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CHARACTERIZATION AND STANDARDIZATION OF ATLANTIC SAILFISH (*ISTIOPHORUS ALBICANS*) CATCH RATES IN THE EAST ATLANTIC FROM THE PORTUGUESE PELAGIC LONGLINE FISHERY (1999-2015)

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SUMMARY

This document analyzes the catch, effort and standardized CPUE trends for the eastern Atlantic stock of Atlantic sailfish (Istiophorus albicans) captured by the Portuguese pelagic longline fleet from 1999-2015. Nominal annual CPUE were calculated as kg/1000 hooks and were standardized with Generalized Linear Models (GLM) with Tweedie distribution and using year, quarter, area and targeting effects (ratios) as explanatory variables. Model goodness-of-fit was determined with AIC and the pseudo coefficient of determination, and model validation was analyzed with residual analysis. The final standardized CPUE series shows a general decrease in the initial years, between 1999 and 2010, followed by a general increase in the more recent years, until 2015, with some inter-annual oscillations. This paper presents the first index of abundance for Atlantic sailfish estimated from captures from the Portuguese pelagic longline fleet in the east Atlantic and can be used for future stock assessments of the species.

RÉSUMÉ

*Le présent document analyse les tendances de la prise, de l'effort et de la CPUE standardisée pour le stock oriental de voiliers de l'Atlantique (*Istiophorus albicans*) capturés par la flottille palangrière pélagique portugaise entre 1999 et 2015. Des CPUE annuelles nominales ont été calculées comme kg/1.000 hameçons et ont été standardisées avec des modèles linéaires généralisés (GLM) avec une distribution Tweedie et en utilisant l'année, le trimestre, la zone et les effets de ciblage (ratios) comme variables explicatives. La qualité de l'ajustement du modèle a été déterminée au moyen de AIC et du pseudo coefficient de détermination et la validation du modèle a été analysée avec une analyse résiduelle. La série finale des CPUE standardisées montre une baisse générale au cours des premières années, entre 1999 et 2010, suivie d'une augmentation générale ces dernières années, jusqu'en 2015, avec quelques oscillations interannuelles. Ce document présente le premier indice d'abondance pour les voiliers de l'Atlantique estimé à partir des captures de la flottille palangrière pélagique portugaise opérant dans l'Atlantique Est et il peut être utilisé dans de futures évaluations de stocks de cette espèce.*

RESUMEN

En este documento se analizan las tendencias de captura, esfuerzo y CPUE estandarizada para el stock oriental de pez vela del Atlántico (Istiophorus albicans) capturado por la flota de palangre pelágico portuguesa entre 1999 y 2015. Las CPUE nominales anuales se calcularon como kg/1.000 anzuelos, y fueron estandarizadas con modelos lineales generalizados (GLM) con una distribución Tweedie y utilizando año, trimestre, área y efectos de especie objetivo (ratios) como variables explicativas. La bondad del ajuste del modelo se determinó con AIC y con el pseudo coeficiente de determinación, y la validación del modelo se realizó con un análisis residual. La serie final de las CPUE estandarizadas muestra un descenso general en los años iniciales, entre 1999 y 2010, seguido de un aumento general en los años más recientes, hasta 2015, con algunas oscilaciones interanuales. Este documento presenta el primer índice de abundancia para el pez vela del Atlántico estimado a partir de capturas de la flota de palangre pelágico portuguesa en el Atlántico este, y puede utilizarse en futuras evaluaciones de stock de esta especie.

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KEYWORDS

Atlantic sailfish, catch and effort, CPUE standardization, generalized linear models, pelagic longline fisheries.

1. Introduction

The Portuguese pelagic longline fishery in the Atlantic Ocean started in the late 1970's. In the North Atlantic 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 shallow water pelagic drift longline during night sets targeting mainly swordfish (SWO, *Xiphias gladius*), and it can have important by-catches of pelagic shark, mainly blue shark (BSH, *Prionace glauca*) and shortfin mako (SMA, *Isurus oxyrinchus*). However, this is a multi-species fishery and other species, including bony fishes as the Atlantic sailfish (SAI, *Istiophorus albicans*) are also captured occasionally.

Fisheries management is usually based on stock assessment models that require data on the abundance of the species under assessment (Hilborn and Walters, 1992). 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-dependent 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.

Given the ICCAT schedule to conduct a stock assessment of Atlantic sailfish during 2016, the aim of this study is to provide the first standardized index of abundance of that species captured by the Portuguese pelagic longline fishery in the east Atlantic.

2. Material and methods

2.1. Data collection

The data used for this study was collected by fishery observers onboard Portuguese pelagic longline vessels, port-sampling during landings and skippers logbooks (self-reporting) voluntarily provided to IPMA, for the period 1995-2015. The information on the total catch was provided by the Portuguese Fisheries Authorities (DGRM). The percentage of the catch covered in the analysis as regards to the overall yearly SAI catch in the east Atlantic varied between years, ranging from minimums of 0.1% to maximums of 90.9% per year, with an overall percentage of 2.2% across all years (excluding data from 1995-1998 that was not used in the CPUE standardization; see explanation below and **Table 1**). Data from a total of 1,740 trips or sub-trip (consecutive sets in the same trip, area and month) were used, which amounted to a total fishing effort of 12,865 sets, corresponding to 16,198,538 hooks (**Table 1**). Trips and sub-trips that were carried out outside the species general distribution range (i.e., outside 50°N in the northeast Atlantic and 32°S in the southeast Atlantic; according to Nakamura, 1985) were excluded from the analysis.

2.2. CPUE standardization

Catch and effort data for CPUE standardization was available between 1995 and 2015. The data from the first years of the series (1995 to 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 2015. 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).

As Atlantic sailfish is a relatively rare bycatch in this fishery, there were a large number of trips or sub-trips (91.9% of the data) with zero sailfish catches that results in a response variable of CPUE=0. As these zeros can cause mathematical problems for fitting the models, the approach chosen was a Tweedie model with link=log that can model both the continuous component of the response variable for the positive observations and the mass of zeros for the zero catches. For this model the nominal CPUE was used directly in the response variable given this specific characteristic of the distribution.

The covariates considered and tested in the models were:

- Year: analyzed between 1999 and 2015;
- 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 but not used in the final models. 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. However, due to the lack of sufficient data in the various levels of the covariates considered for the interactions, the models using interactions had problems in convergence. As such, the final models used in the standardization process were only simple effects models without interactions.

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., 2013; 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 for including targeting effects into the CPUE standardization process for the Portuguese pelagic longline fishery have been tested in the past. Coelho et al. (2015) 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. (2015) 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 the fishing areas according to **Figure 1**, that were defined by Ortiz et al. (2010) for swordfish and used before for other CPUE standardizations of the Portuguese fleet, as Santos et al. (2013) and Coelho et al. (2015) 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 Atlantic sailfish 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 catching mainly 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.

Statistical analysis for this paper was carried out with the R Project for Statistical Computing version 3.2.0 (R Core Team, 2015) using several additional libraries (Venables and Ripley, 2002; Wickham, 2007, 2009; Fox and Weisberg, 2011; Gross and Ligges, 2012; Becker et al., 2013; Bivand and Lewin-Koh, 2013; Dunn, 2013; Stabler et al., 2013; Lenth, 2014).

3. Results and Discussion

3.1 Distribution of the catch and effort

Atlantic sailfish is a rare bycatch in the Portuguese pelagic longline fishery. The catches of this species are only occasional and spread along the east Atlantic stock area, but particularly concentrated in tropical and equatorial regions (**Figure 1**). Regarding the fishery, most of the effort took place in the temperate northeast, as that is a major area of operation of the Portuguese pelagic longline fleet in the Atlantic (**Figure 2**). However, the effort is also distributed along a wide spatial distribution, including both temperate and tropical waters of the eastern Atlantic, in both hemispheres (**Figure 2**).

The total effort of the Portuguese longline fleet in the east Atlantic analyzed for this work increased in the first years of the series, and slightly decreased in the more recent years (**Figure 3**). This is related with the total fishing effort from the Portuguese pelagic longline fleet in the Atlantic Ocean and also with the annual coverage of the sampling effort. The analyzed sailfish catches did not directly follow this trend, as there was an increase in the catches until 2001, followed by a decrease between 2002 and 2012, and an increase in the more recent years (**Figure 3**). In terms of targeting, analyzed in the swordfish *vs.* swordfish + blue shark catches, the initial year of the series had higher ratios and were followed by lower values in the remaining years, that have been oscillating but not showing any major trends (**Figure 3**).

3.2 CPUE data characteristics

Overall, 91.9% of the trips or sub-trips considered in this study had zero sailfish catches in the east Atlantic stock area, even when excluding data outside the species latitudinal habitat range (**Figure 4**).

The nominal time series of the Atlantic sailfish CPUE is presented in **Figure 5**. There was a peak in the start of the series in 1999, followed by a sharp decrease until 2003, then a period until 2010 with oscillations and relatively lower CPUEs, and then an increase since 2010 until de end of the series in 2015 (**Figure 5**). The nominal Atlantic sailfish CPUE distribution was highly skewed to the right, due to the presence of the large mass of zeros (**Figure 6**). Once log-transformed (positives only) the distribution became more normal shaped (**Figure 6**).

3.3 CPUE standardization

All the explanatory variables tested for the Atlantic sailfish CPUE standardization were significant and contributed significantly for explaining part of the deviance (**Table 2**). As mentioned, it was not possible to include interactions due to the lack of sufficient data in all combinations, which resulted in problems with model convergence if interactions were used. On the final model, the factors that contributed most for the deviance were the area, followed by quarter, year and targeting effects (**Table 2**).

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 model was adequate with no major outliers or trends in the residuals (**Figure 7**).

The final standardized Atlantic sailfish CPUE index (kg/1000 hooks) for the Portuguese pelagic longline fishery in the east Atlantic stock between 1999-2015 shows a general decrease in the initial years, between 1999 and 2010, followed by a general increase in the more recent years until 2015, with some inter-annual oscillations (**Figure 8**). The final standardized CPUE series suggested to be used in future Atlantic sailfish stock assessments is presented in **Table 3**.

4. Acknowledgments

Data used in this study was collected integrated in PNAB (*Programa Nacional de Amostragem Biologica*) within the EU *DCF - Data Collection Framework*. Special thanks are due to all skippers that voluntarily provided data from their fishing activities in the ICCAT convention area and to the fishery observers and technicians that collected the onboard and port sampling data. Rui Coelho is supported by an *Investigador-FCT* contract from the Portuguese Foundation for Science and Technology (FCT) supported by the EU European Social Fund and the *Programa Operacional Potencial Humano* (Ref: IF/00253/2014).

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Table 1. Annual Atlantic sailfish catch (tones, MT) by the Portuguese pelagic longline fishery in the east Atlantic sailfish stock area, 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 SAI catch (MT)	Covered in the analysis			
		SAI Catch (MT)	%	Effort (sets)	Effort (hooks)
1995	1.62	0.06	3.7	47	75,200
1996	1.42	0.06	3.9	52	83,200
1997	1.52	1.29	84.9	332	817,809
1998	27.26	0.14	0.5	368	841,190
1999	53.00	1.95	3.7	586	1,158,210
2000	10.70	2.26	21.1	1005	1,516,920
2001	3.30	3.00	90.9	877	1,137,656
2002	7.60	1.06	13.9	687	842,250
2003	12.66	0.06	0.5	734	851,102
2004	19.19	0.19	1.0	775	856,183
2005	31.24	1.15	3.7	922	1,069,434
2006	136.36	1.76	1.3	638	734,954
2007	42.76	1.36	3.2	737	793,390
2008	48.63	0.52	1.1	770	832,716
2009	103.19	1.39	1.3	857	947,204
2010	170.38	0.11	0.1	818	866,082
2011	121.46	0.67	0.6	616	684,341
2012	70.13	0.73	1.0	700	766,003
2013	108.62	2.54	2.3	969	987,028
2014	32.71	2.17	6.6	474	496,066
2015	-	3.69	-	615	611,920

Table 2. Deviance table of the parameters used for the Atlantic sailfish CPUE standardization models for the east Atlantic, using a Tweedie GLM with link=log. 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**	**F-stat.**	***p-value***
(Intersept only)			1641	11019.9		
Year	16	904.5	1625	10115.4	4.73	< 0.001
Year + Quarter	3	1890.0	1622	8225.3	52.72	< 0.001
Year + Quarter + Area	4	2113.5	1618	6111.8	44.21	< 0.001
Year + Quarter + Area + Target Ratio	9	498.3	1609	5613.5	4.63	< 0.001

Table 3. Nominal and standardized CPUEs (kg/1000 hooks) for Atlantic sailfish captured by the Portuguese pelagic longline fishery in the east 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	3.12	3.98	2.05	7.73	16.2
2000	1.58	1.52	0.78	2.97	23.2
2001	0.92	1.40	0.64	3.06	26.4
2002	1.02	2.12	0.89	5.00	23.8
2003	0.28	0.74	0.23	2.36	34.8
2004	0.39	1.28	0.48	3.43	30.8
2005	1.15	1.18	0.59	2.38	20.9
2006	1.46	0.41	0.18	0.96	22.3
2007	1.63	0.47	0.22	1.01	23.3
2008	0.57	0.29	0.10	0.84	30.5
2009	1.05	0.37	0.16	0.84	23.6
2010	0.10	0.08	0.01	0.47	50.3
2011	1.44	0.90	0.33	2.45	21.6
2012	2.35	0.83	0.35	1.95	20.7
2013	1.69	0.71	0.30	1.67	22.0
2014	3.68	1.77	0.74	4.20	16.6
2015	2.61	1.52	0.69	3.34	17.6

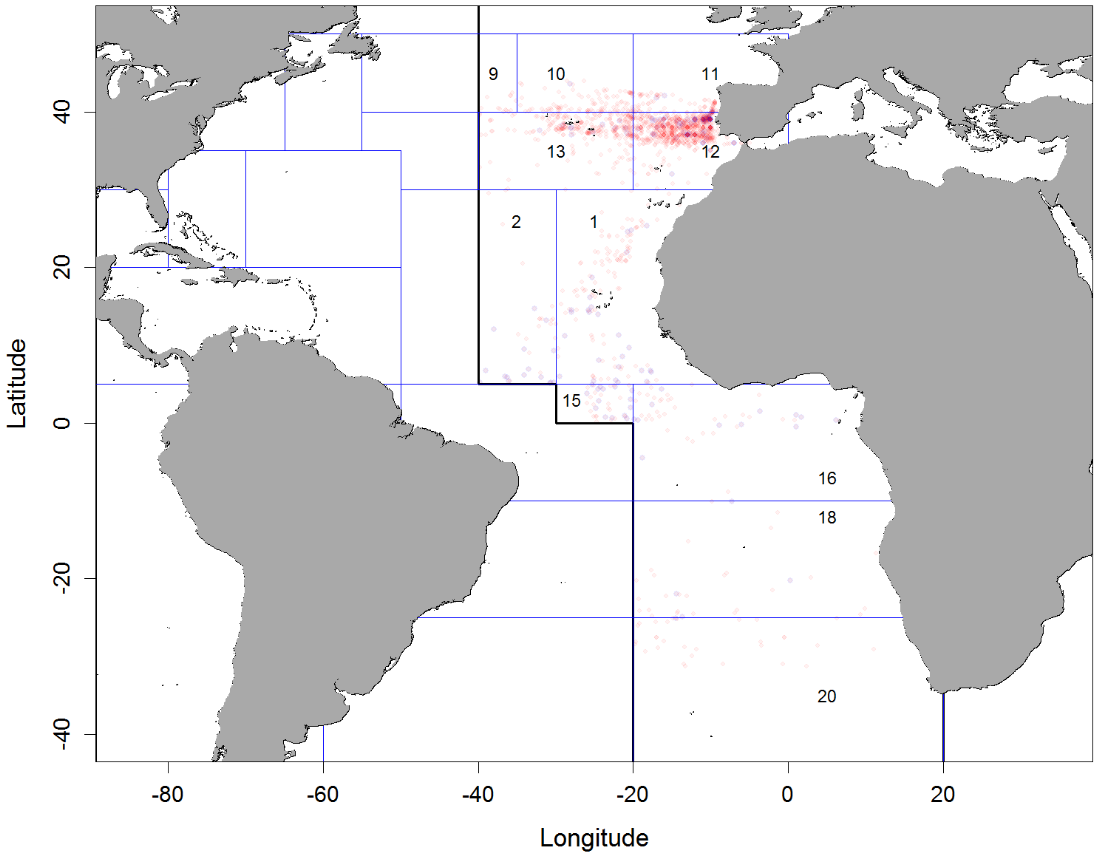

Figure 1. Sampling locations with the definition of fishing areas of the east Atlantic sailfish stock used in this study (according to the area definitions by Ortiz et al., 2010). The red dots represent sampling locations (trips or sub-trips) and the violet dots represent trips or sub-trips with positive sailfish catches. Due to small sample sizes, the areas "9+10+11", "12+13", "1+2", "15+16" and "18+20" were joined for the models, creating latitudinal gradients in the area definitions.

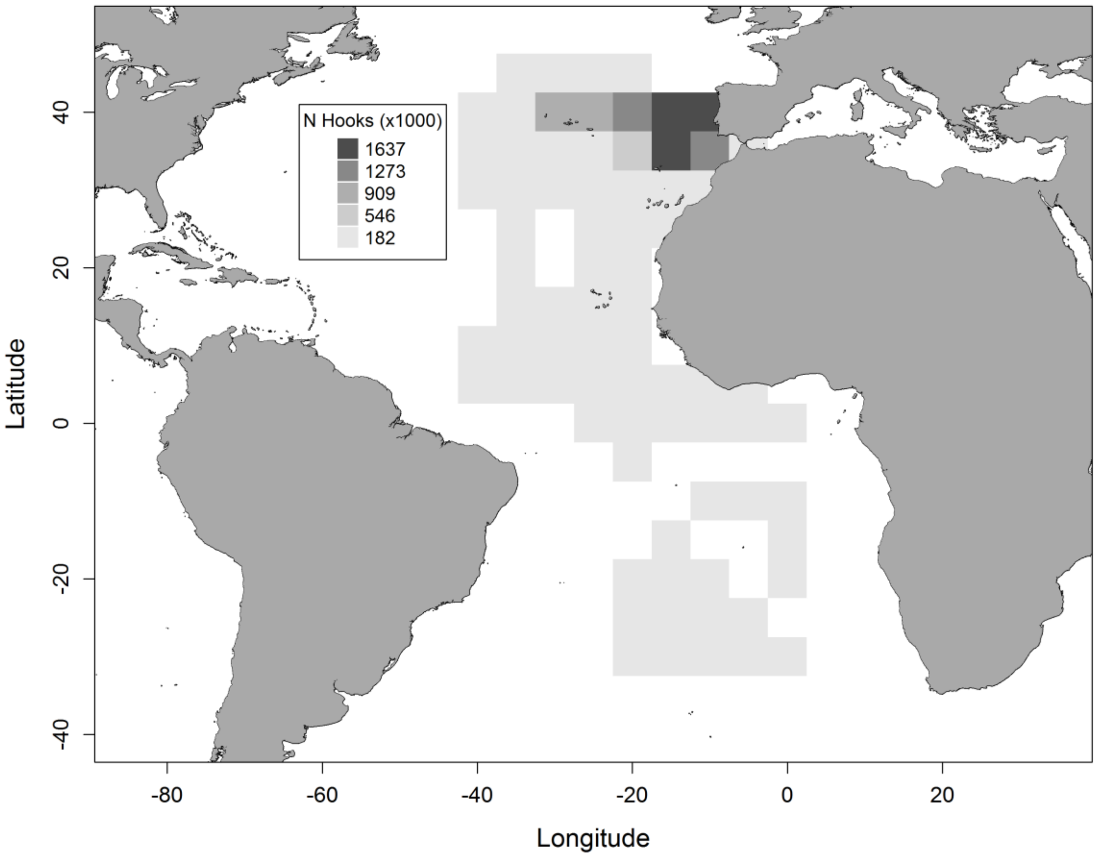

Figure 2. Effort distribution of the sampling in the east Atlantic sailfish stock distribution area used in this study for the period 1995 to 2014. The effort is represented in number of hooks (x1000) in 5x5 grids. Note that trips or sub-trips outside the SAI species range (i.e., northern than 50°N in the NE and southern than 32°S in the SE Atlantic, according to Nakamura, 1985) were excluded.

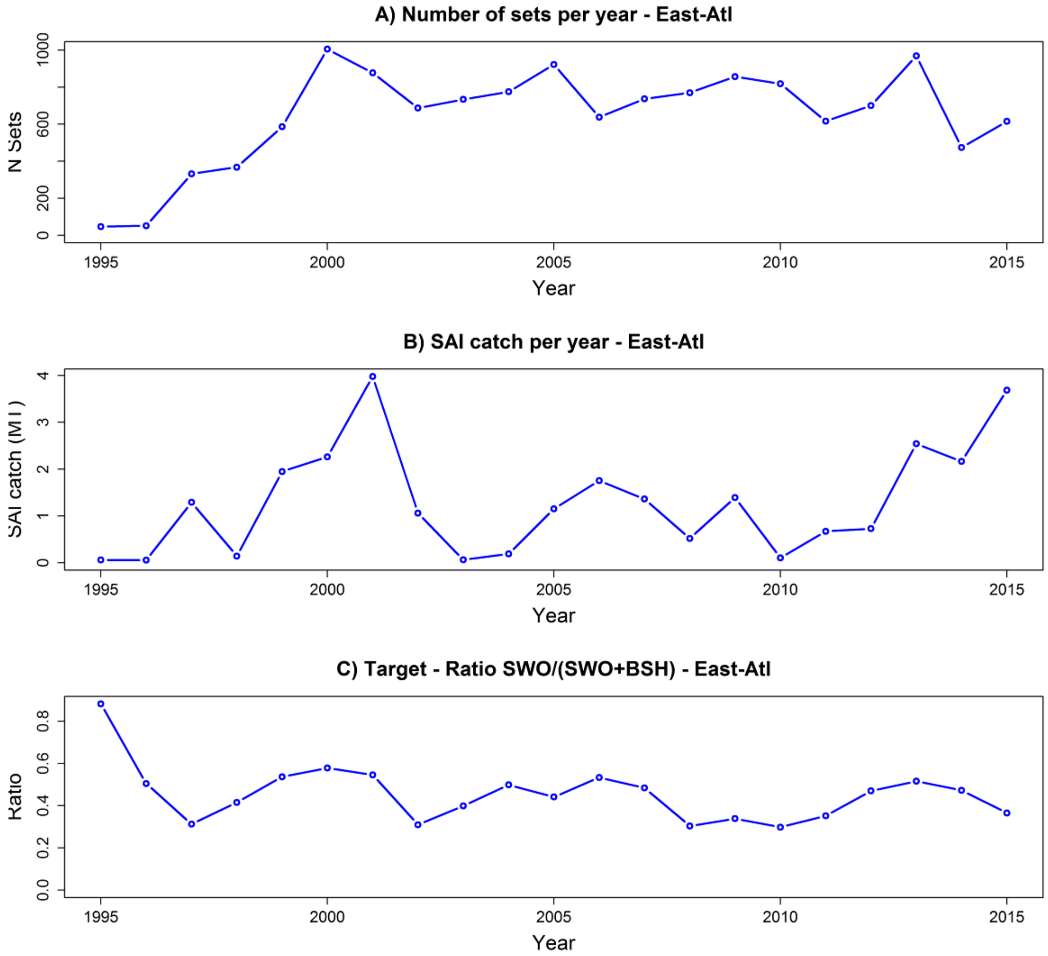

Figure 3. Descriptive plots of the sample used in this study in terms of total effort in sets (A), total catch of Atlantic sailfish (B), and targeting, measured as the ratio of swordfish compared to the swordfish and blue shark catches (C). Data refers to the Portuguese pelagic longline fleet in the east Atlantic sailfish stock area.

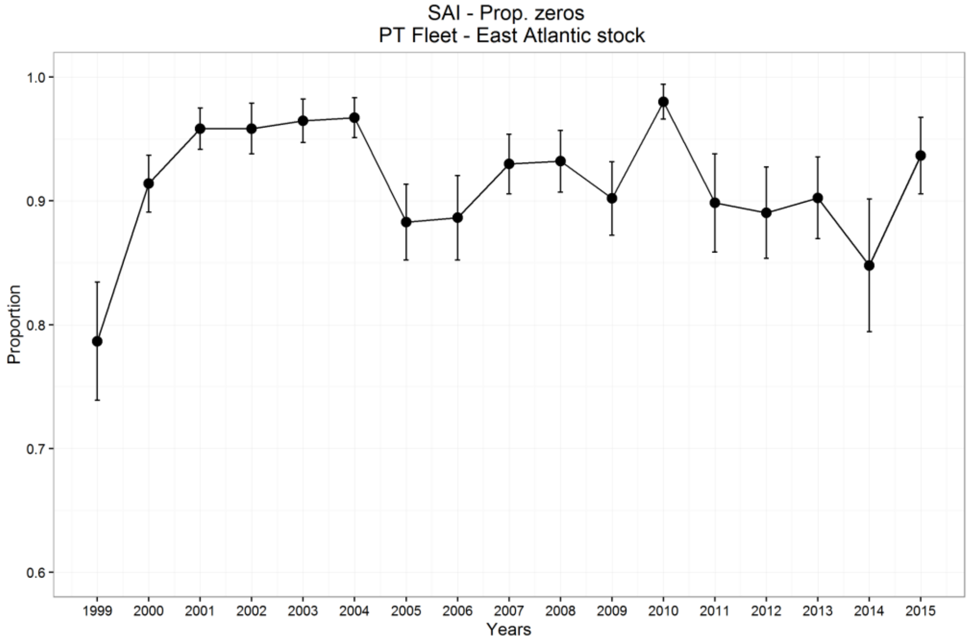

Figure 4. Proportion of trips or sub-trips with zero Atlantic sailfish catches in the Portuguese pelagic longline fishery in the east Atlantic sailfish stock area between 1999 and 2014. The error bars refer to the standard errors.

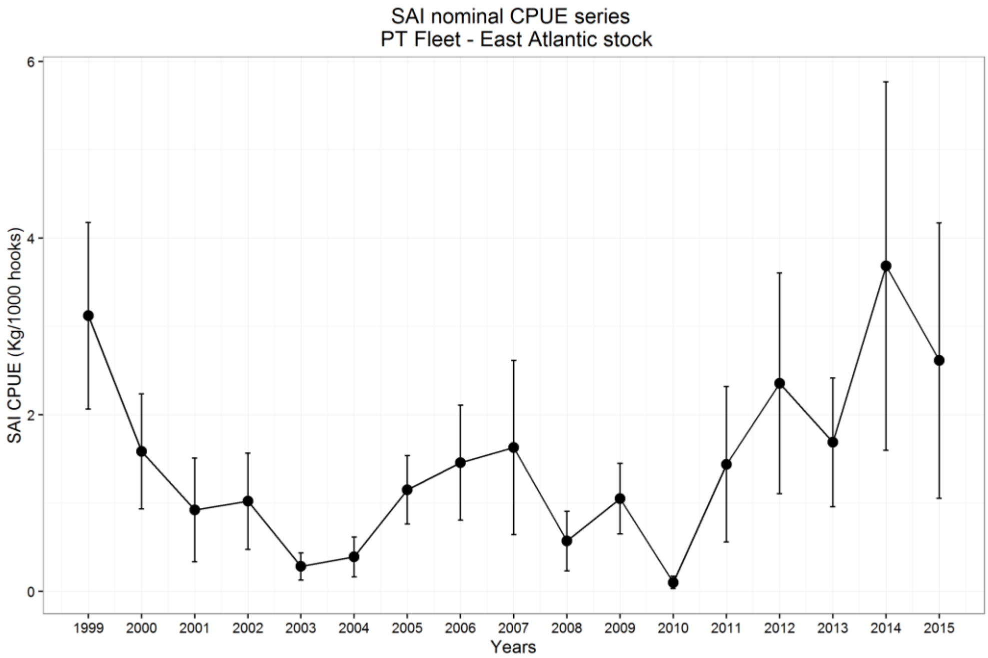

Figure 5. Nominal CPUE series (kg/1000 hooks) for Atlantic sailfish caught by the Portuguese pelagic longline fishery in the east Atlantic stock. Data is represented between 1999 and 2015, which is the period used in the CPUE standardization. The error bars refer to the standard errors.

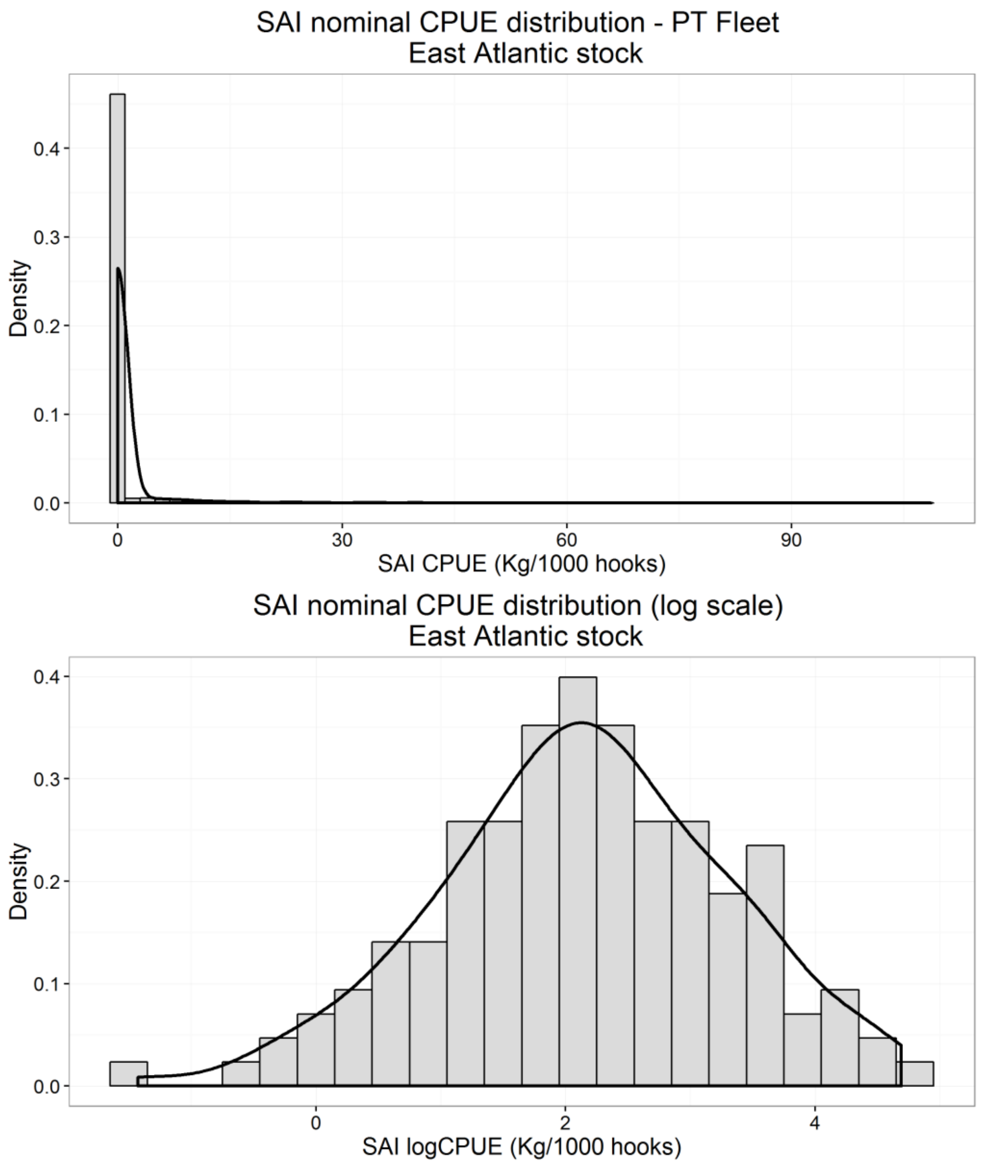

Figure 6. Distribution of the nominal Atlantic sailfish CPUE captured by the Portuguese pelagic longline fleet in the east Atlantic stock, in non-transformed (top) and log-transformed scale (excluding zeros, bottom).

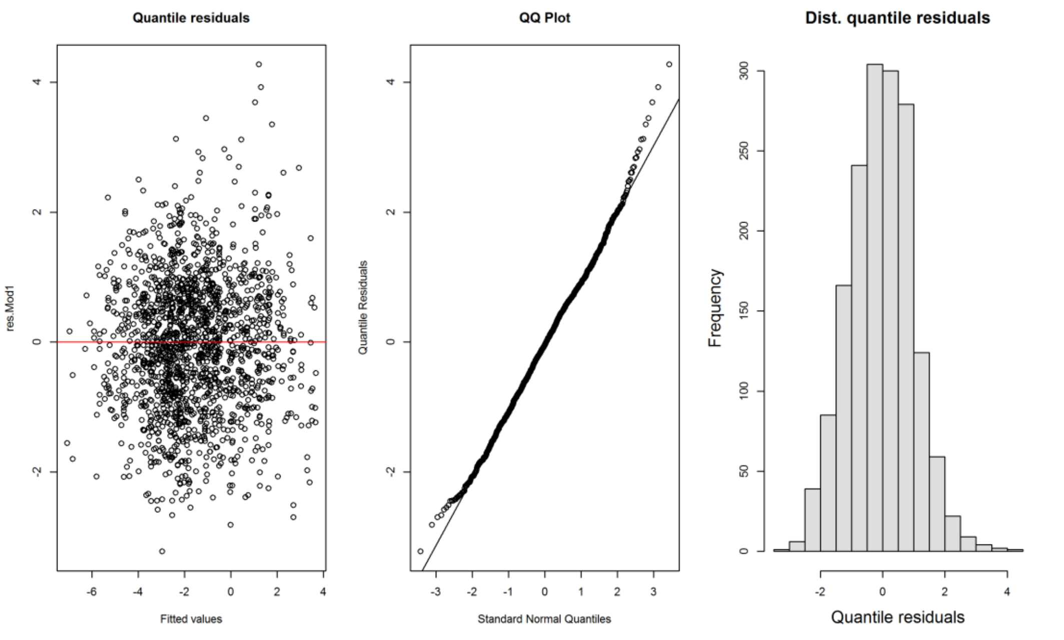

Figure 7. Residual analysis for the Tweedie GLM for the Atlantic sailfish CPUE standardization in the east Atlantic stock It is represented the residuals along the fitted values (left), the QQPlot (middle) and the histogram of the distribution of the residuals (right).

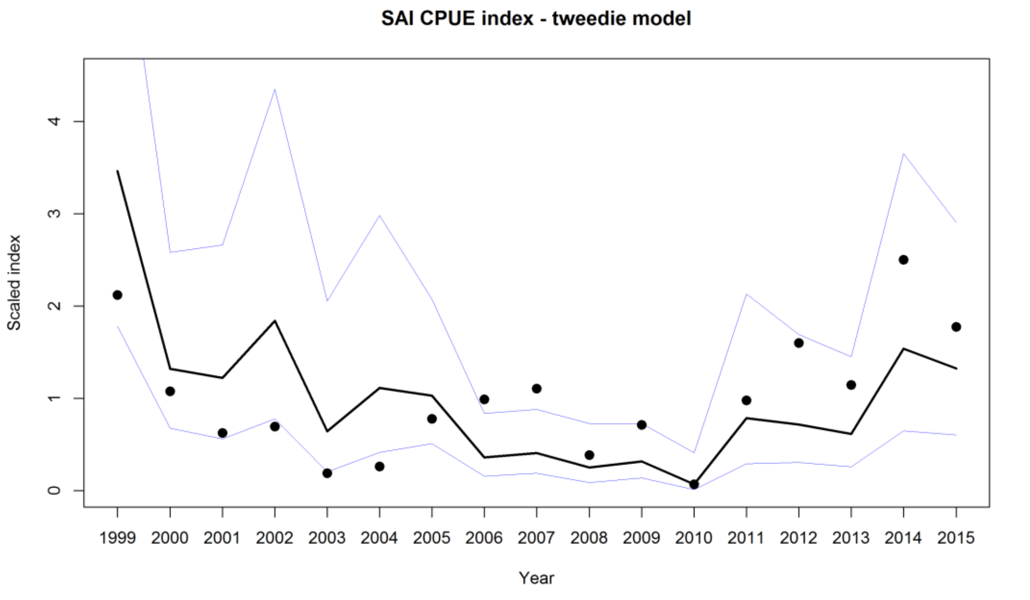

Figure 8. Standardized CPUE series for Atlantic sailfish captured by the Portuguese pelagic longline fleet in the east Atlantic stock using a Tweedie GLM (black line). The light blue lines refer to the 95% confidence intervals of the standardized series, and the nominal series is represented in the black dots. For comparison purposes the standardized and nominal CPUE series were scaled by the means.