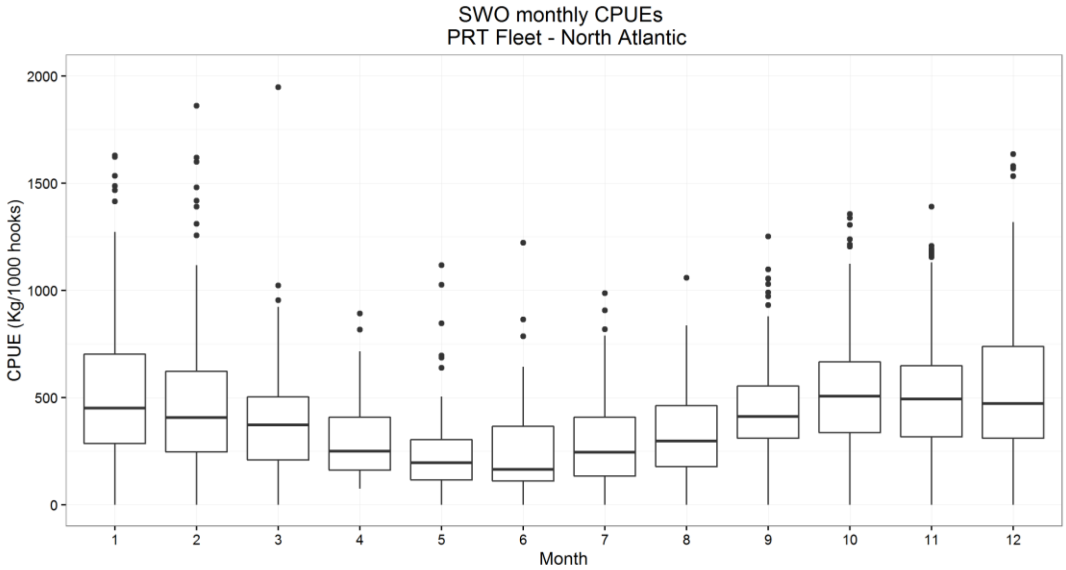


Figure 10. Distribution of the nominal swordfish CPUE captured by the Portuguese pelagic longline fleet in the North Atlantic, in non-transformed (top) and log-transformed scale (excluding zeros, bottom).



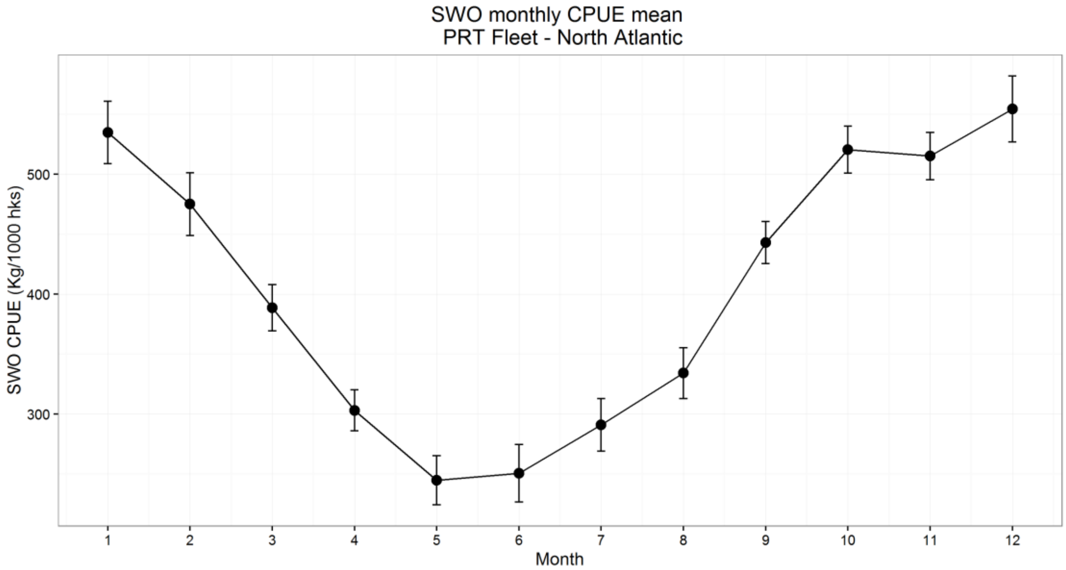
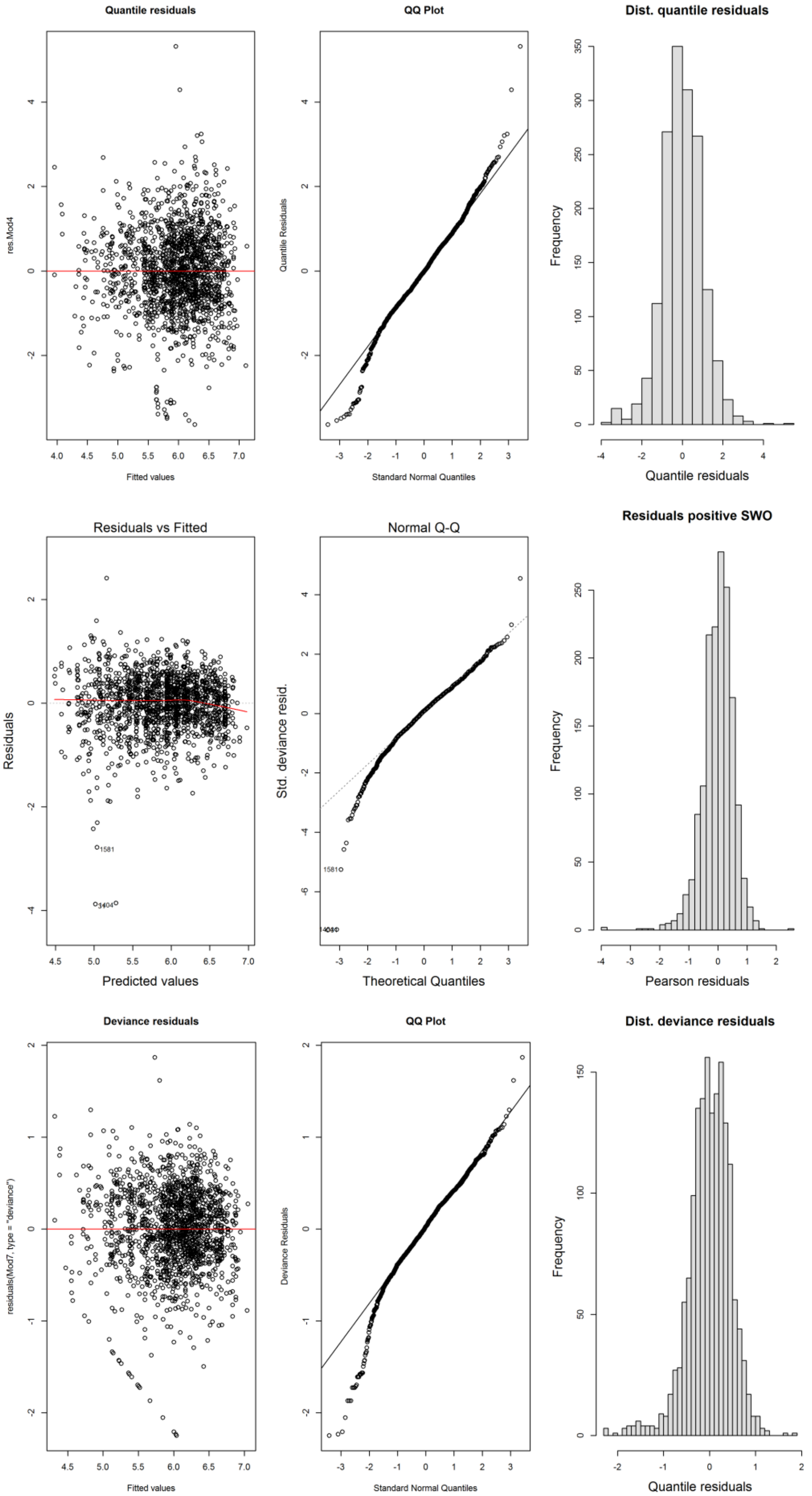


Figure 11. Monthly distribution of the SWO CPUEs caught by the Portuguese pelagic longline fishery in the North Atlantic Ocean, between 1999 and 2016. The plot on the top are boxplots of the CPUE and the plot on the bottom are the monthly averages with the standard errors.


Quantile residuals
res.Mod4
Fitted values
QQ Plot
Quantile Residuals
Standard Normal Quantiles
Dist. quantile residuals
Frequency
Quantile residuals
Residuals vs Fitted
Residuals
Predicted values
1581
1404
Normal Q-Q
Std. deviance resid.
Theoretical Quantiles
1581
Residuals positive SWO
Frequency
Pearson residuals
Deviance residuals
residuals(Mod7, type = "deviance")
Fitted values
QQ Plot
Deviance Residuals
Standard Normal Quantiles
Dist. deviance residuals
Frequency
Quantile residuals

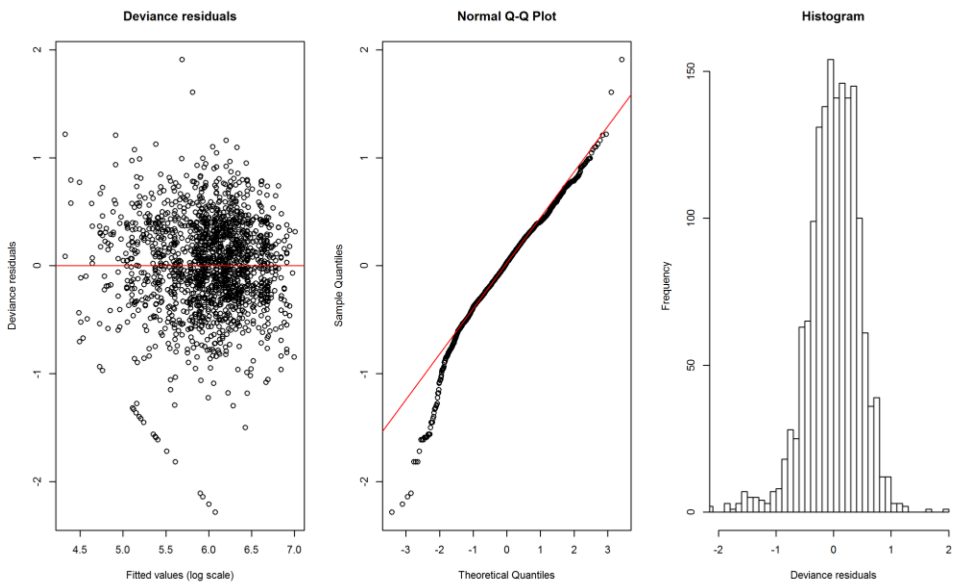


Figure 12. Residual analysis for the final models used as sensitivity runs for the SWO CPUE standardization in the North Atlantic. The 3 graphics on the top are from the tweedie model (quantile residuals), the 2nd row is from the Delta model (lognormal component), the 3rd row is from the GLM lognormal (adding a constant) and the bottom row is from the GLMM lognormal (adding a constant). The graphics on the left represent the values of the residuals along the predicted (log) values, the graphics in the middle represent the QQPlots, and the graphics on the right represent the frequency distribution (histograms) of the residuals. On the graphics on the left, the dotted grey line represents a horizontal line at y=0 and the solid red line the smoothed fit to the residuals.

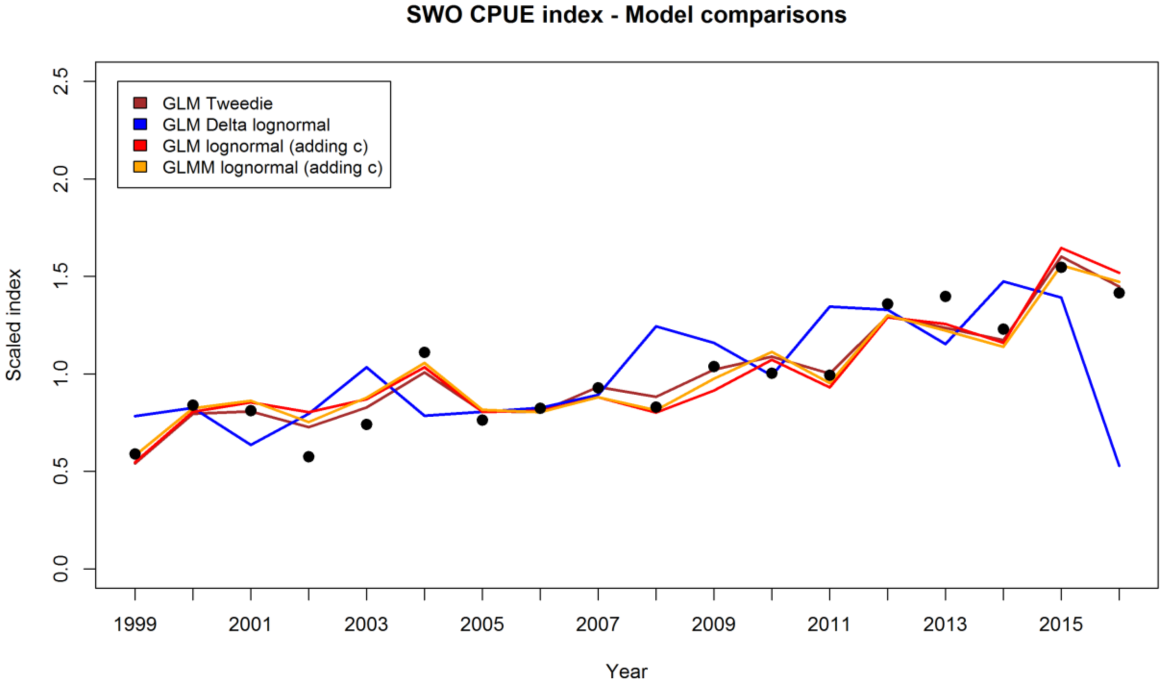


Figure 13. Comparison of the relative annual indexes of abundance for SWO captured by the Portuguese pelagic longline fleet in the North Atlantic (point estimates), using the following models: GLM tweedie, GLM Delta lognormal, GLM lognormal adding a constant and GLMM lognormal adding a constant. The black circles represent the nominal CPUEs. For comparison purposes the indexes and nominal series are scaled by their respective means.

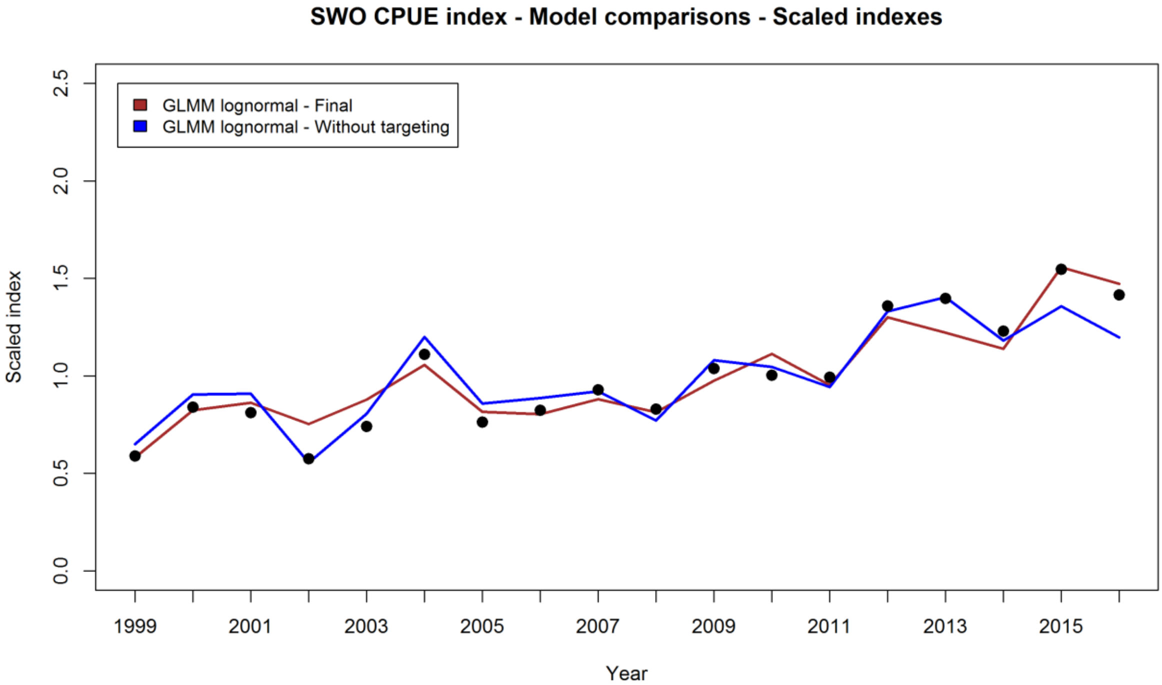


Figure 14. Comparison of the relative annual indexes of abundance for SWO captured by the Portuguese pelagic longline fleet in the North Atlantic (point estimates), using the final model (GLMM lognormal) with and without the targeting factor. The black circles represent the nominal CPUEs. For comparison purposes the indexes and nominal series are scaled by their respective means.

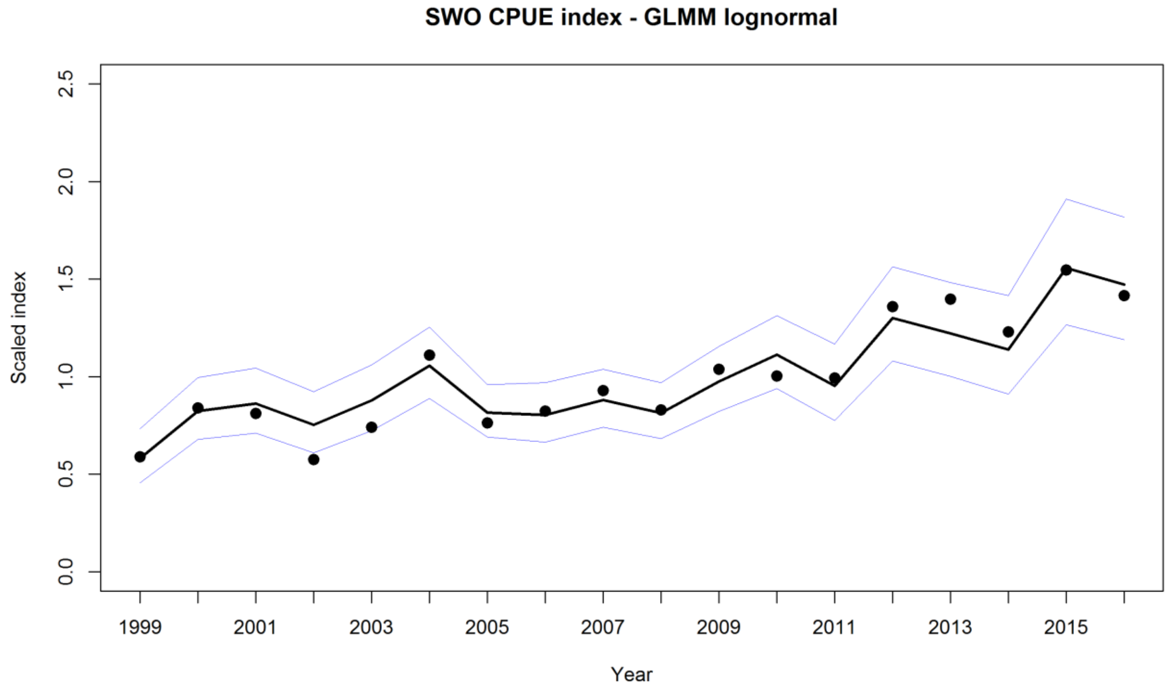


Figure 15. Final relative annual indexes of abundance for SWO captured by the Portuguese pelagic longline fleet in the North Atlantic (point estimates), using a GLMM lognormal. The black circles represent the nominal CPUEs. The errors lines represent the 95% confidence intervals of the series.