STANDARDIZED CPUE FOR SWORDFISH (*XIPHIAS GLADIUS*) CAUGHT BY THE PORTUGUESE PELAGIC LONGLINE FISHERY IN THE NORTH ATLANTIC

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SUMMARY

*Non age-structured production model analyses of North Atlantic swordfish have been used in addition to age structured virtual population analyses by ICCAT's SCRS to evaluate the status of the resource and to provide a basis for management advice. Production models require a standardized index of relative abundance in terms of biomass. Generalized Linear Modeling (GLM) procedures were used to standardize swordfish catch (biomass) and nominal effort (number of hooks) data from the Portuguese longline fleets operating in the North Atlantic between 1997 and 2012. As in past analyses, main effects included: year, area, quarter, a nation-operation variable accounting for gear and operational differences thought to influence swordfish catchability, a target variable to account for trips where sharks were predominant in the catch or potentially also targeted, and interaction terms for year*area.*

RÉSUMÉ

*Le SCRS de l'ICCAT a utilisé des analyses du modèle de production structuré par âge de l'espadon de l'Atlantique Nord en plus des analyses de population virtuelle structurée par âge afin d'évaluer l'état de la ressource et de fournir une base pour l'avis de gestion. Les modèles de production nécessitent un indice standardisé d'abondance relative en termes de biomasse. Des procédures du modèle linéaire généralisé (GLM) ont été utilisées afin de standardiser les données de capture (biomasse) et d'effort nominal (numéro d'hameçons) de l'espadon provenant des flottilles palangrières du Portugal ayant opéré dans l'Atlantique Nord entre 1997 et 2012. Comme lors des analyses antérieures, les principaux effets incluaient : année, zone, trimestre, une variable nation-opération tenant compte de l'engin et des différences opérationnelles censés influencer la capturabilité de l'espadon, une variable cible pour tenir compte des sorties où les requins étaient prédominants dans la capture ou aussi potentiellement ciblés, et des termes d'interaction pour année*zone.*

RESUMEN

*Se utilizaron análisis de modelos de producción no estructurados por edad del pez espada del Atlántico norte, además de análisis de población virtual estructurados por edad realizados por el SCRS de ICCAT para evaluar el estado del recursos y facilitar una base para el asesoramiento en materia de ordenación. Los modelos de producción requieren un índice estandarizado de abundancia relativa en términos de biomasa. Se utilizaron procedimientos de modelación lineal generalizada (GLM) para estandarizar los datos de captura (biomasa) y el esfuerzo nominal (número de anzuelos) de pez espada de las flotas palangreras portuguesas que operaron en el Atlántico norte entre 1972 y 2012. Como en análisis anteriores, los principales efectos incluían: año, área, trimestre, una variable de nación-operación que tiene en cuenta las diferencias operativas y en el arte que se cree que influyen en la capturabilidad del pez espada, una variable de especie objetivo para tener en cuenta las mareas en las que los tiburones predominaban en la captura o eran también potencialmente especie objetivo, y términos de interacción para año*área.*

KEYWORDS

Swordfish, catch/effort, pelagic longlines, CPUE standardization, generalized linear models, generalized linear mixed models[1]

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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 working document is to present the standardized swordfish (SWO – *Xiphias gladius*) CPUE index for the Portuguese pelagic longline fishery in the North Atlantic Ocean.

2. Materials and methods

2.1 Fishery data

The data used for this study was collected by fishery observers' onboard Portuguese pelagic longline vessels, interviews of skippers during landings and by skippers logbooks (self reporting) voluntarily provided to IPMA, for the period 1995-2012. 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 catch) varied between years, ranging from minimums of 2% to maximums of 78% per year (**Table 1**). Data from a total of 1,406 trips or sub-trip (consecutive sets in the same trip, area and month) were used, which amounted to a total fishing effort of 12,273,325 hooks.

2.2 Catch and effort characteristics

The response variable considered for this study was Catch per Unit of Effort (CPUE), measured as biomass (total live weight in kg) per 1000 hooks.

Differences in gear construction (multi-filament nylon *vs.* monofilament), gear dimensions and operating practices (set time and haul time, area, season, target species) have been previously described by Hoey *et al.* (1988). The Portuguese fleet introduced the semi-automatic Florida style (using a monofilament mainline) between 2000-2004. Therefore a gear factor (multifilament or monofilament) was considered, based on the date when this changed occurred at each vessel. The information was obtained directly from skippers or from DGRM records. For those vessels for which such information was not available, it was considered the use of the semi-automatic Florida style fear from the 1st January 2004.

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 percentage of the swordfish retained catch and the combined swordfish and blue shark retained catches by trip (or sub-trip). This percent was categorized into four levels based on the 0.25 percentiles ($0 \leq 0.25$, $0.25 \leq 0.50$, $0.50 \leq 0.75$, and $0.75 \leq 1.0$).

The catches were assigned the fishing areas (**Figure 1**) used by Ortiz *et al.* (2010) during the 2009 swordfish stock assessment. In this specific study some of these were aggregated (specifically 1+2, 9+10 and 13+14) into larger zones, due to the low number of trips in some of the areas.

2.3 Model development

The standardized CPUE series was estimated with Generalized Linear Models (GLM) and Generalized Linear Mixed Models (GLMM) assuming a Normal distribution for the log transformed CPUE data. The models were built considering the information per "trip" or "sub-trip" from the North Atlantic areas. On a very small number of trips or sub-trips (0.22% of the data) there were 0 catches of swordfish, and therefore a constant (10% of the mean, as recommended by Campbell, 2004) was added to the data. The data from the first two years of the series (1995 and 1996) were excluded from the model runs due to low number of observations, so the final CPUE time series was analyzed for the period 1997 and 2012.

The explanatory variables considered and tested for the models were:

- Year: analyzed between 1997 and 2012;
- Quarter: 1: Jan-Mar; 2: Apr-Jun; 3: Jul-Sep; 4: Oct-Dec;
- Fishing area: using the areas represented in **Figure 1** and considering the aggregations previously mentioned;
- Gear type: multifilament or monofilament;
- Ratio: percentage of retained swordfish compared to the combined swordfish and blue shark catch, categorized by the 25% quantiles;
- Interactions between factors other than Year: included as fixed effects;
- Interactions with factor Year: included as random effects.

The significance of the explanatory variables was assessed with likelihood ratio tests comparing each univariate model to the null model, and by analyzing the deviance tables. Once a full simple effects model was built all possible pairs of interactions were tested with likelihood ratio tests to compare the complete simple effects model to the models with interactions. The significant interaction terms were used in the final model, with any interactions involving the factor Year included as a random effect in a GLMM model. AIC values were calculated to compare different candidate models. Goodness-of-fit and model validation was carried out with residual analysis.

The final standardized CPUEs were estimated by least square means (LSMeans) for the effects of year averaged over the effects of the other variables. A sensitivity analysis was carried out comparing the final model estimated parameters with alternative candidate models, specifically by: 1) adding a constant of 1 instead of 10% of the mean to the response variable; 2) discretizing the ratio factor by the 10% percentiles instead of 25% and 3) removing some interactions.

All statistical analysis for this paper was carried out with the R Project for Statistical Computing version 3.0.0 (R Core Team, 2013).

3. Results and discussion

For the North Atlantic region it is possible to observe a general increasing trend for the yearly nominal SWO CPUE considering the studied period of 1997-2012 and data for the Portuguese pelagic longline fleet (**Figure 2**). This was observed for most fishing areas within the north Atlantic, but particularly within areas 9+10, 12 and 13+14 (**Figure 3**). Overall, the distribution of those nominal SWO CPUE was highly asymmetrical and skewed to the right (**Figure 4**).

For the final selected GLMM model the factors that contributed more for explaining part of the deviance were the ratio, followed by year, season and fishing area (**Table 2**). Some interactions were also significant, particularly the interactions between year and quarter and between year and fishing area (**Table 2**), with those used as random variables within the final GLMM. In this final model the pseudo R^2 value calculated was 55.0%. In terms of residual analysis and model validation, no major outliers were detected in the final model, with the residuals randomly distributed along the data (**Figure 5)**.

The standardized SWO CPUE between 1997 and 2012 showed a general increasing trend, which is consistent with the nominal values observed during that period for the North Atlantic (**Table 3, Figure 6**). Regarding the sensitivity analysis that was carried out, in general the estimated model parameters were very similar to the original final model. Some slight differences were detected when the ratios were categorized by the 10% percentiles instead of using 25%, but in general the same overall trend was detected (**Figure 7**).

Acknowledgments

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Table 1. Annual swordfish catch (MT) by the Portuguese pelagic longline fishery; and resumed information of the data covered in the analysis: catch (MT), relative percentage, number of trips (or sub-trips) and effort (number of hooks). Data below the dotted line is that used in the CPUE standardization for the Portuguese pelagic longline fleet in the North Atlantic.

		Covered in the analysis			
Year	**Total catch**	**Catch**	**%**	**Trips**	**Effort**
1995	1617	35.7	2	8	75,200
1996	1703	26.3	2	4	83200
1997	903	74.4	8	28	367,500
1998	773	128.0	17	42	494,400
1999	777	254.3	33	66	918,800
2000	732	529.7	72	142	1,418,610
2001	735	375.3	51	139	1,034,908
2002	766	202.0	26	92	783,850
2003	1032	287.0	28	113	851,102
2004	1320	426.4	32	125	876,482
2005	900	380.7	42	109	1,048,178
2006	949	202	21	72	522,917
2007	778	247.2	32	94	566,740
2008	747	259.5	35	85	602,012
2009	898	328.1	37	80	650,286
2010	1054	349.6	33	90	791,564
2011	1203	208.4	18	48	475,009
2012	1167	420.8	36	69	712,567

Table 2. Deviance table for the explanatory variables used in the SWO CPUE standardization for the Portuguese pelagic longline fleet in the North Atlantic. The Df and deviance refer to the specific degrees of freedom needed and deviance explained by each additional variable included sequentially in the models. In this table both the simple effects and interaction terms are presented, but in the final models the interaction terms that included the factor year were used as random variables.

Model	**Df**	**Dev.**	**Resid. Df**	**Resid. Dev.**	**Fstat.**	***p-value***
Intercept only			1393	520.91		
Year	15	66.137	1378	454.77	26.22	< 0.001
Year + Quarter	3	57.455	1375	397.32	113.9	< 0.001
Year + Quarter + FishingArea	4	14.208	1371	383.11	21.13	< 0.001
Year + Quarter + FishingArea + GearType	1	0.095	1370	383.01	0.56	0.453
Year + Quarter + FishingArea + GearType + Ratio	3	123.522	1367	259.49	244.89	< 0.001
Year + Quarter + FishingArea + GearType + Ratio + Quarter:FishingArea	12	5.358	1355	254.13	2.66	0.001
Year + Quarter + FishingArea + GearType + Ratio + Quarter:FishingArea + FishingArea:Ratio	12	4.74	1343	249.39	2.35	0.006
Year + Quarter + FishingArea + GearType + Ratio + Quarter:FishingArea + FishingArea:Ratio + Year:Quarter	45	24.78	1298	224.61	3.28	< 0.001
Year + Quarter + FishingArea + GearType + Ratio + Quarter:FishingArea + FishingArea:Ratio + Year:Quarter + Year:FishingArea	55	14.674	1243	209.94	1.59	0.005
Year + Quarter + FishingArea + GearType + Ratio + Quarter:FishingArea + FishingArea:Ratio + Year:Quarter + Year:FishingArea + Year:GearType	6	1.954	1237	207.99	1.94	0.071

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

Year	**Nominal CPUE**	**Standardized CPUE index**			
		Index	**Lower 95%CI**	**Upper 95%CI**	**CV (%)**
1997	201.0	211.5	152.4	288.6	2.32
1998	261.4	219.6	153.9	307.5	2.53
1999	270.3	198.7	137.9	280.3	2.55
2000	385.5	311.6	237.8	404.9	2.05
2001	372.1	325.7	242.6	433.2	2.24
2002	264.0	257.1	192.7	339.2	2.12
2003	339.8	302.5	231.7	391.7	2.01
2004	508.9	377.5	290.6	487.2	2.03
2005	350.2	293.0	221.3	384.4	2.11
2006	377.5	312.8	225.6	428.5	2.46
2007	430.7	324.5	238.0	437.8	2.35
2008	412.3	337.9	246.6	458.2	2.40
2009	530.0	444.4	326.7	599.8	2.42
2010	480.9	416.3	306.7	560.7	2.39
2011	475.1	367.5	263.1	507.9	2.57
2012	623.2	456.8	334.7	618.7	2.45

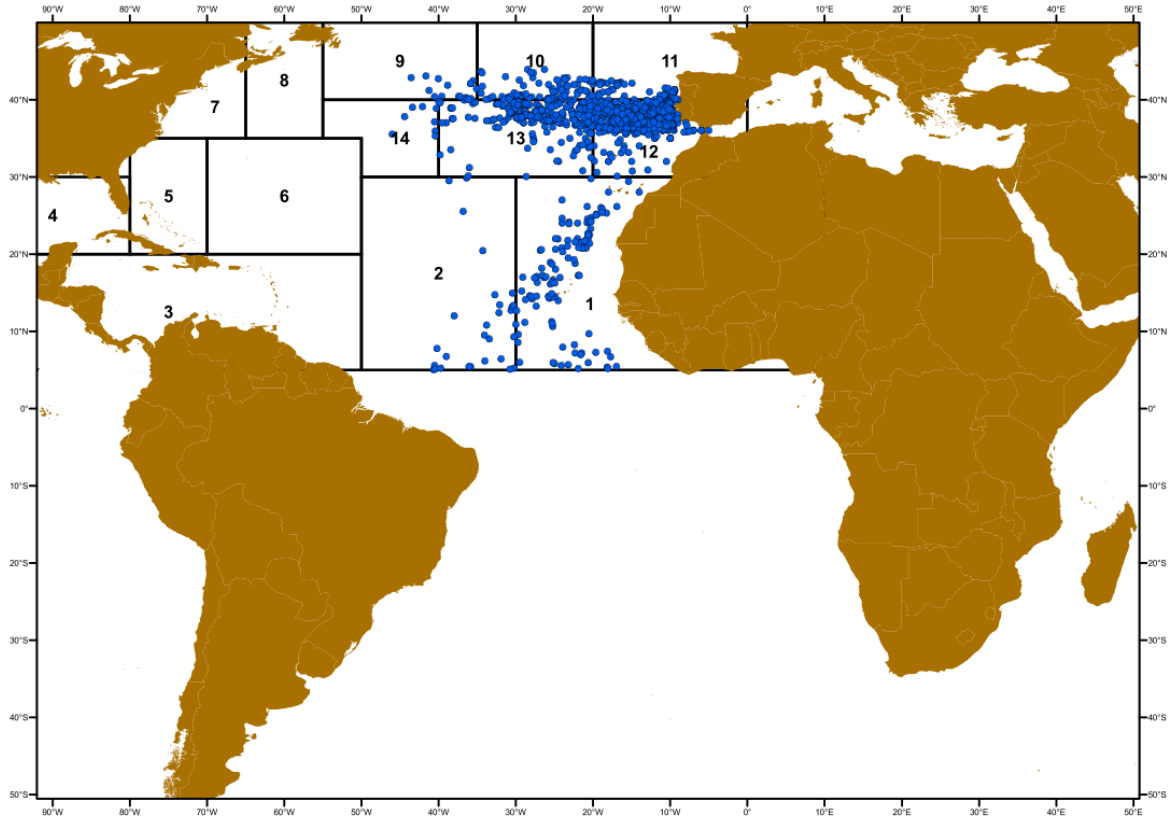

Figure 1. Map with the definition of the fishing areas in the North Atlantic used in this study. Due to small sample sizes, the areas 1+2, 9+10 and 13+14 were joined for the analysis and models.

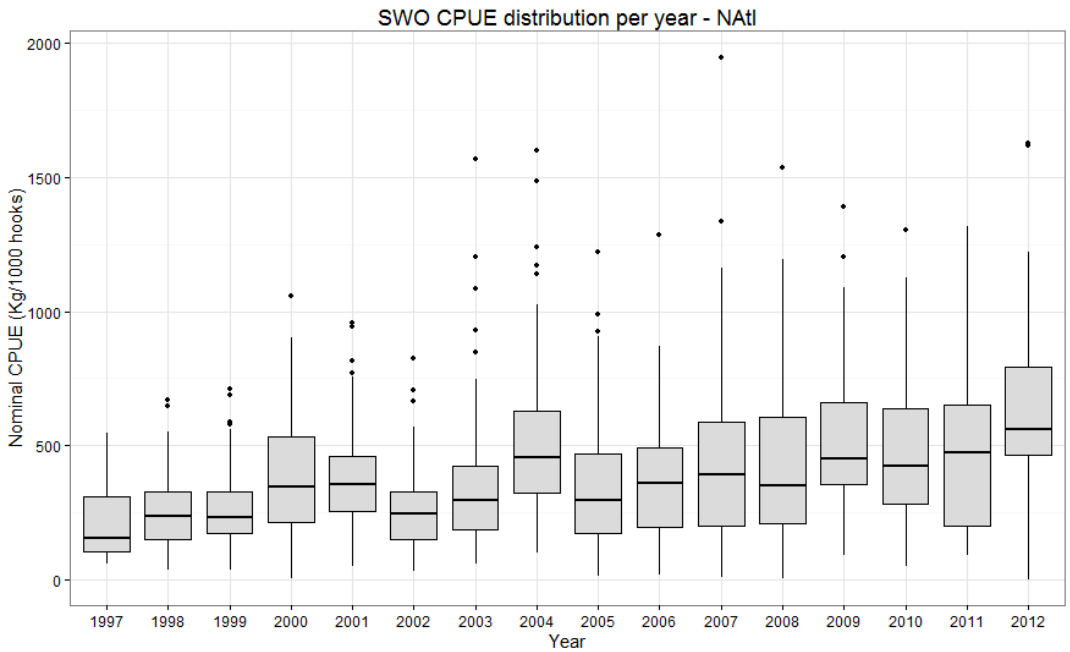

Figure 2. Boxplots with the Nominal CPUEs observed between 1997 and 2012 for the SWO captured in the North Atlantic by the Portuguese longline fleet.

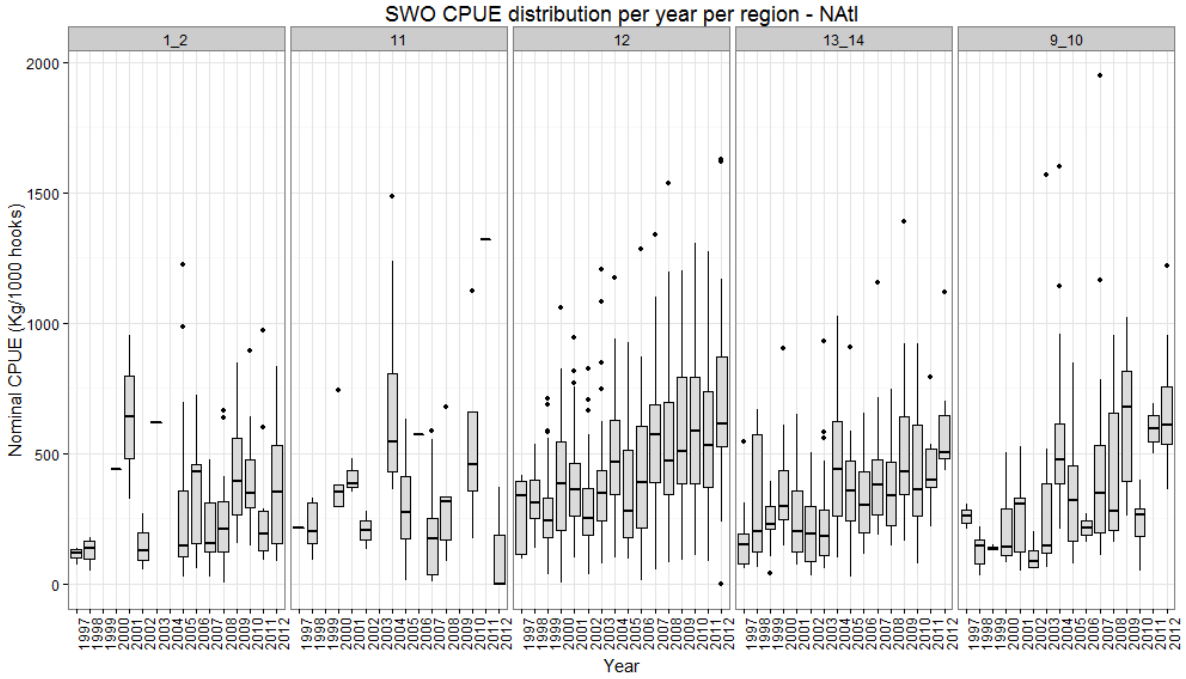

Figure 3. Boxplots with the Nominal CPUEs observed between 1997 and 2012 for the SWO captured per Fishing Area in the North Atlantic by the Portuguese longline fleet.

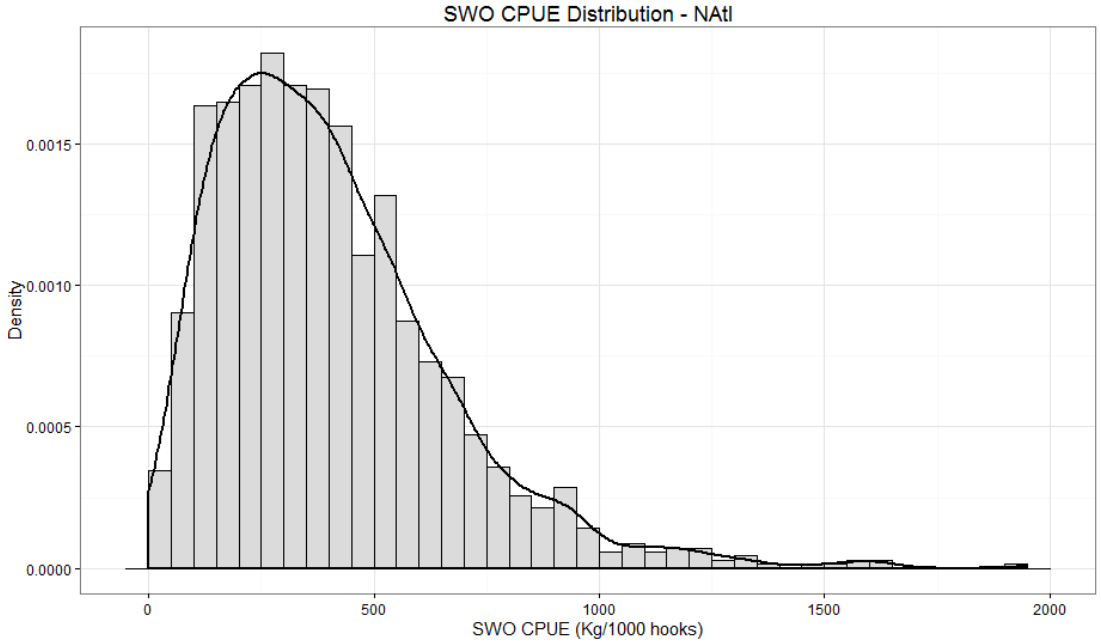

Figure 4. Distribution (density) of the nominal CPUE for the SWO captured in the North Atlantic by the Portuguese longline fleet.

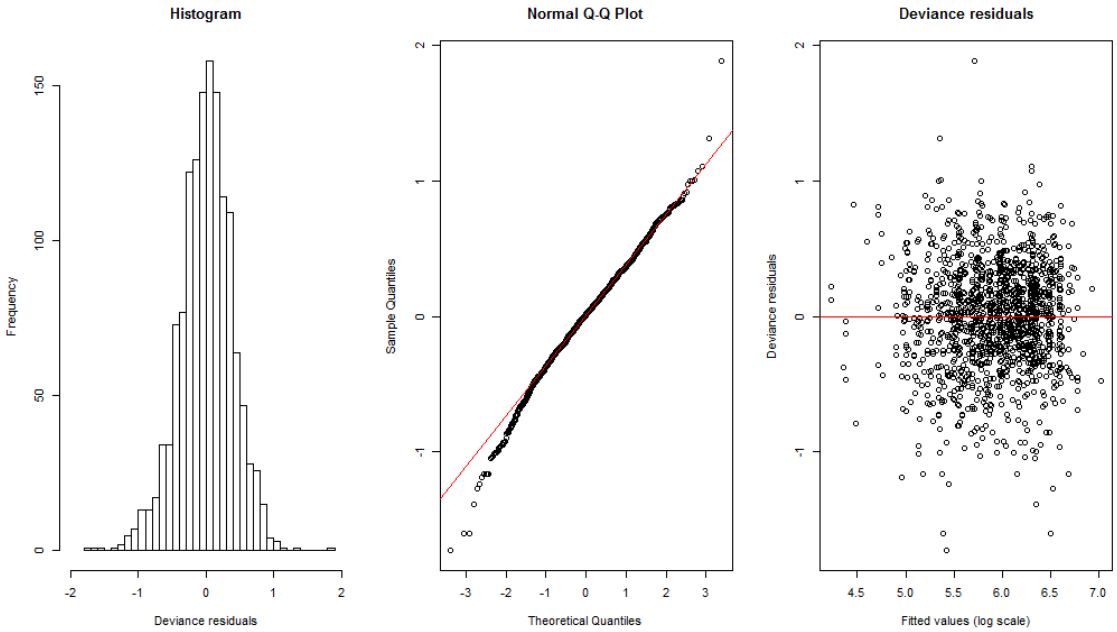

Figure 5. Residual analysis for the final GLMM lognormal model used in the SWO CPUE standardization for the Portuguese pelagic longline fleet in the North Atlantic. The graphic on the left represents the frequency distribution (histograms) of the deviance residuals, the graphic in the middle represent the QQPlot and the graphic on the right represents the deviance residuals along the predicted values (in the log scale).

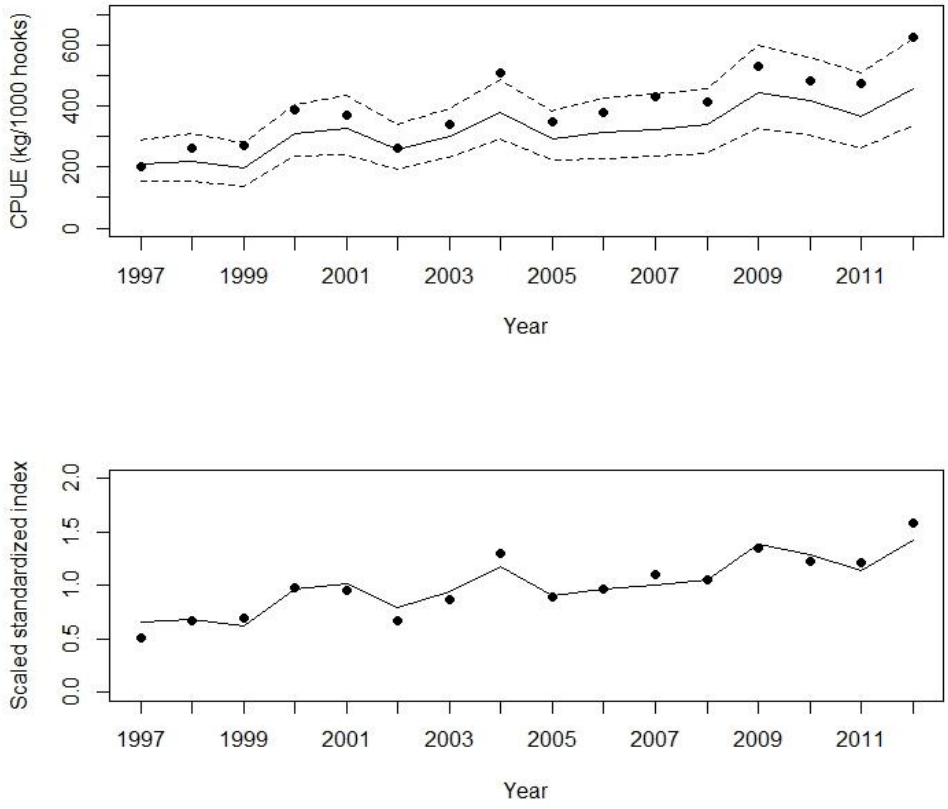

Figure 6. Annual relative index of abundance for SWO (standardized CPUE kg/1000 hooks) captured by the Portuguese pelagic longline fleet in the North Atlantic. The black circles represent the nominal CPUEs, the solid lines the standardized series and the dotted lines the 95% confidence intervals.

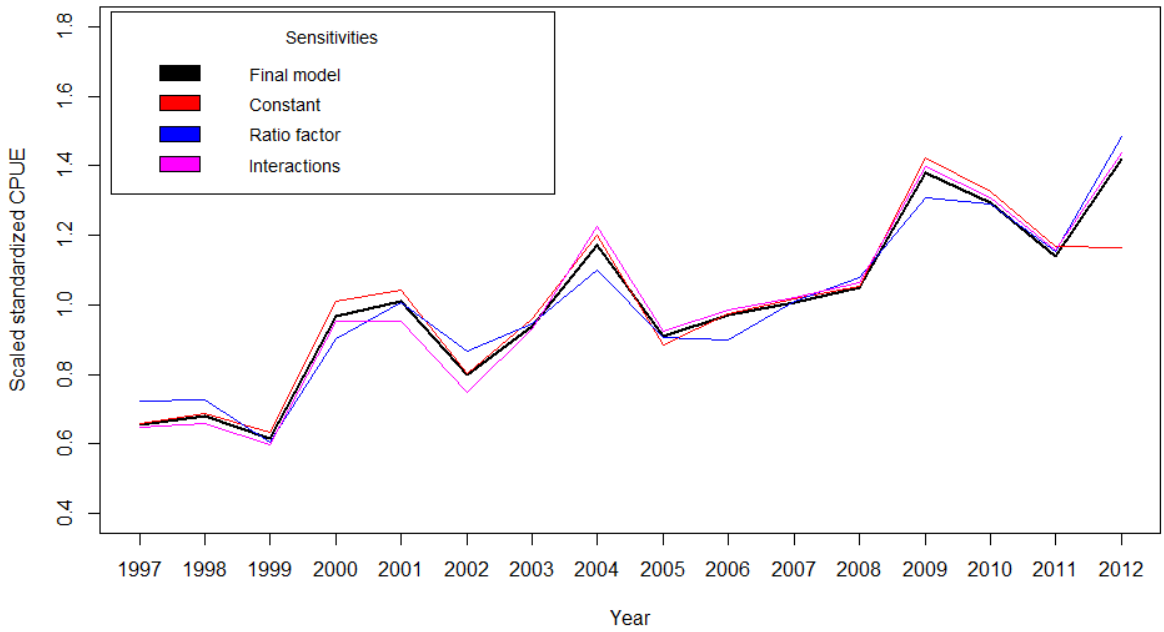

Figure 7. Sensitivities of the estimated model parameters to some of the model specifications: 1) constant added to the CPUE (using 1 instead of 10% of the mean); 2= ratio factor (categorizing by the 10% percentiles instead of the 25%); 3) removing the Year:Gear type interaction and the corresponding simple effect of Gear Type.