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STANDARDIZED CPUE FOR THE SHORTFIN MAKO (*ISURUS OXYRINCHUS*) CAUGHT BY THE PORTUGUESE PELAGIC LONGLINE FISHERY

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SUMMARY

*Portuguese longliners targeting swordfish and operating in the Atlantic Ocean regularly capture elasmobranch fishes as by-catch. Of those, the blue shark (*Prionace glauca*) and the shortfin mako (*Isurus oxyrinchus*) constitute the two main shark species captured. This paper reports the CPUE trends and standardization of the shortfin mako captured by this fleet. The data was collected by fishery observers and compiled from self reporting skippers' logbooks. The CPUEs (kg/1000hooks) were standardized with Generalized Linear Models (GLMs) using the delta method and tweedie models. The factors year, quarter, location and vessel were used as explanatory variables, and model validation was carried out with residual analysis. The results presented are part of an ongoing study, and provide the first preliminary standardized trends of the shortfin mako catch rates from the Portuguese longline fishery operating in the Atlantic Ocean.*

RÉSUMÉ

*Les palangriers portugais ciblant l'espadon et opérant dans l'océan Atlantique capturent régulièrement des poissons élasmobranches en tant que prises accessoires. Parmi ceux-ci, le requin peau bleue (*Prionace glauca*) et le requin-taupe bleu (*Isurus oxyrinchus*) représentent les deux principales espèces de requins capturées. Ce document fait état des tendances et de la standardisation de la CPUE du requin-taupe bleu capturé par cette flottille. Les données ont été recueillies par des observateurs des pêcheries et proviennent des carnets de pêche remplis par les capitaines. Les CPUE (kg/1.000 hameçons) ont été standardisées en utilisant les modèles linéaires généralisés (GLM) au moyen de la méthode delta et des modèles tweedie. Les facteurs année, trimestre, localisation et navire ont servi de variables explicatives et la validation du modèle a été réalisée avec une analyse résiduelle. Les résultats présentés font partie d'une étude actuellement en cours de réalisation et fournissent les premières tendances standardisées préliminaires des taux de capture du requin-taupe bleu de la pêcherie palangrière portugaise opérant dans l'océan Atlantique.*

RESUMEN

*Los palangreros portugueses que dirigen su actividad al pez espada y que operan en el océano Atlántico suelen capturar regularmente peces elasmobranquios de forma fortuita. De éstos, la tintorera (*Prionace glauca*) y el marrajo dientuso (*Isurus oxyrinchus*) constituyen las dos principales especies de tiburones capturadas. Este documento presenta las tendencias y estandarización de la CPUE del marrajo dientuso capturado por esta flota. Los datos fueron fueron recopilados por los observadores pesqueros o se extrajeron de los cuadernos de pesca de los patrones. Las CPUE (kg/1.000 anzuelos) se estandarizaron con modelos lineales generalizados (GLM) utilizando el método delta y modelos tweedie. Los factores año, trimestre, localización y buque se utilizaron como variables explicativas y la validación del modelo se llevó a cabo con un análisis residual. Los resultados presentados son parte de un estudio en curso y proporcionan las primeras tendencias estandarizadas preliminares de las tasas de captura de marrajo dientuso procedentes de la pesquería de palangre portuguesa que opera en el océano Atlántico.*

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KEYWORDS

By-catch, CPUE standardization, delta method, generalized linear models, Isurus oxyrinchus, pelagic longlines, Tweedie models

1. Introduction

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-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 objective of this study is to present preliminary standardized CPUE indexes for the shortfin mako shark (SMA – *Isurus oxyrinchus*) captured by the Portuguese pelagic longline fishery targeting swordfish in the Atlantic Ocean. A secondary objective is to evaluate differences in the series modeled with two different approaches, specifically the delta-method and tweedie models.

2. Materials and methods

The data used for this study was collected by fishery observers onboard Portuguese pelagic longline vessels and by skippers logbooks (self reporting) voluntarily provided to IPIMAR. The information on the total effort (total number of sets per year) was provided by the Portuguese Fisheries authorities (DGPA). The percentage of sets covered that was used for the analysis varied between years and hemispheres, and ranged from minimums of 6.5% to maximums of 24.0% per year (**Table 1**). One exception was the year 2003 for the Southern Atlantic, for which no data was available at this point. Overall, the percentage of coverage used for the analysis represented 11.2% for the North and 10.8% for the South Atlantic.

The response variable considered for this study was Catch per Unit of Effort (CPUE), measured as biomass (total weight in kg) per 1000 hooks. The standardized CPUE series were estimated with GLMs, using the delta-method approach and tweedie models, both chosen because pelagic sharks (including the shortfin mako) are captured as bycatch in this fishery and there are fishing sets where no catches occur (true zeros in the databases). Both these modeling approaches can be used under situations when the response variable is continuous but has an added mass of zeros, which is the case of the present study.

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 SMA and 0 = set with zero catches of SMA. The second model was used to estimate the expected CPUE of the positive sets of SMA, 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), using functions available in library tweedie (Dunn 2011) in R (R Development Core Team 2012).

Regardless of the method used, separate models were created for the North and South Atlantic, and for the purpose of this study the 5ºN parallel was used to separate the two hemispheres. This separation is recommended for shark species in the ICCAT manual (ICCAT 2006-2009), and has been previously used in other studies focusing SMA in the Atlantic Ocean (e.g. Mejuto *et al*. 2009 for the Spanish fleet).

With both modeling approaches, the explanatory variables initially considered for the models were:

- Year (analyzed between 2000 and 2011);
- Vessel (corresponding to the different vessels);
- Quarter (1: Jan-Mar; 2: Apr-Jun; 3: Jul-Sep; 4: Oct-Dec);
- Region (using the FAO subareas, in some cases merged due to small samples sizes in particular areas) (**Figure 1**).

Significance of the explanatory variables 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 tables. Goodness-of-fit and model validation was carried out with residual analysis, specifically using the Pearson residuals for the lognormal models and the quantile residuals for the tweedie models. The quantile residuals were used for the tweedie models as recommended by Dunn and Smyth (1996) for these types of non-normal regressions.

The final standardized CPUEs were estimated by least square means (LSMeans) for the effects of year averaged over the effects of the other variables. For the delta-method the LSMeans were calculated as the yearly probability of having a positive set multiplied by the expected catch rate conditional to the set being positive (Lo *et al.* 1992).

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).

3. Results and Discussion

3.1 North Atlantic

For the North Atlantic region, the percentage of fishing sets with zero SMA catches was 60.1%. The nominal SMA CPUE distribution was highly skewed to the right, with an initial peak of zero values (**Figure 2**). With a log-transformation of the positive sets the data becomes more symmetrical and bell shaped, closer to what is expected by a normal distribution (**Figure 2**).

Using the delta-lognormal method, all the explanatory variables initially tested (i.e. year, quarter, vessel and region) contributed significantly for explaining part of the deviance, and therefore the models used were the complete simple effects models. For the lognormal model the factors that contributed more for explaining part of the deviance were the year, followed by region, vessel and quarter (**Table 2**). For the binomial models the factors explaining more of the deviance were the vessel, followed by region, quarter and year (**Table 2**). The Nagelkerke R^2 values for the two models were 12.4% and 10.6%, respectively for the lognormal model conditional to the positive sets and for the binomial model.

For the tweedie model the *p-index* of the distribution was calculated at 1.41, which can account for 58.4% of zeros and is relatively similar to the 60.1% of actual zeros in the sample. All the explanatory variables initially tested were also significant, and so the full simple effect model was used. The variables contributing more for the deviance explanation were the vessel effect, followed by region, year and quarter (**Table 2**). The Nagelkerke R^2 value for the final tweedie model was estimated at 15.0%.

In terms of residual analysis and model validation, both the Pearson residuals for the lognormal model and the quantile residuals for the tweedie model seemed randomly distributed along the data and followed a bell shaped normal distribution. Some possible outliers may be present, but no major problems (i.e. trends) were detected in the residual analysis (**Figure 3)**.

The nominal CPUEs of SMA catches between 2000 and 2011 showed some variability along the years but in general the values remained relatively stable. The standardized series in general followed those nominal CPUEs, and no major differences were detected between the expected values calculated with the delta-lognormal and the tweedie models (**Table 3, Figure 4**).

3.2 South Atlantic

For the South Atlantic region the percentage of fishing sets with zero SMA catches was very similar to the North Atlantic, in this case with 59.4% of zeros. The nominal SMA CPUE distribution was also highly skewed to the right, with an initial peak of zero values, and a log-transformation (positive sets) turned the data more symmetrical and bell shaped (**Figure 5**). In this case the log-transformed distribution of CPUEs followed a normal distribution, as verified with a Kolmogorov-Smirnov test with Lilliefors correction (D = 0.0306, p-value = 0.057).

For the South Atlantic, and because there was less data available, the vessel effects were not considered. The remaining explanatory variables (i.e. year, quarter, region) were all significant, and therefore used in the final models. For the lognormal model the variable explaining more of the deviance was the factor year, followed by the region and quarter (**Table 4**). For the binomial model the factor contributing more to explaining the deviance was the region, followed by year and quarter (**Table 4**). The Nagelkerke R^2 values for these two final models were 24.2% and 20.1%, respectively for the lognormal and the binomial models.

For the tweedie model the *p-index* of the tweedie distribution was calculated at 1.44, which can account for 58.0% of zeros and was again very similar to the 59.4% of actual zeros in the sample. All the explanatory variables initially tested (year, quarter and region) were also significant, and so the full simple effect model was used. The variables contributing more for the deviance explanation in these models were the year, followed by region and quarter (**Table 4**). The Nagelkerke R^2 value for the final tweedie model was estimated at 30.4%.

In terms of residual analysis, the Pearson residuals of the lognormal model for the delta-method seemed randomly distributed along the predicted values, and followed a normal distribution (Kolmogorov-Smirnov Lilliefors normality test: D = 0.0207, p-value = 0.501) (**Figure 6)**. Likewise, the quantile residuals analyzed for the tweedie models also seemed randomly distributed along the fitted values, and also showed a distribution close to a normal distribution (**Figure 6**).

For the South Atlantic, the nominal CPUEs of SMA between 2000 and 2011 showed a much higher variability than for the North Atlantic, and in general with higher CPUE values. The standardized series calculated with the delta-lognormal method and with the tweedie models were again similar, but also had high variability and in general wider confidence intervals (**Table 5, Figure 7**). This relatively high variability in the CPUEs and confidence intervals are probably related to the fact that there is less and data available for the Southern Atlantic, with a lower percentage of coverage, in particular for some of the early years of the series. For some of the spatial-temporal combinations in that hemisphere, the coverage of percentage is very low, which further increases the variability. Further, no data was available for the South Atlantic for the year 2003.

3.3 Final remarks

Using GLMs with the delta method and tweedie distributions seem good approaches to analyze fisheries data with a continuous response variable (e.g. CPUE data) that also have a considerable amount of zeros in the response variable. Particularly the delta method has been commonly applied to these types of studies, including several studies focused on pelagic sharks (e.g. Hazin *et al*. 2008, Cortés 2009; Mejuto *et al*. 2009). On the other hand, using tweedie models does not seem to be such a common procedure, even though those models have also been applied before to CPUE standardization of both bony fishes and pelagic sharks (e.g. Candy 2004, Shono 2008).

In this study we used both approaches (i.e. delta-method and tweedie models) and both seemed to perform reasonably well. The residual analysis did not detect any major problem with any of the models, and the standardized CPUE series were in general similar, following relatively similar trends and with overlapped confidence intervals. Other alternatives for dealing with zeros in the response variable are available to standardize CPUEs, and an extensive revision on these methodologies was provided by Maunder & Punt (2004). Besides the delta-method, Maunder & Punt (2004) also discuss zero inflated models (e.g. ZIP, Zero-Inflated Poisson; ZINB, Zero-Inflated Negative Binomial) but those can only be used for discrete response variables, which is not the case of our study. Additionally, there is also the possibility of adding a small constant to the response variable in order to remove the zero values, but such technique seems more adequate for cases when the proportion of zeros is relatively small in the sample (Campbell 2004), which again is not the case of our study, with the zeros accounting for more than 50% of the datasets.

Several limitations need to be addressed and considered with regards to our study. One possible limitation is the fact that we only used simple effects models and did not account for eventual interactions between the variables. Another limitation is the fact that we only used fixed effects, while some authors have used random effects, especially in the interactions involving the effects of year with other variables (e.g. Ortiz and Arocha 2004). Finally, the use of the region effects based on the FAO subareas may also be a limiting factor for the analysis. Future work with this datasets may consider the use of the geographical coordinates as continuous variables instead of categorical regions (e.g. by using non-linear effects within GAM models), or other type of categorical discretization based on the coordinates instead of the FAO subareas. Future models may also consider the utilization of random effects and interactions.

For these reasons, and also because the dataset used in this study is still relatively limited and only represents part of the total effort carried out by the Portuguese longline fleet, the models presented in this paper should be regarded as preliminary and part of an ongoing effort to collect, compile and analyze more data. Both the fishery observer data collection, as well as the data compilation from skippers' logbooks is still ongoing, and we expect in the future to increase the data available and used for the analysis. Particularly with regards to the skippers' logbooks, an effort is presently being carried out to collect and compile historical data from the earlier years of the fishery, which might improve and expand the time series covered by the analysis.

4. Acknowledgments

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Table 1. Number of pelagic longline fishing sets by the Portuguese fleet per year in the North and Southern hemispheres of the Atlantic Ocean that were used for the analysis in this paper.

Year	*North Atl*	*South Atl*
2000	664	112
2001	569	82
2002	435	72
2003	614	
2004	752	69
2005	805	121
2006	440	222
2007	449	167
2008	503	303
2009	516	244
2010	617	258
2011	461	446

Table 2. Deviance tables of the parameters used for the SMA models for the North Atlantic using the delta method (2 models) and the tweedie model. For each variable it is indicated the degrees of freedom (Df) used for parameter estimation, the deviance explained, the residual degrees of freedom, the residual deviance after incorporating the variable, and the significance (*p-value*).

Delta method model 1: Lognormal for positive catch rates					
Parameter	Df	Deviance	Resid. Df.	Resid. deviance	Significance (*p-value*)
Null			2725	2236	
Year	11	115	2714	2121	< 0.01
Region	7	82	2707	2039	< 0.01
Quarter	3	26	2704	2013	< 0.01
Vessel	8	75	2696	1938	< 0.01
Delta method model 2: Binomial for proportion of positive sets					
Parameter	*Df*	*Deviance*	*Resid. Df.*	*Resid. deviance*	*Significance (p-value)*
Null			6824	9183	
Year	11	80	6813	9104	< 0.01
Region	7	232	6806	8871	< 0.01
Quarter	3	137	6803	8735	< 0.01
Vessel	8	558	6795	8176	< 0.01
Tweedie Model					
Parameter	*Df*	*Deviance*	*Resid. Df.*	*Resid. deviance*	*Significance (p-value)*
Null			6824	163854	
Year	11	4330	6813	159524	< 0.01
Region	7	4704	6806	154821	< 0.01
Quarter	3	2813	6803	152008	< 0.01
Vessel	8	13348	6795	138660	< 0.01

Table 3. Nominal and standardized CPUEs (kg/1000 hooks) for SMA captured by the Portuguese pelagic longline fishery in the North Atlantic. The CPUEs were standardized using the delta-lognormal and the tweedie GLM methodologies. For the standardized CPUEs both the point estimates and the 95% confidence intervals are indicated.

Year	*Nominal CPUE*	*Delta-Method*			*Tweedie-Model*		
		Index	*Lower 95%CI*	*Upper 95%CI*	*Index*	*Lower 95%CI*	*Upper 95%CI*
2000	21.20	20.86	16.32	25.39	18.32	13.74	24.43
2001	24.27	28.15	21.78	34.52	20.32	15.10	27.35
2002	38.35	25.67	20.18	31.16	27.66	20.81	36.75
2003	28.95	37.26	29.60	44.92	24.86	18.80	32.87
2004	39.56	28.95	23.37	34.53	34.52	26.53	44.93
2005	26.12	23.66	18.97	28.34	26.40	20.45	34.09
2006	15.16	28.24	21.48	35.00	14.14	10.35	19.31
2007	44.45	20.87	16.11	25.63	20.88	15.63	27.90
2008	22.92	23.20	17.75	28.65	13.27	9.89	17.81
2009	35.79	20.25	15.85	24.66	21.59	16.35	28.53
2010	37.14	30.30	24.10	36.51	23.94	18.48	31.01
2011	43.76	33.33	26.65	40.01	31.26	24.31	40.19

Table 4. Deviance tables of the parameters used for the SMA models for the South Atlantic using the delta method (2 models) and the tweedie model. For each variable it is indicated the degrees of freedom (Df) used for parameter estimation, the deviance explained, the residual degrees of freedom, the residual deviance after incorporating the variable, and the significance (*p-value*).

Delta method model 1: Lognormal for positive catch rates					
Parameter	*Df*	*Deviance*	*Resid. Df.*	*Resid. deviance*	*Significance (p-value)*
Null			851	813	
Year	10	125	841	688	< 0.01
Region	7	65	834	624	< 0.01
Quarter	3	22	831	602	< 0.01
Delta method model 2: Binomial for proportion of positive sets					
Parameter	*Df*	*Deviance*	*Resid. Df.*	*Resid. deviance*	*Significance (p-value)*
Null			2095	2832	
Year	10	190	2085	2642	< 0.01
Region	7	341	2078	2301	< 0.01
Quarter	3	60	2075	2241	< 0.01
Tweedie Model					
Parameter	*Df*	*Deviance*	*Resid. Df.*	*Resid. deviance*	*Significance (p-value)*
Null			2095	74035	
Year	10	11664	2085	62371	< 0.01
Region	7	10481	2078	51891	< 0.01
Quarter	3	887	2075	51004	< 0.01

Table 5. Nominal and standardized CPUEs (Kg/1000 hooks) for shortfin mako captured by the Portuguese pelagic longline fishery in the South Atlantic Ocean. The CPUEs are standardized using the delta-lognormal and the tweedie GLM methodologies. For the standardized CPUEs both the point estimates and the 95% confidence intervals are indicated.

Year	*Nominal CPUE*	*Delta-Method*			*Tweedie-Model*		
		Index	*Lower 95%CI*	*Upper 95%CI*	*Index*	*Lower 95%CI*	*Upper 95%CI*
2000	117.02	48.02	25.66	70.38	81.09	59.06	111.32
2001	42.62	24.24	9.50	38.98	32.71	19.05	56.17
2002	17.51	42.88	26.78	58.98	47.80	25.25	90.48
2003	NA	NA	NA	NA	NA	NA	NA
2004	36.99	150.42	94.55	206.28	42.33	24.35	73.59
2005	34.88	110.54	76.29	144.79	116.73	75.59	180.26
2006	28.84	81.22	49.61	112.83	62.93	44.10	89.81
2007	16.19	75.93	47.82	104.03	39.26	25.13	61.35
2008	61.18	71.64	55.47	87.81	86.05	66.51	111.34
2009	64.44	76.19	56.93	95.45	66.45	51.36	85.97
2010	29.96	52.50	36.35	68.65	34.29	24.48	48.02
2011	161.96	133.97	100.38	167.56	107.71	89.40	129.79

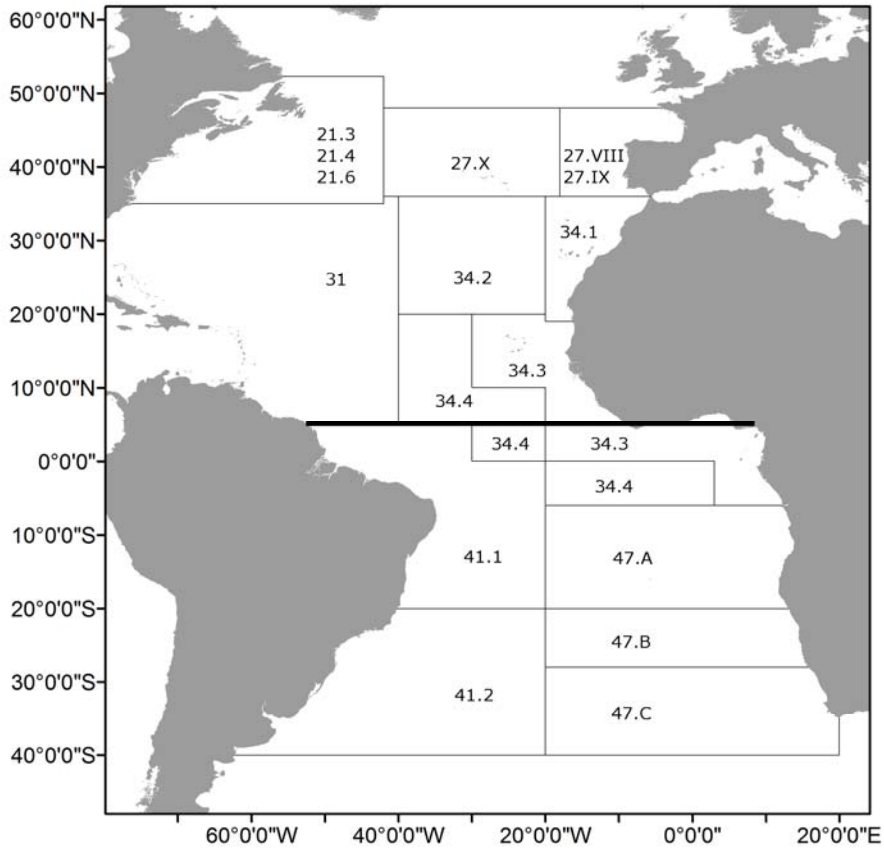

Figure 1. Map with the Regions (based on the FAO subareas) that were used in this study as the location explanatory variable. For the purposes of the analysis, the northern and southern SMA stocks were separated by the 5ºN parallel (thick black line).

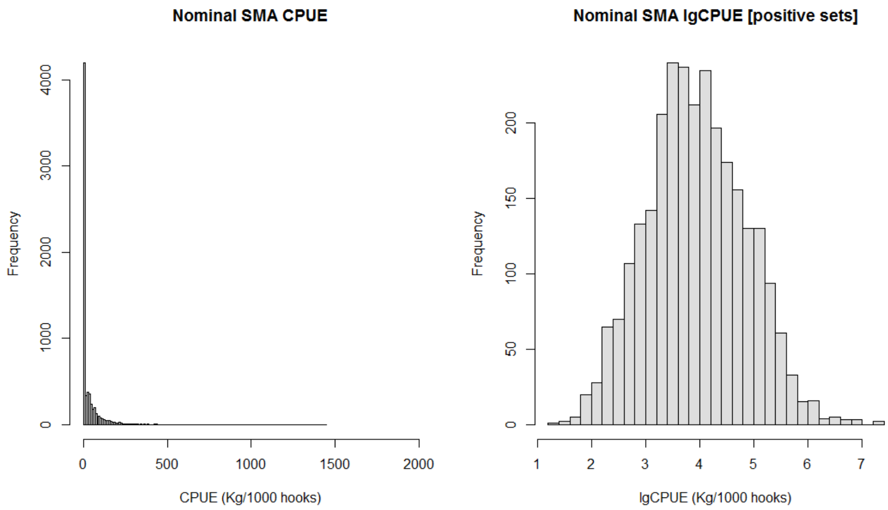

Figure 2. Distribution of nominal CPUE and log-transformed CPUE (conditional to the positive fishing sets) for SMA captured in the North Atlantic by the Portuguese longline fleet.

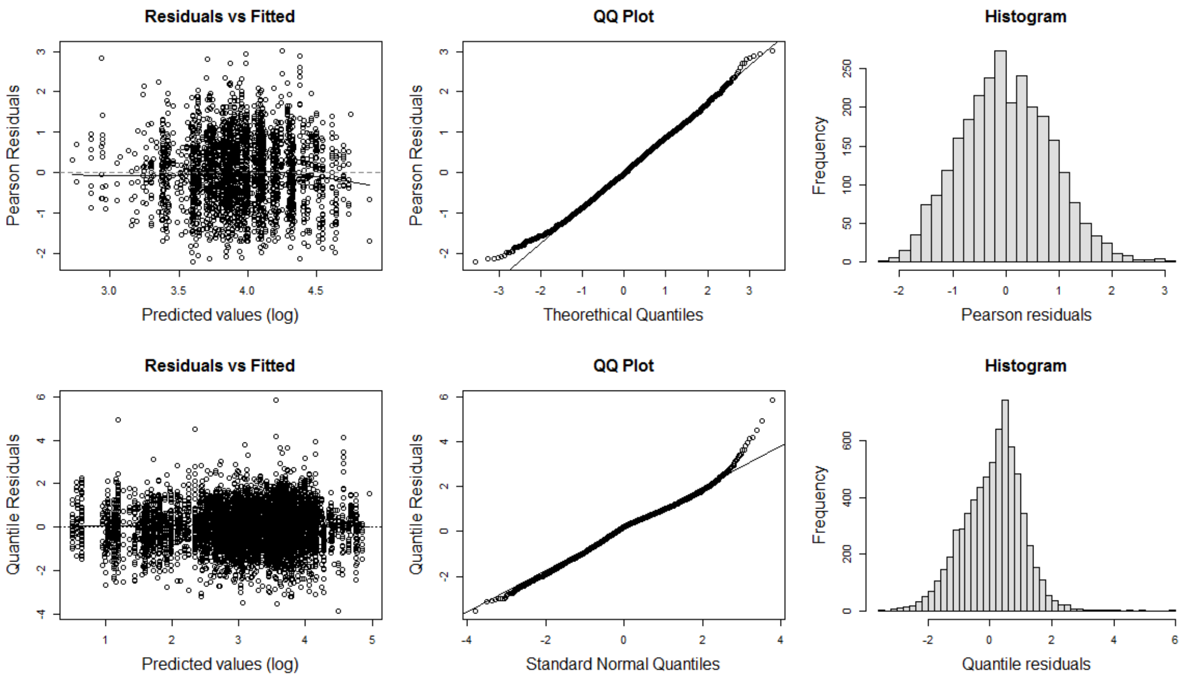

Figure 3. Residual analysis for the final models used for the SMA CPUE standardization in the North Atlantic. The 3 graphics on the top are from the delta-method (Pearson residuals) and the 3 graphic on the bottom are from the tweedie models (quantile residuals). The graphic on the left represent the 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 black line the smoothed fit to the residuals.

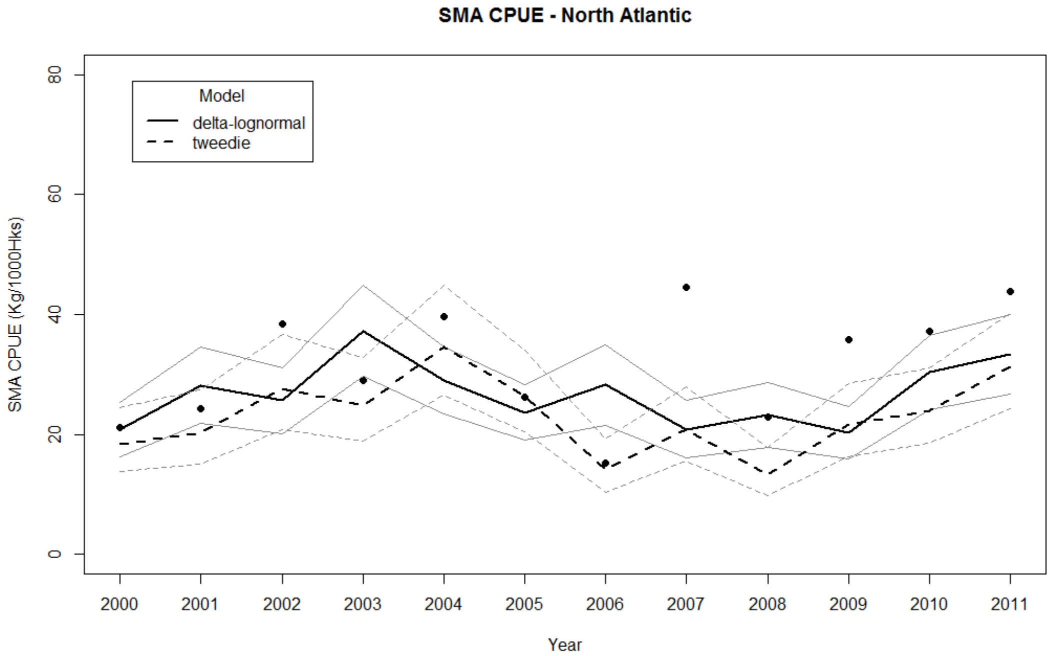

Figure 4. Annual relative indexes of abundance for SMA captured by the Portuguese pelagic longline fleet in the North Atlantic, using the delta-lognormal (solid lines) method and a tweedie model (dotted lines). The black circles represent the nominal CPUEs, the black lines the standardized series, and the grey lines the 95% confidence intervals.

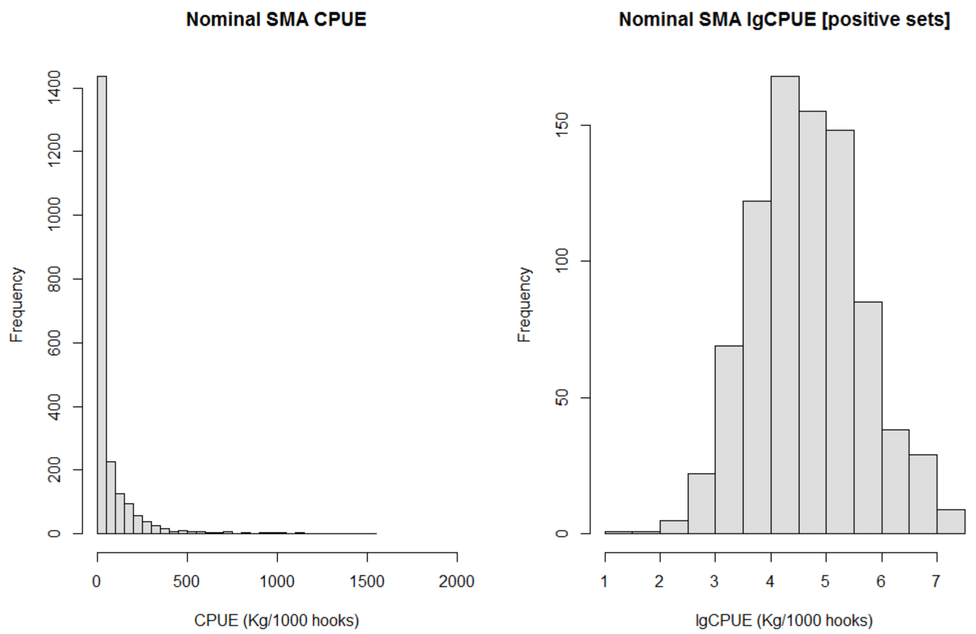

Figure 5. Distribution of nominal CPUE and log-transformed CPUE (conditional to the positive fishing sets) for SMA captured in the South Atlantic by the Portuguese longline fleet.

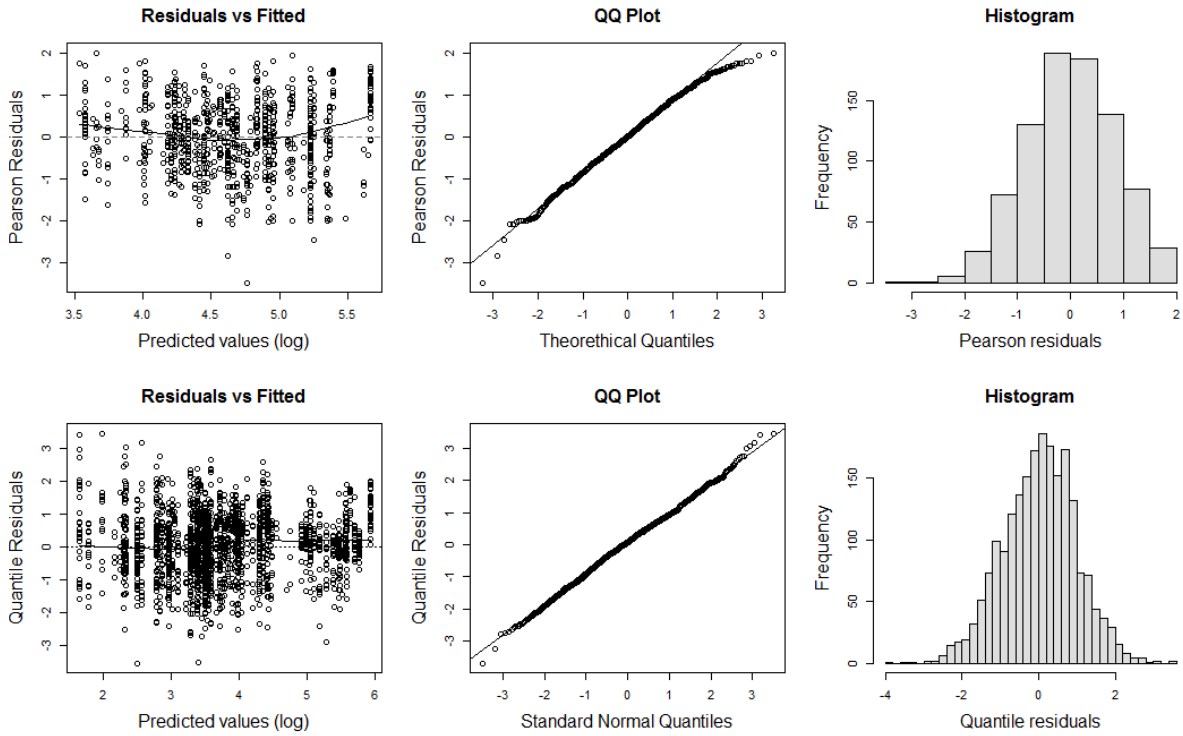

Figure 6. Residual analysis for the final models used for the SMA CPUE standardization in the South Atlantic. The 3 graphics on the top are from the delta-method (Pearson residuals) and the 3 graphic on the bottom are from the tweedie models (quantile residuals). The graphic on the left represent the 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 black line the smoothed fit to the residuals.

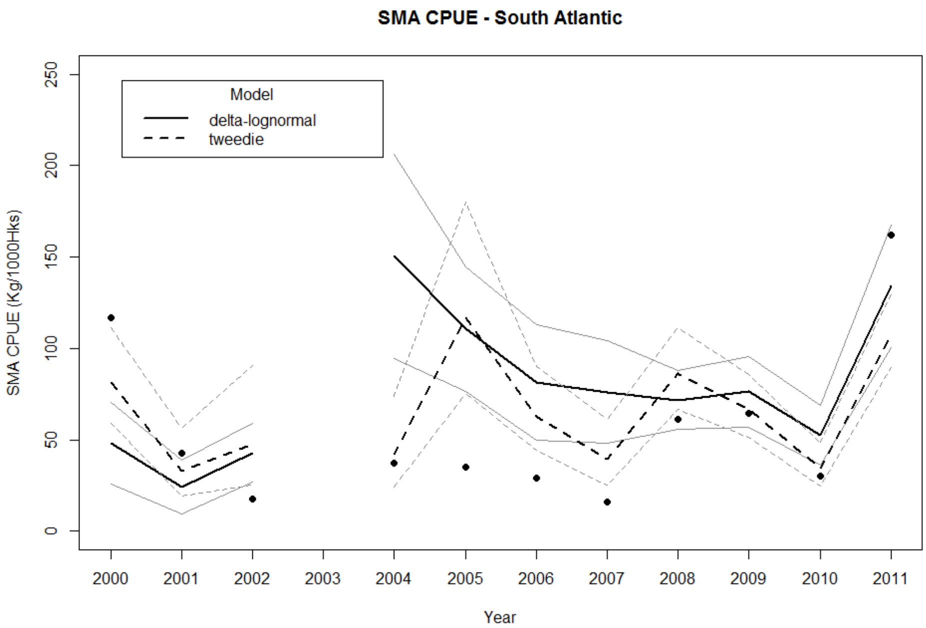

Figure 7. Annual relative indexes of abundance for SMA captured by the Portuguese pelagic longline fleet in the South Atlantic, using the delta-lognormal (solid lines) method and a tweedie model (dotted lines). The black circles represent the nominal CPUEs, the black lines the standardized series, and the grey lines the 95% confidence intervals.