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BLUE SHARK CATCHES BY THE PORTUGUESE PELAGIC LONGLINE FLEET BETWEEN 1998-2013 IN THE INDIAN OCEAN: CATCH, EFFORT AND STANDARDIZED CPUE.

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SUMMARY

The Portuguese pelagic longline fishery in the Indian Ocean started in the late 1990's, targeting mainly swordfish in the southwest region. A recent effort by the *Portuguese Institute for the Ocean and Atmosphere* (IPMA) was made to collect of historical catch and effort data on this fishery since the late 1990's to the present date, as well as vessel monitoring system (VMS) data. This working document analyses the catch, effort and standardized CPUE trends for that period. Nominal annual CPUEs were calculated as kg/1000 hooks, and were standardized with Generalized Linear Models (GLM) using year, quarter, area, gear type, vessel, swordfish/blue shark ratio and regional:seasonal interactions. Sensitivity analyses were carried out for the model type used (lognormal, tweedie or gamma), to the inclusion of the ratio factor in the models, and to the definition of the areas. Model goodness-of-fit and comparison was carried out with AIC and the coefficient of determination (R^2), and model validation with a residual analysis. The final standardized CPUE trends shows a general decrease in the initial years between 2000 and 2005, followed by an increase until 2008, and then another general decrease in the more recent years until 2013. The final results present an updated annual index of abundance for the blue shark captured by the Portuguese pelagic longline fleet in the Indian Ocean, that can in the future be integrated in stock assessment models for that species in that region.

KEYWORDS: Indian Ocean, blue shark, Prionace glauca, fishery indicators, CPUE standardization, generalized linear models, pelagic longline fisheries.

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1. Introduction

The Portuguese pelagic longline fishery in the Indian Ocean started in the late 1990's and has traditionally targeted swordfish (*Xiphias gladius*, SWO) even though, in certain areas and seasons, it also catches relatively high quantities of sharks as bycatch (particularly blue shark *Prionace glauca,* BSH).

The Portuguese fishing vessels operating in the IOTC area of competence consist only of pelagic longliners targeting swordfish, traditionally ranging in size from 35 to about 50m. On recent years the mean vessel size was 40 m of total length. The number of vessels licensed increased from the beginning of the fishery in 1998 (five vessels) until 2009 (24 vessels). The number of active vessels followed a similar trend, with a peak in 2006 (17 vessels). However, during the last 5 years, the active vessels in the convention area decreased to as low as three (in 2009, 2012), with a slight increase in 2013. The reasons beyond such decrease of active fishing units in the IOTC convention area were related with the increase of exploitation costs (particularly oil in late 2000's), but also due to piracy related problems in the SW Indian Ocean, which has been traditionally the fishing area for the Portuguese fleet.

Following the preliminary working documents presented by the authors in 2012 and 2013 (Coelho et al., 2012, 2013), this study provides an updated overview of the blue shark catches by the Portuguese pelagic longline fishery operating in the Indian Ocean between 1998 and 2013. Specific objectives are to present new information on the catch, effort and CPUE trends (nominal and standardized) that can contribute for future stock assessments of blue shark in the Indian Ocean.

2. Material and methods

2.1. Catch and effort

In a recent effort by the *Portuguese Institute for the Ocean and Atmosphere* (*IPMA, I.P.),* the historical catch and effort data from the Portuguese longliners targeting swordfish in the Indian Ocean were compiled and analyzed. This included information on the catches, fishing effort in number of hooks per set and geographical location integrated from VMS data (**Table 1**). This data mining exercise allowed us to recover most of the time series for the Portuguese pelagic longline fleet operating in Indian Ocean.

Table 1: Number of fishing sets with catch, effort and location information carried out by the Portuguese pelagic longline fleet in the Indian Ocean between 1998 and 2013. The percentage of sets per year analyzed for this paper is also indicated.

Year	Sets (n)	Sets with effort (Hooks)	Sets with locations (VMS)	Sets used for analysis (%)
1998	113	113	113	100.0
1999	140	140	140	100.0
2000	270	270	270	100.0
2001	635	635	635	100.0
2002	687	687	647	94.2
2003	588	588	588	100.0
2004	370	370	370	100.0
2005	143	143	143	100.0
2006	1809	1809	1809	100.0
2007	1320	1320	1314	99.5
2008	238	238	238	100.0
2009	482	482	482	100.0
2010	456	456	456	100.0
2011	633	633	633	100.0
2012	516	516	516	100.0
2013	1312	1312	1312	100.0
Total	**9712**	**9712**	**9666**	**99.5**

The spatial catch and effort was mapped and plotted in order to identify the major areas of operation of the fleet in the Indian Ocean. The CPUE, measured in blue sharks (BSH) biomass per 1000 hooks (kg/1000 hooks), was plotted along the quarters of the year, in order to describe the patterns of the catches of this species by the fleet in that region and seasons.

2.3. CPUE standardization

The CPUE analysis was carried out using the official fisheries statistics collected by the Portuguese Fisheries authorities, to which VMS and skippers logbook data was added. Operational data at the fishing set level was used, with the catch data referring to the total (round) weight of blue shark captured per fishing set. The available catch data started in 1998 and was available until 2013. However, the first 2 years of the series (1998 and 1999) were not used for the models because there was more limited information in those initial years of the fisheries. For the CPUE standardization, the response variable considered for this study was catch per unit of effort (CPUE), measured as biomass of live fish (kg) per 1000 hooks deployed. The standardized CPUE were estimated with Generalized Linear Models (GLM).

There were some fishing sets with zero blue shark catches that result in a response variable of CPUE=0. As these zeros can cause mathematical problems for fitting the models, three different methodologies were used and compared, specifically tweedie, gamma and lognormal models. For the tweedie models the nominal CPUE was used directly for the response variable given that this distribution can handle a certain proportion of zeros. For the gamma and lognormal models, the response variable was defined as the nominal CPUE + constant (*c*), with *c* set to 10% of the overall mean catch rate or to 1 (used in a sensitivity analysis). 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%), the method of adding a constant to the response variable performs relatively well.

The covariates considered and tested in the models were:

- <u>Year</u>: analyzed between 2000 and 2013;
- <u>Quarter of the year</u>: 4 categories: 1 = January to March, 2 = April to June, 3 = July to September, 4 = October to December;
- <u>Area</u>: Using areas divided based on sea temperature at 50m depth (following Mejuto et al., 2008), Longhust ecological regions (Longhurst, 2007), or FAO regions; see **Figures 1 to 3 of the Annexes** for maps with the locations of the areas used;
- <u>Vessel ID</u>;
- <u>Gear type</u>: multifilament (old Spanish style) or monofilament (Florida style);
- <u>Ratio</u>: based on the SWO/SWO+BSH ratio of the captures;
- <u>Quarter - Area</u> interactions.

The 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 explained by each covariate. Goodness-of-fit and model comparison was carried out with the Akaike Information Criteria (AIC) and the 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 (marginal means), that for comparison purposes were scaled by the mean standardized CPUE in the time series.

The factor ratio was defined as the percentage of swordfish catches related to combined swordfish and blue shark catches. 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 consistently applied to other fleets that have a similar method of operation, such as the Spanish fleet, with applications both to the Atlantic and the Indian Ocean (e.g., Ramos-Cartelle et al., 2011; Mejuto et al., 2012; Santos et al., 2013). The ratio factor was calculated for each set and then divided into ten categories using the 0.1 quantiles.

Once a final candidate model was selected, several sensitivity analyses were carried out to test the influence of the model type, the ratio variable and geographical areas to the final model:

- Sensitivity to model type: The base case model using a lognormal distribution with a constant of 10% of the mean was compared to 1) a lognormal model with a c=1, 2) a tweedie model and 3) a gamma model.
- Sensitivity to the ratio factor: The base model using the ratios categorized by the 0.1 quantiles was compared to 1) a model with a different ratio categorization of 0.25 instead of 0.1 quantiles, and 2) by removing the ratio factor from the model.
- Sensitivity to the area effects: The base case model based on the sea temperature at 50m depth as used by Mejuto et al. (2008) was compared to 1) Longhurst ecological regions (Longhurst, 2007), 2) FAO areas and subareas, and 3) a model without spatial effects. **Figures 1 to 3 of the Annexes** provide maps with the definition of the areas used and tested in the models.

The various model specification and characteristics considered in this comparative approach are listed in detail in **Table 2**.

Table 2: Specifications of the candidate models run for the blue shark CPUE standardization for the Indian Ocean by the Portuguese pelagic longline fleet. The model types, specifications and explanatory variables are described, as well as some additional comments including the number of estimated parameters (pars). In the model characteristics, the "*c*" refers to the constant that was added to the response variable in the lognormal and gamma models.

	Model	Caracteristics	Explanatory variables	Comments
Base cases	Mod1	GLM Lognormal (c=10%mean)	Year + Quarter + Area + Vessel + Ratio + Gear type	Full simple effect model (54 pars)
	Mod2	GLM Lognormal (c=10%mean)	Year + Quarter + Area + Vessel + Ratio + Quarter:Area	Model with area:season interaction (68 pars)
Sensitivity to model type	Mod3	GLM Lognormal (c=1)	Year + Quarter + Area + Vessel + Ratio + Quarter:Area	Lognormal GLM with area:season interaction (68 pars)
	Mod4	GLM Tweedie (link=log)	Year + Quarter + Area + Vessel + Ratio + Quarter:Area	Tweedie GLM with area:season interaction (68 pars)
	Mod5	GLM Gamma (link=log; c=10%mean)	Year + Quarter + Area + Vessel + Ratio + Quarter:Area	Gamma GLM with area:season interaction (68 pars)
Sensitivity to Ratio factor	Mod6	GLM Lognormal	Year + Quarter + Area + Vessel + Ratio + Quarter:Area	Model with Ratio factor categorized by the 0.25 quantiles (62 pars)
	Mod7	GLM Lognormal	Year + Quarter + Area + Vessel + Quarter:Area	Model without Ratio factor (59 pars)
Sensitivity to Area	Mod8	GLM Lognormal	Year + Quarter + AreaLongh + Vessel + Ratio + Quarter:AreaLongh	Using Longhurst ecological areas (52 pars)
	Mod9	GLM Lognormal	Year + Quarter + AreaFAO + Vessel + Ratio + Quarter:AreaFAO	Using FAO Areas and Subareas (60 pars)
	Mod10	GLM Lognormal	Year + Quarter + Vessel + Ratio	Model without spatial effects (48 pars)

Statistical analysis for this paper was carried out with the R Project for Statistical Computing version 3.0.1 (R Core Team, 2013) using several additional libraries (Wickham, 2009; Fox and Weisberg, 2011; Dunn, 2011; Højsgaard and Halekoh, 2012; Bivand and Lewin-Koh, 2013; Hastie, 2013; Lenth, 2014).

3. Results and Discussion

3.1. Catch and effort

3.1.1. Spatial distribution of the catch and effort

The areas of operation in the Indian Ocean in terms of fishing effort for the Portuguese pelagic longline fleet, for the period between 1998 and 2013, is shown in **Figure 1**. Most of the effort took place in the south and southwest regions, with a higher concentration in the area south of Madagascar Island and closer to South Africa and south Mozambique (**Figure 1**).

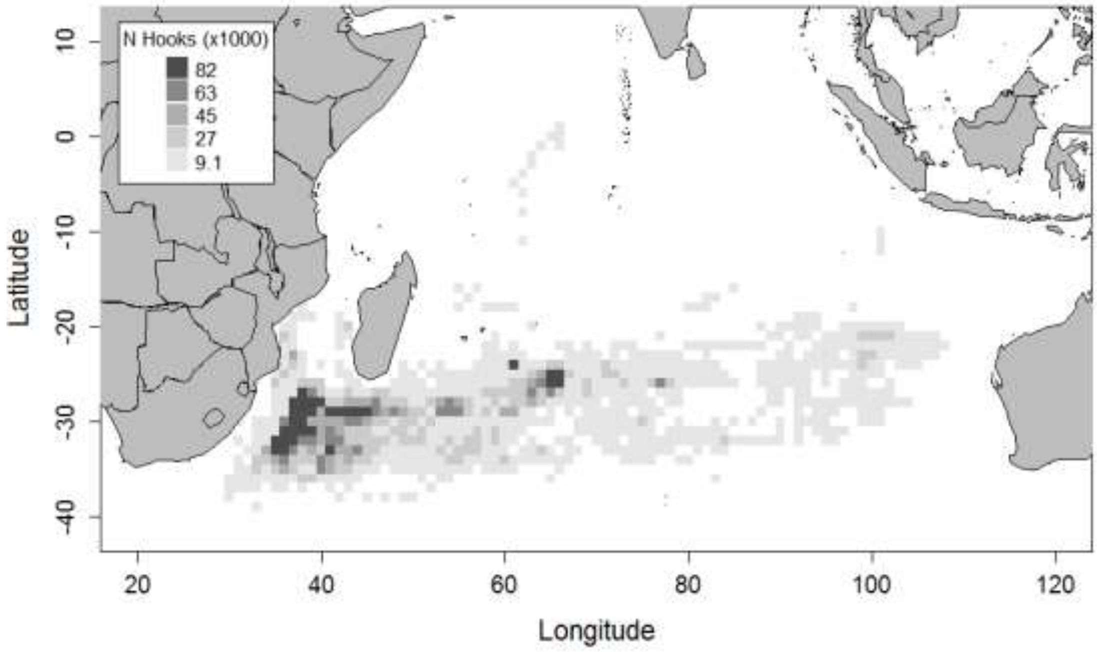

Figure 1. Effort distribution of the Portuguese pelagic longline fleet for the 1998-2013 period in the Indian Ocean. The effort is represented in 1°x1° grids with darker and lighter colors representing respectively to areas with more and less effort in number of hooks.

The BSH catches are also spread throughout the Indian Ocean region, but also follow this general trend of a higher concentration in the southwest region, south of Madagascar Island and closer to South Africa and south Mozambique (**Figure 2**).

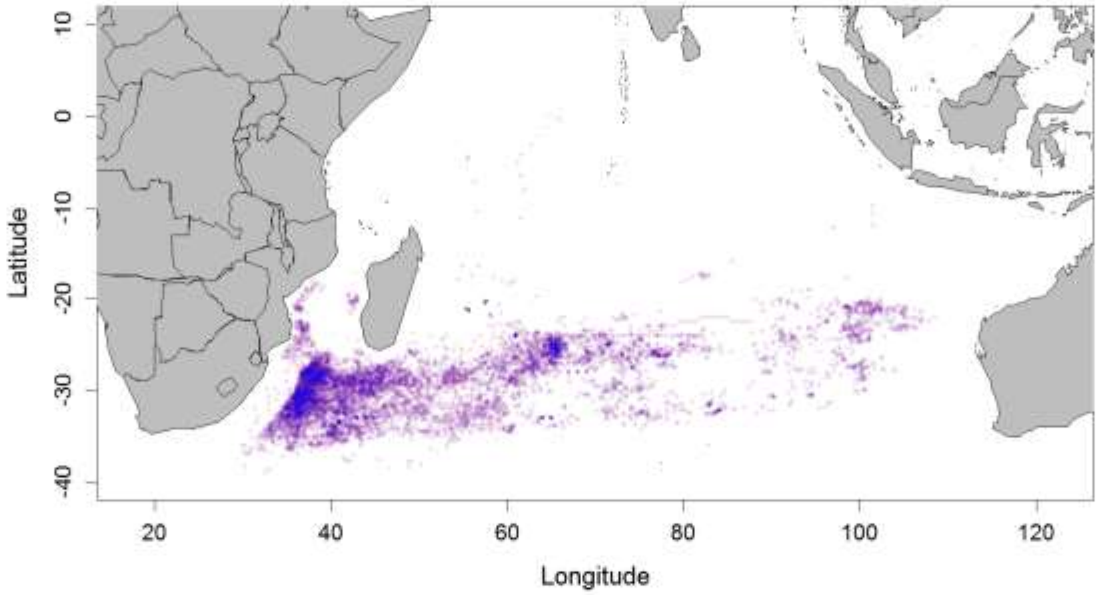

Figure 2. Location of the Portuguese pelagic longline sets reported by the fleet with logbooks between 1998 and 2013 for the entire Indian Ocean. Full color saturation indicates higher blue shark CPUE while the lighter red color represents sets with zero BSH catches.

3.1.2. Yearly and seasonal variability in the catch and effort

The total effort of the Portuguese longline fleet in the Indian Ocean remained relatively constant between 1999 and 2004, followed by an increase during 2006-2007and then a sharp decrease in the 2008 (**Figure 3**). Since then, and for the more recent years (2009 to 2013) the effort has been increasing again to values higher than in the early 2000's and closer to the 2006-2007 period (**Figure 3**).

The total blue shark catches also tended to follow this general trend, with a peak during 2006-2007, followed by a sharp decrease in 2008, and then a more steady and progressive increase for the more recent period (**Figure 3**). In terms of ratios of swordfish compared to the swordfish + blue shark catches, the ratios were higher in the first 2 years of the time series, then tended to be lower between 2000 and 2005, and finally were higher in the more recent period between 2005 and 2013 but with a slight decreasing trend (**Figure 3**).

The increase after 2005 might be a result of a change in the fishery, namely in terms of gear material, i.e. the replacement of the traditional multifilament by nylon monofilament gear which provides higher swordfish catches. Whereas, the slight decrease after 2008 is probably related by another change in the fishing gear (nylon monofilament by wire leaders) and bait (mackerel alternating with of squid, or instead of, in areas/periods of higher shark abundance). Several authors (Ward et al., 2009; Vega and Licandeo, 2009; Afonso et al., 2012) have demonstrated that higher blue shark catch rates are obtained when wire leaders are used.

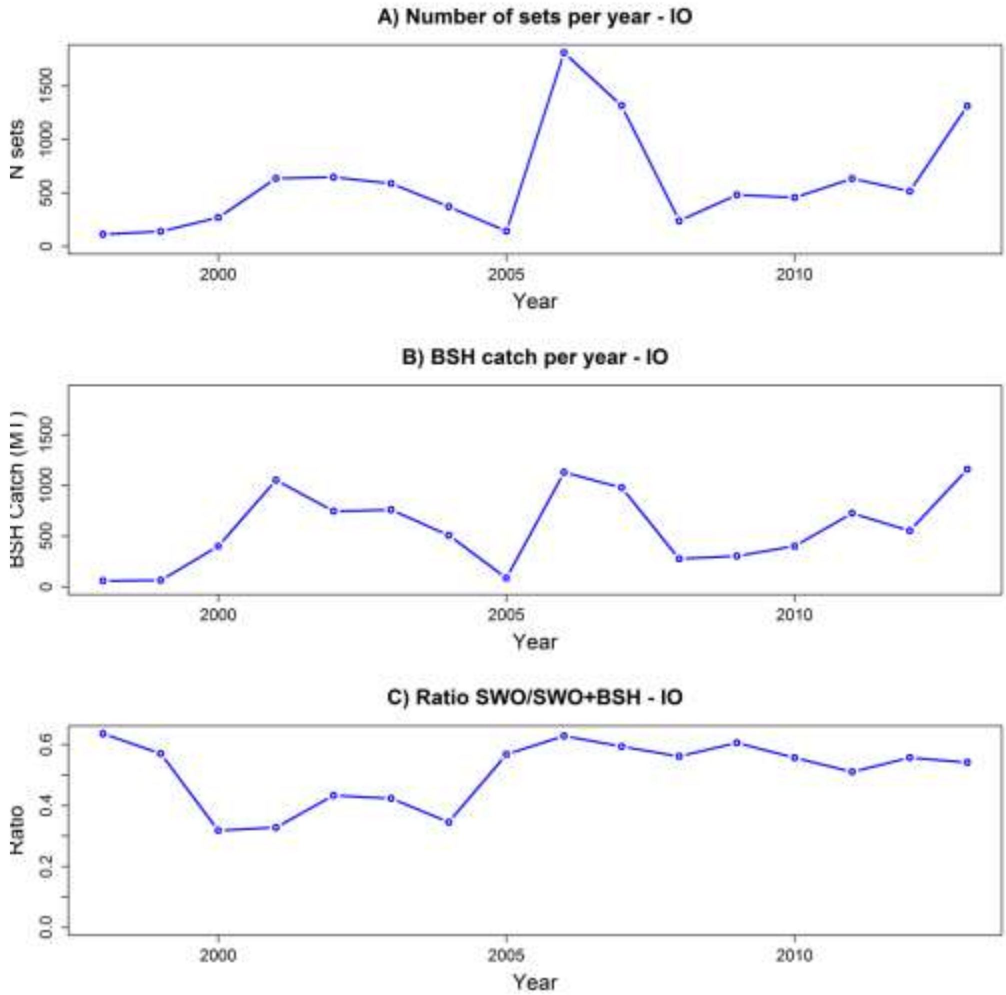

Figure 3: Descriptive plots of the total effort in sets (A), the total catch of blue shark (B), and the ratio of swordfish compared to the swordfish and blue shark catches (C), for the Portuguese longline fleet operating in the Indian Ocean.

In terms of seasonality in the CPUE, and even though there was some considerable inter-annual variability, it was possible to observe a general trend of higher CPUEs in the 1st half of the year followed by lower CPUEs towards the end of the year (**Figure 4**).

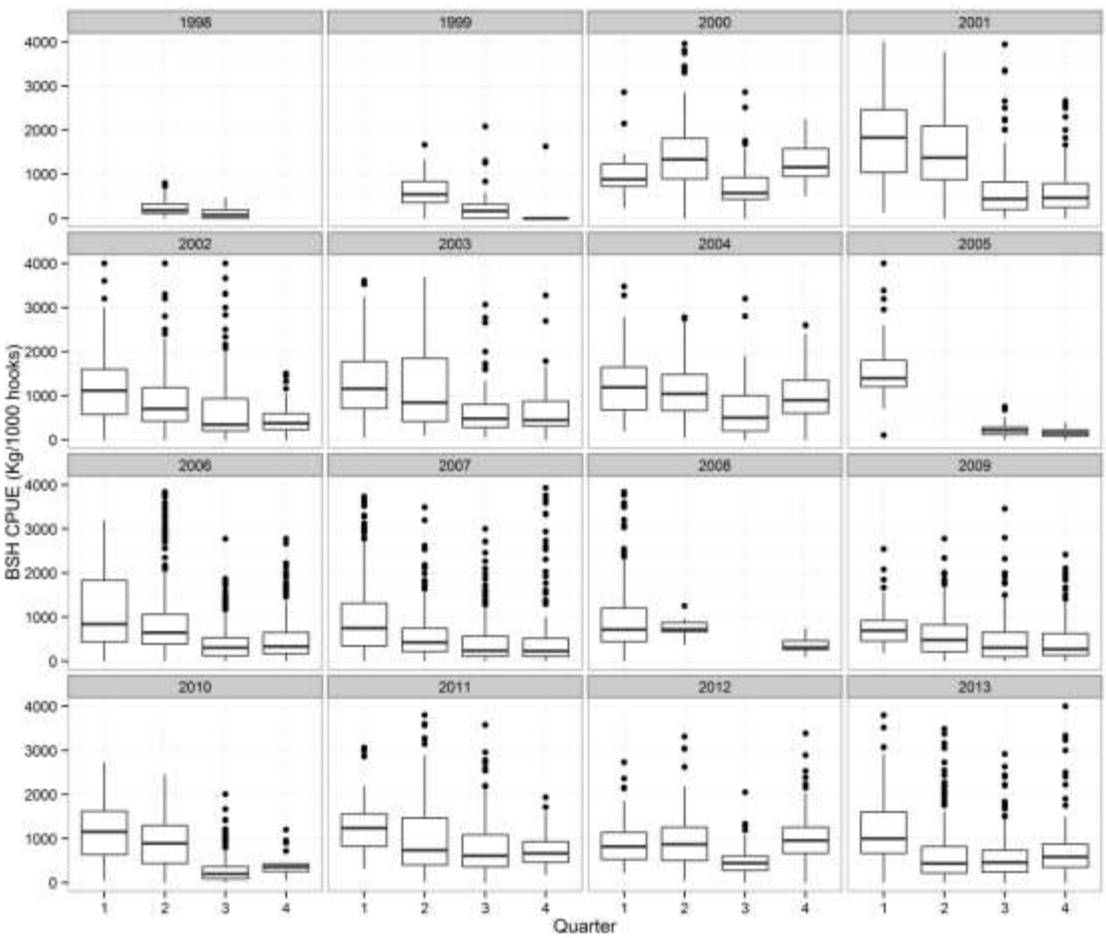

Figure 4. Quarterly blue shark CPUE (kg/1000 hooks) by the Portuguese pelagic longline fleet in the Indian Ocean, per year. In the boxplots the middle lines represents the median, the box the quartiles, the whiskers the non-outlier range and the points the outliers.

3.3. CPUE standardization

3.3.1. CPUE data characteristics

The nominal time series of the blue shark CPUE for the Portuguese pelagic longline fleet operating in the Indian Ocean is presented in **Figure 5**. In general there was a decreasing tendency between the initial and final years of the series, even though several peaks were recorded in several years along the series, especially in 2000, 2004, 2008 and 2011 (**Figure 5**).

The percentage of fishing sets with zero catches of BSH in the Indian Ocean was low, specifically 3.86%. The nominal blue shark CPUE distribution was highly skewed to the right and become more normal shaped in the log-transformed scale (**Figure 6**).

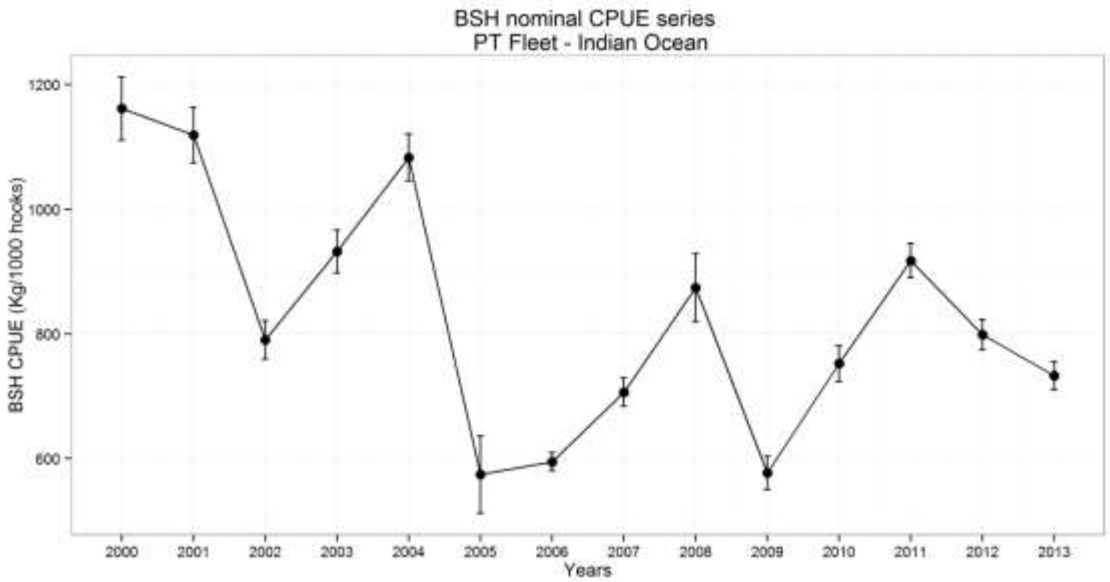

Figure 5. Nominal CPUE series (kg/1000 hooks) for blue shark caught by the Portuguese pelagic longline fishery in the Indian Ocean, between 2000 and 2013. The error bars refer to the standard errors.

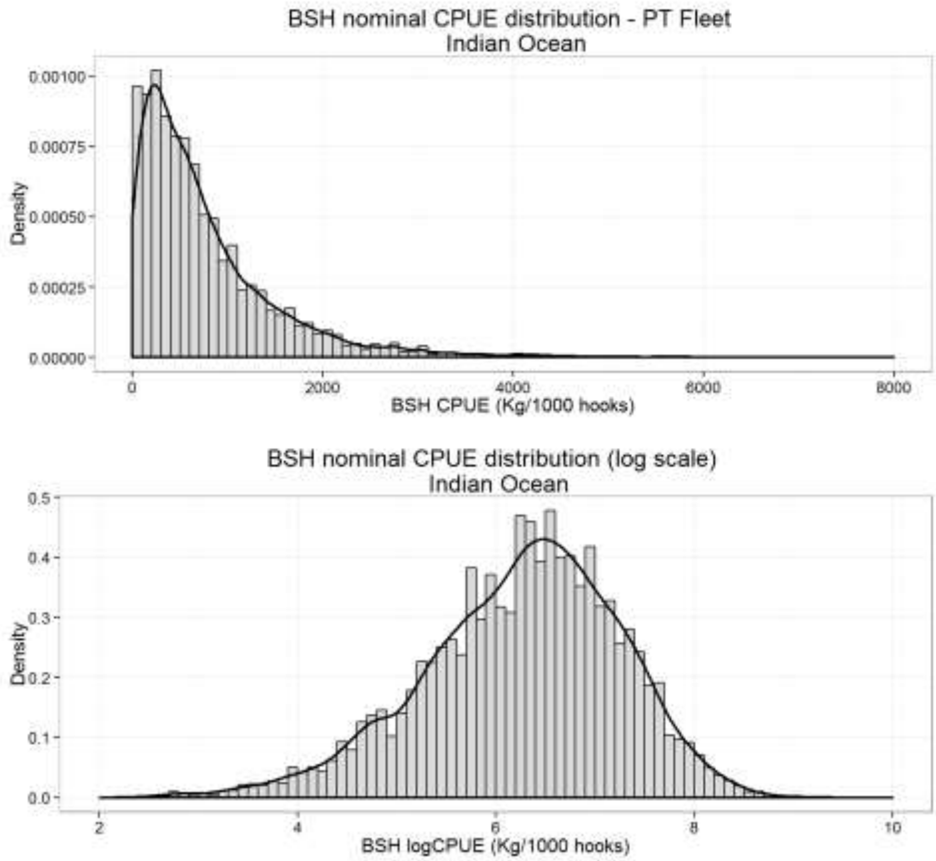

Figure 6: Distribution of the nominal blue shark CPUE captured by the Portuguese longline fleet in the Indian Ocean in non-transformed (top plot) and log-transformed (bottom plot) scales.

3.3.2. Model construction

For the base case lognormal models, all the explanatory variables tested for the blue shark CPUE standardization were significant and contributed significantly for explaining part of the deviance, except the gear type that was not significant and was therefore removed from the final models. This is likely due to the fact that most vessels changed to the modern gear type around the same time period, and therefore there is a lack of contrasts of both gear types on all the years and this creates modeling problems. The interaction between area and quarter was significant and improved the goodness-of-fit (decrease in AIC and increase in R^2) and was therefore included in the models (**Table 3**).

On both models (with and without spatial:seasonal interactions), the factors that contributed most for the deviance explanation were the ratio factor followed by the vessel, the quarter and then the year effects (**Table 3**).

In terms of model validation both models seemed adequate for this particular situation with a low quantity of zeros. However, in the residual analysis, including the residuals distribution along the fitted values, the QQ plots and the residuals histograms, it was possible to detect the presence of some outliers (**Figure 7**).

Table 3. Deviance table of the parameters used for the blue shark CPUE standardization models for the Indian Ocean using a lognormal error distribution with c=10% of the mean. For each parameter it is indicated the degrees of freedom used (Df), the deviance explained (Dev), the residual degrees of freedom (Resid Df) and deviance (Resid Dev) after incorporating sequentially each variable. The significance (F-stat and p-value) of each variable is also indicated as well as the goodness-of-fit values (AIC and R^2).

Model	Variables	Df	Dev.	Resid. Df	Resid. Dev	F-stat.	*p-value*
Mod 1: Full simple effects model (AIC=10599; R2=76.7%)	Intersept only			9410	7249.3		
	Year	13	494.1	9397	6755.2	211.76	< 0.001
	Year + Quarter	3	821.6	9394	5933.6	1525.86	< 0.001
	Year + Quarter + Area	5	173.8	9389	5759.8	193.65	< 0.001
	Year + Quarter + Area + Vessel	23	992.3	9366	4767.6	240.37	< 0.001
	Year + Quarter + Area + Vessel + Ratio	9	3088.3	9357	1679.3	1911.91	< 0.001
	Year + Quarter + Area + Vessel + Ratio + Gear type	1	0.0	9356	1679.2	0.21	0.646
Mod 2: Model with spatial/seasonal interaction (AIC=10416; R2=77.2%)	Intersept only			9410	7249.3		
	Year	13	494.1	9397	6755.2	216.23	< 0.001
	Year + Quarter	3	821.6	9394	5933.6	1558.07	< 0.001
	Year + Quarter + Area	5	173.8	9389	5759.8	197.74	< 0.001
	Year + Quarter + Area + Vessel	23	992.3	9366	4767.6	245.44	< 0.001
	Year + Quarter + Area + Vessel + Ratio	9	3088.3	9357	1679.3	1952.26	< 0.001
	Year + Quarter + Area + Vessel + Ratio + Quarter:Area	15	37.2	9342	1642	14.11	< 0.001

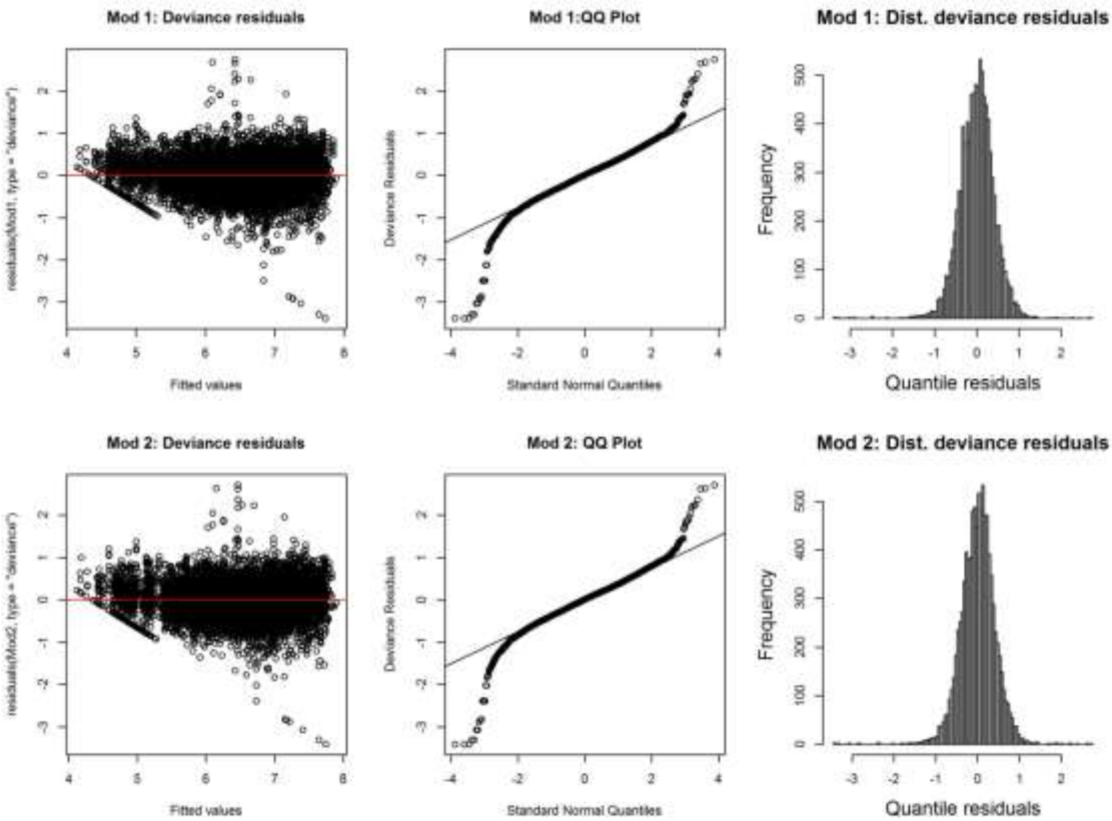

Figure 7. Residual analysis for the lognormal models tested for the blue shark CPUE standardization in the Indian Ocean, specifically a model with simple effects only (Mod1) and a model with quarter/area interactions (Mod2). For each model it is presented the residuals along the fitted values on the log scale (graphics on the left), the QQPlot (graphics on the middle) and the histogram of the distribution of the residuals (graphics on the right).

For those two first models using a lognormal error distribution with and without season:area interaction, the relative indexes of abundance were very similar. On both cases the index showed a decrease in the initial years between 2000 and 2005, then followed by an increase until 2008, and finally another general decrease in the more recent years until 2013 (**Figure 8**).

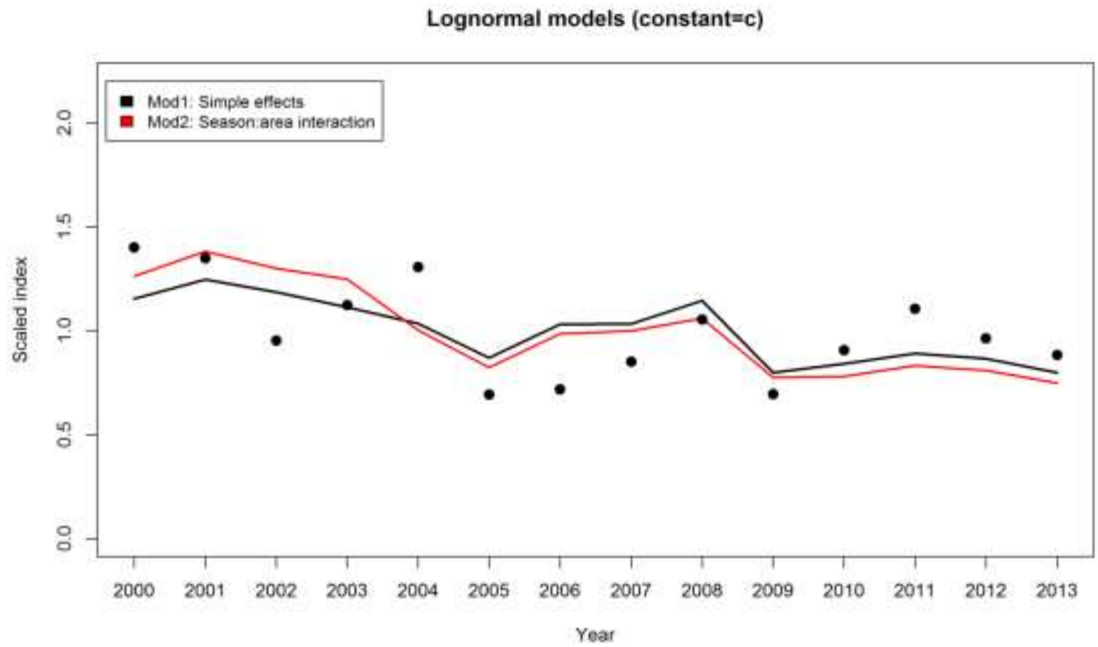

Figure 8. Standardized CPUE series for blue shark captured by the Portuguese pelagic longline fleet in the Indian Ocean using a lognormal GLM with and without interactions. The solid lines and the black dots refer respectively to the standardized and nominal CPUE series.

3.3.3. Sensitivity to the model type

A sensitivity analysis was run for testing various candidate model types that were compared to the original lognormal (adding a constant *c*=10% of the mean). Specifically, the tested models were a lognormal with constant c=1, a tweedie model and a gamma with constant *c*=10% of the mean.

The comparison of those models with the base case lognormal, resulted in relatively similar patterns for all cases, even thought there were some differences (**Figure 9**). Specifically, the lognormal with c=1 had higher values in the first years and lower in the later years, while the gamma and tweedie had an opposite effect, with lower values in the first years and higher in the later years (**Figure 9**).

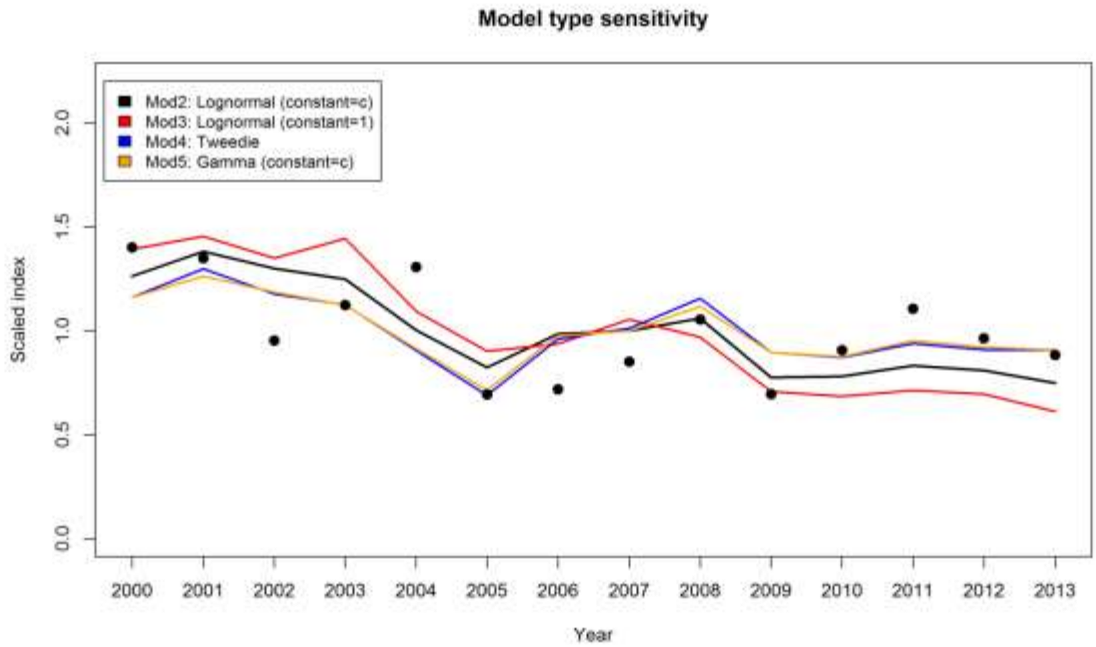

Figure 9. Sensitivity analysis to the model type for the blue shark CPUE standardization from the Portuguese pelagic longline fleet in the Indian Ocean. The scaled annual indexes of abundance of the final model selected (Mod2) is represented in black, and compared to alternative models in red (Mod3: lognormal with constant=1), blue (Mod4: tweedie model) and orange (Mod5: gamma model).

Like in the base case, the factors that contributed most for the deviance explanation were the ratio factor followed by the vessel, quarter and then the year effects (**Table 4**). In terms of R^2 comparison, the best fitted model was the original lognormal using a constant of 10% of the mean (Mod2: R^2=77.2%). Note that in this case the AIC values are not compared directly because the response variable (CPUE, CPUE+c and CPUE+1) is not the same for all models. After the lognormal base case, the best fit was given by the gamma, followed by the tweedie, and then the lognormal with *c*=1.

Table 4. Deviance table of the parameters for the sensitivity analysis of the model types for the blue shark CPUE standardization in the Indian Ocean. For each parameter it is indicated the degrees of freedom used (Df), the deviance explained (Dev), the residual degrees of freedom (Resid Df) and deviance (Resid Dev) after incorporating sequentially each variable. The significance (F-stat and p-value) of each variable is indicated as well as the R^2 values.

Model	Variables	Df	Dev.	Resid. Df	Resid. Dev	F-stat.	*p-value*
Mod 3: Lognormal (cons=1) (R^2=69.6%)	Intersept only			9410	20663		
	Year	13	1022.5	9397	19641	117.7	< 0.001
	Year + Quarter	3	1432.9	9394	18208	715.0	< 0.001
	Year + Quarter + Area	5	426.2	9389	17782	127.6	< 0.001
	Year + Quarter + Area + Vessel	23	1772.7	9366	16009	115.4	< 0.001
	Year + Quarter + Area + Vessel + Ratio	9	9653.9	9357	6355	1605.7	< 0.001
	Year + Quarter + Area + Vessel + Ratio + Quarter:Area	15	114.5	9342	6241	11.4	< 0.001
Mod 4: Tweedie (R^2=70.3%)	Intersept only			9410	107485		
	Year	13	5223.0	9397	102262	116.8	< 0.001
	Year + Quarter	3	10926.0	9394	91336	1058.3	< 0.001
	Year + Quarter + Area	5	2329.0	9389	89007	135.4	< 0.001
	Year + Quarter + Area + Vessel	23	13925.0	9366	75082	175.9	< 0.001
	Year + Quarter + Area + Vessel + Ratio	9	42755.0	9357	32326	1380.5	< 0.001
	Year + Quarter + Area + Vessel + Ratio + Quarter:Area	15	620.0	9342	31707	12.0	< 0.001
Mod 5: Gamma (cons=c) (R^2=75.9%)	Intersept only			9410	6699		
	Year	13	348.3	9397	6350	127.4	< 0.001
	Year + Quarter	3	733.3	9394	5617	1162.7	< 0.001
	Year + Quarter + Area	5	160.6	9389	5456	152.8	< 0.001
	Year + Quarter + Area + Vessel	23	939.9	9366	4517	194.4	< 0.001
	Year + Quarter + Area + Vessel + Ratio	9	2876.4	9357	1640	1520.2	< 0.001
	Year + Quarter + Area + Vessel + Ratio + Quarter:Area	15	37.4	9342	1603	11.9	< 0.001

In terms of residual analysis there were some problems with the lognormal model with constant c=1 (Mod 3) that were particularly noticeable in the QQPlot (**Figure 10**). For the tweedie (Mod4) and gamma (Mod5) models the residual analysis produced better results, even though some outliers were still visible in both cases (**Figure 10**).

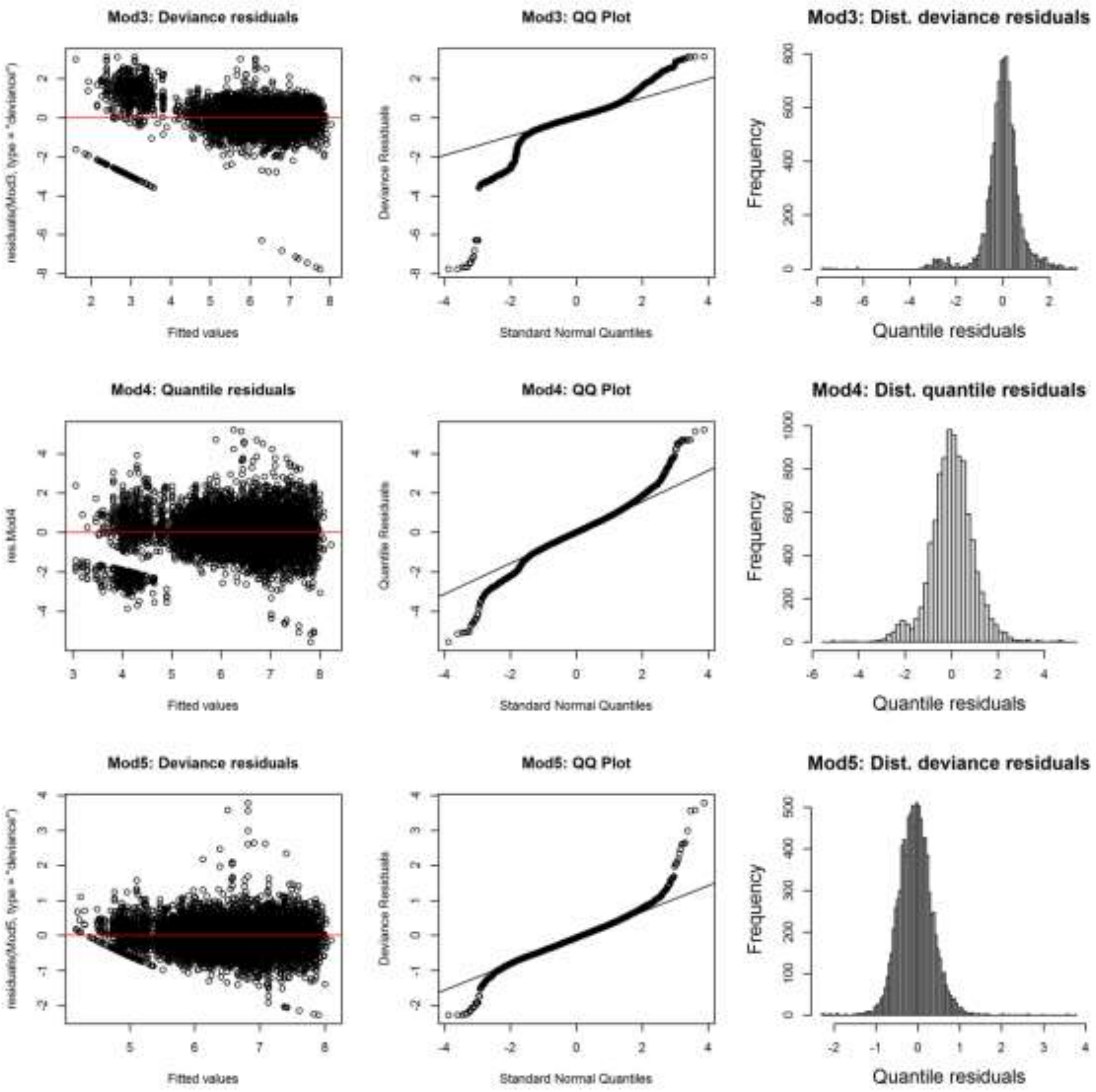

Figure 10. Residual analysis for the various model types (sensitivity analysis) tested for the blue shark CPUE standardization in the Indian Ocean, specifically a lognormal with constant *c*=1 (Mod 3), a tweedie model (Mod4) and a gamma model (Mod 5). For each model it is presented the residuals along the fitted values on the log scale (graphics on the left), the QQPlot (graphics on the middle) and the histogram of the distribution of the residuals (graphics on the right).

3.3.4. Sensitivity to the Ratio factor

Another sensitivity analysis was run for testing the influence of the ratio (swordfish / swordfish + blue shark) factor on the CPUE series and various candidate models were compared to the original model. Specifically, the original model that was using the ratios categorized by the 0.1 quantiles was compared to a model using the ratios categorized by the 0.25 quantiles and with another model without the ratio factor. This analysis revealed some differences in the standardized CPUE series, particularly when the ratio variable was removed from the model (**Figure 11**). However, the general pattern of the CPUEs remained similar even when the ratio factor was removed, with a general decrease along the series, even thought when the ration factor was removed the decrease occurred faster and in the earlier years, and was then followed by a more stable trend in the more recent years (**Figure 11**).

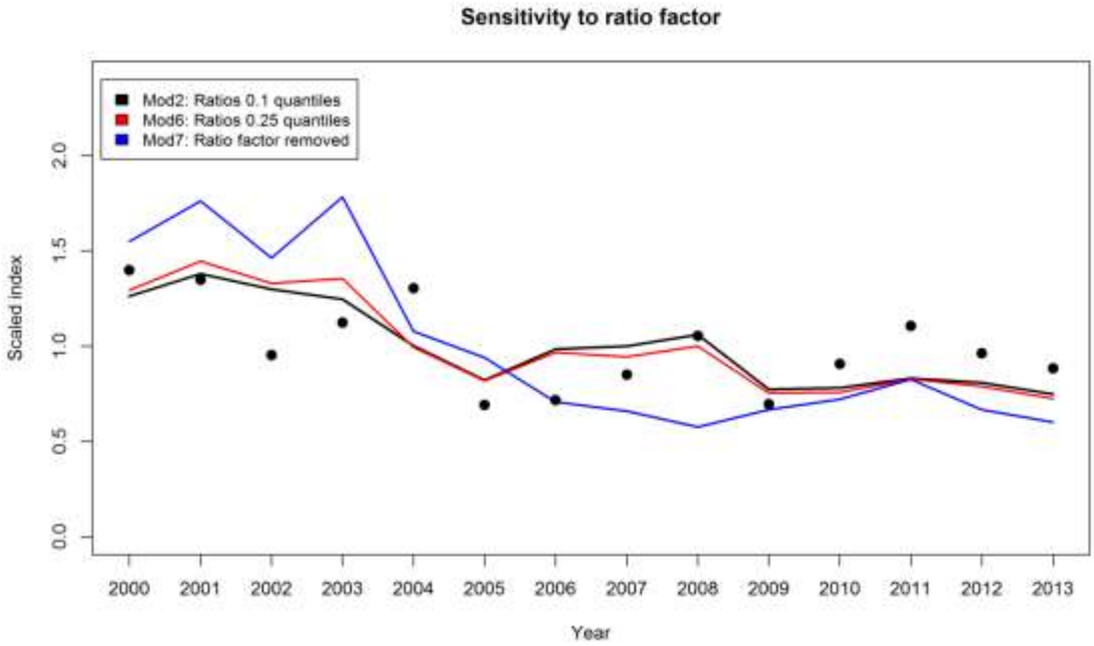

Figure 11. Model sensitivity to the factor ratio for the blue shark CPUE standardization from the Portuguese pelagic longline fleet in the Indian Ocean. The scaled annual indexes of abundance of the final model selected (Mod2) is represented in black, and the alternative models in red (Mod6: using a different ratio categorization) and blue (Mod7: removing the ratio factor).

In terms of goodness-of-fit, the best fitted model was the original base case that used the ratios categorized by the 0.1 quantiles. Using a different categorization produced a slightly worse fit, and by removing the ratio factor the fit was much worse with a high decrease in the R^2 and a high increase in the AIC (**Table 5**). In terms of residual analysis there were no major differences in the models using or not the ratio variable, even though a larger dispersion in the residuals was observed when the ratio factor was removed (**Figure 12**).

Table 5. Deviance table of the parameters for the sensitivity analysis of the ratio variable for the blue shark CPUE standardization in the Indian Ocean. For each parameter it is indicated the degrees of freedom used (Df), the deviance explained (Dev), the residual degrees of freedom (Resid Df) and deviance (Resid Dev) after incorporating sequentially each variable. The significance (F-stat and p-value) of each variable is indicated as well as the R^2 values.

Model	Variables	Df	Dev.	Resid. Df	Resid. Dev	F-stat.	*p-value*
<u>Mod 6</u>: Ratio categorization (AIC=12899; R^2=70.3%)	Intersept only			9410	7249.3		
	Year	13	494.1	9397	6755	166.0	< 0.001
	Year + Quarter	3	821.6	9394	5934	1196.1	< 0.001
	Year + Quarter + Area	5	173.8	9389	5760	151.8	< 0.001
	Year + Quarter + Area + Vessel	23	992.3	9366	4768	188.4	< 0.001
	Year + Quarter + Area + Vessel + Ratio	3	2589.6	9363	2178	3769.9	< 0.001
	Year + Quarter + Area + Vessel + Ratio + Quarter:Area	15	37.6	9348	2140	10.9	< 0.001
<u>Mod 7</u>: Removing ratio variable (AIC=20265; R^2=35.0%)	Intersept only			9410	7249.3		
	Year	13	494.1	9397	6755.2	75.9	< 0.001
	Year + Quarter	3	821.6	9394	5933.6	546.6	< 0.001
	Year + Quarter + Area	5	173.8	9389	5759.8	69.4	< 0.001
	Year + Quarter + Area + Vessel	23	992.3	9366	4767.6	86.1	< 0.001
	Year + Quarter + Area + Vessel + Quarter:Area	15	82.7	9351	4684.9	11.0	< 0.001

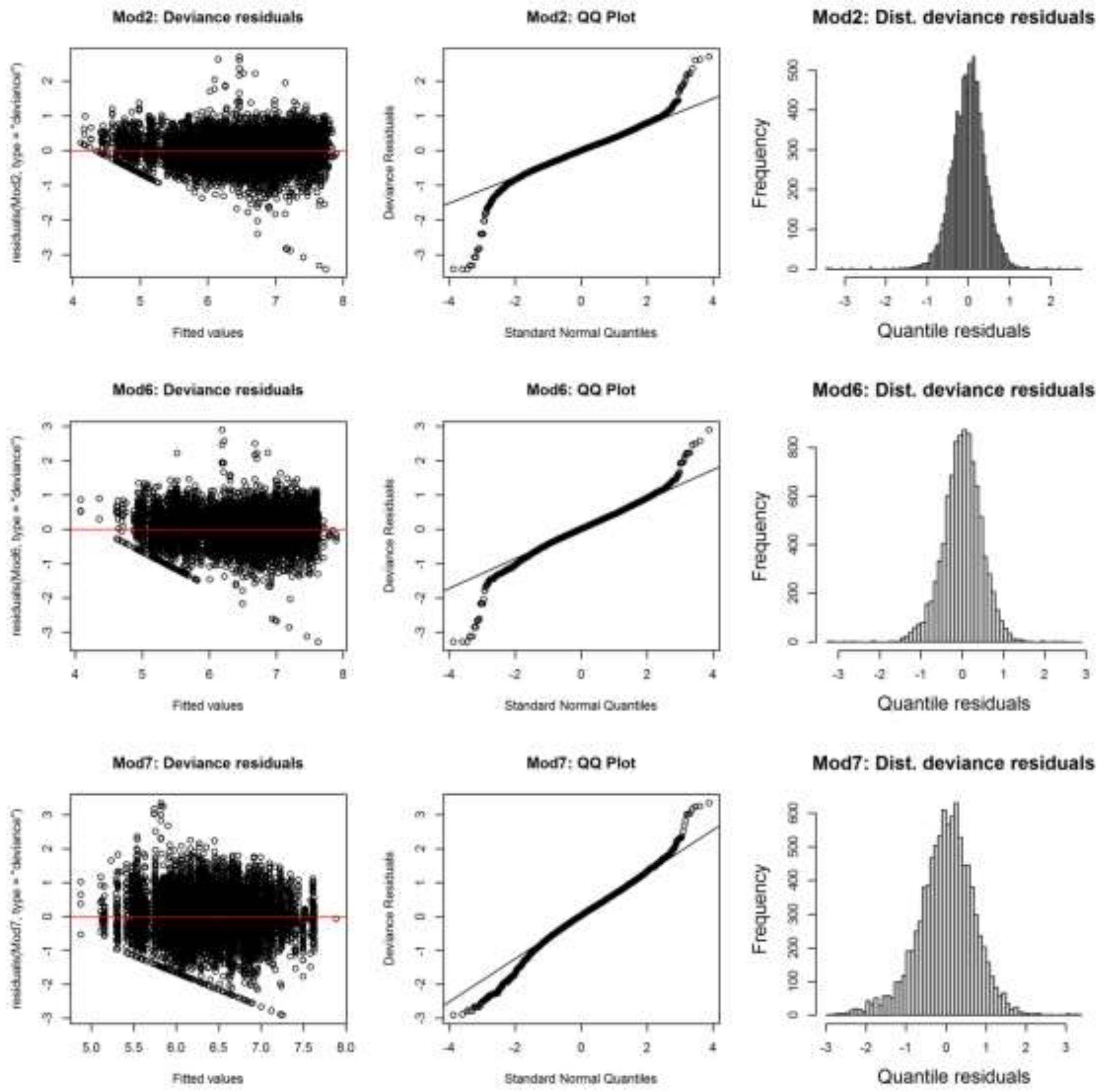

Figure 12. Residual analysis for the various model tested for the sensitivity to the ratio factor for the blue shark CPUE standardization in the Indian Ocean. Mod 2 is the base case model with the ratios categorized by the 01 quantiles, Mod 6 uses a different ratio categorization (0.25 quantiles) and Mod 7 does not include the ratio factor. For each model it is presented the residuals along the fitted values on the log scale (graphics on the left), the QQPlot (graphics on the middle) and the histogram of the distribution of the residuals (graphics on the right).

3.3.5. Sensitivity to the Area

Another sensitivity analysis was run for testing the influence of the areas used on the CPUE series and various candidate models were compared to the original model. Specifically, the original model that was using the Indian Ocean areas as defined by Mejuto et al. (2008) based on sea temperature at 50m depth, was compared to a model using the Longhurst areas, a model with the FAO subareas and a model without the area effects. This analysis revealed very little differences in the standardized CPUE series, even when the area factor was removed (**Figure 13**). This may be occurring, as most of the fishing region for the Portuguese pelagic longline fishery occurs in the southwest region in a region where the spatial effects influencing the blue shark CPUE are smaller.

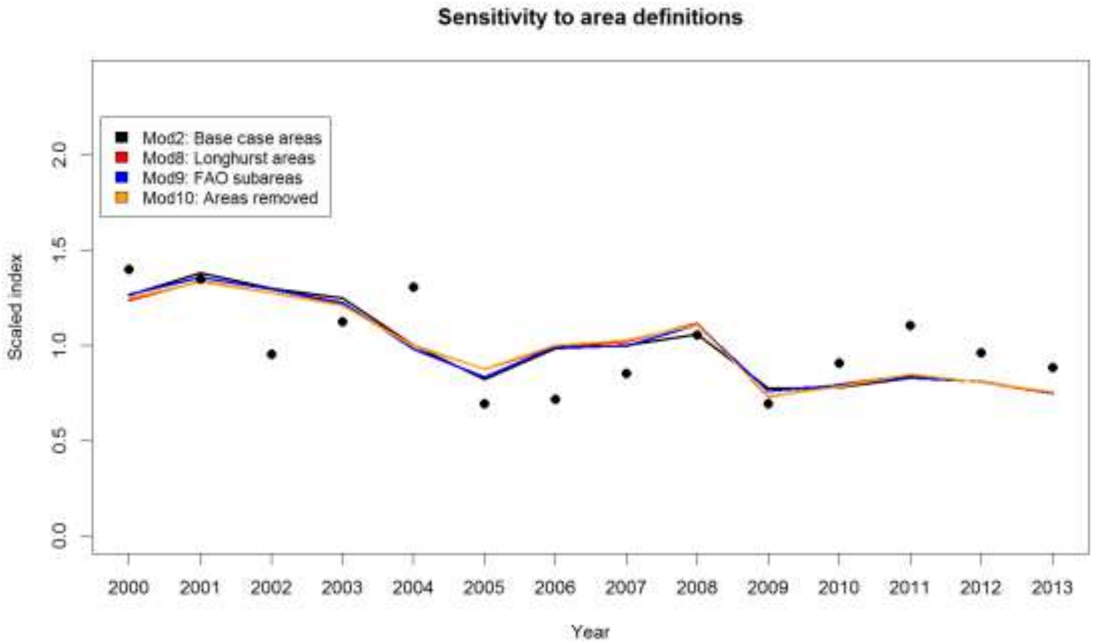

Figure 13. Model sensitivity to the area factor for the blue shark CPUE standardization from the Portuguese pelagic longline fleet in the Indian Ocean. The scaled annual indexes of abundance of the final model selected (Mod2) is represented in black, and the alternative models in red (Mod8: using the Longhurst ecological regions), blue (Mod9: Using FAO subareas), and orange (Mod10: model without area effects).

In terms of goodness-of-fit, the best fitted model was the original base case that used the areas divided according the sea temperature at 50m depth, as defined and used by Mejuto et al. (2008). However, using the Longhurst ecological regions or the FAO areas and subareas produced very similar results, with the R^2 values decreasing only from 77.2% in Mod2, to 76.8% in Mod8 and 76.7% in Mod 9 (**Table 6**). The AIC was also worse in Mod 8; however, it should be noted that the AICs are not entirely comparable between models as the response variable was not exactly the same. Specifically, 51 data points from the MONS and SSTC ecological regions, and 17 datapoints from FAO subareas 51.4, 51.5, 57.2 and 57.4 had to be removed from Mods 8 and 9, respectively, due to the low representativeness of those areas to the fishery. In terms of residual analysis, there were no major differences in the models using different areas (**Figure 14**).

Table 6. Deviance table of the parameters for the sensitivity analysis of the area variable for the blue shark CPUE standardization in the Indian Ocean. For each parameter it is indicated the degrees of freedom used (Df), the deviance explained (Dev), the residual degrees of freedom (Resid Df) and deviance (Resid Dev) after incorporating sequentially each variable. The significance (F-stat and p-value) of each variable is indicated as well as the R^2 values.

Model	Variables	Df	Dev.	Resid. Df	Resid. Dev	F-stat.	*p-value*
Mod 8: Longhurst areas (R^2=76.8%)	Intersept only			9361	7185.9		
	Year	13	491.3	9348	6695	212.1	< 0.001
	Year + Quarter	3	817.0	9345	5878	1528.5	< 0.001
	Year + Quarter + Area	1	118.4	9344	5759	664.3	< 0.001
	Year + Quarter + Area + Vessel	23	952.4	9321	4807	232.4	< 0.001
	Year + Quarter + Area + Vessel + Ratio	9	3143.5	9312	1663	1960.4	< 0.001
	Year + Quarter + Area + Vessel + Ratio + Quarter:Area	3	4.8	9309	1659	9.0	< 0.001
Mod 9: FAO subareas (R^2=76.7%)	Intersept only			9395	7213.6		
	Year	13	490.2	9382	6723	211.2	< 0.001
	Year + Quarter	3	811.5	9379	5912	1515.2	< 0.001
	Year + Quarter + Area	3	33.3	9376	5879	62.1	< 0.001
	Year + Quarter + Area + Vessel	23	999.9	9353	4879	243.5	< 0.001
	Year + Quarter + Area + Vessel + Ratio	9	3201.5	9344	1677	1992.5	< 0.001
	Year + Quarter + Area + Vessel + Ratio + Quarter:Area	9	10.7	9335	1667	6.6	< 0.001
Mod 10: Removing areas (R^2=76.5%)	Intersept only			9412	7257.7		
	Year	13	495.4	9399	6762.4	210.7	< 0.001
	Year + Quarter	3	823.6	9396	5938.8	1518.1	< 0.001
	Year + Quarter + Vessel	23	988.5	9373	4950.4	237.7	< 0.001
	Year + Quarter + Vessel + Ratio	9	3257.0	9364	1693.3	2001.3	< 0.001

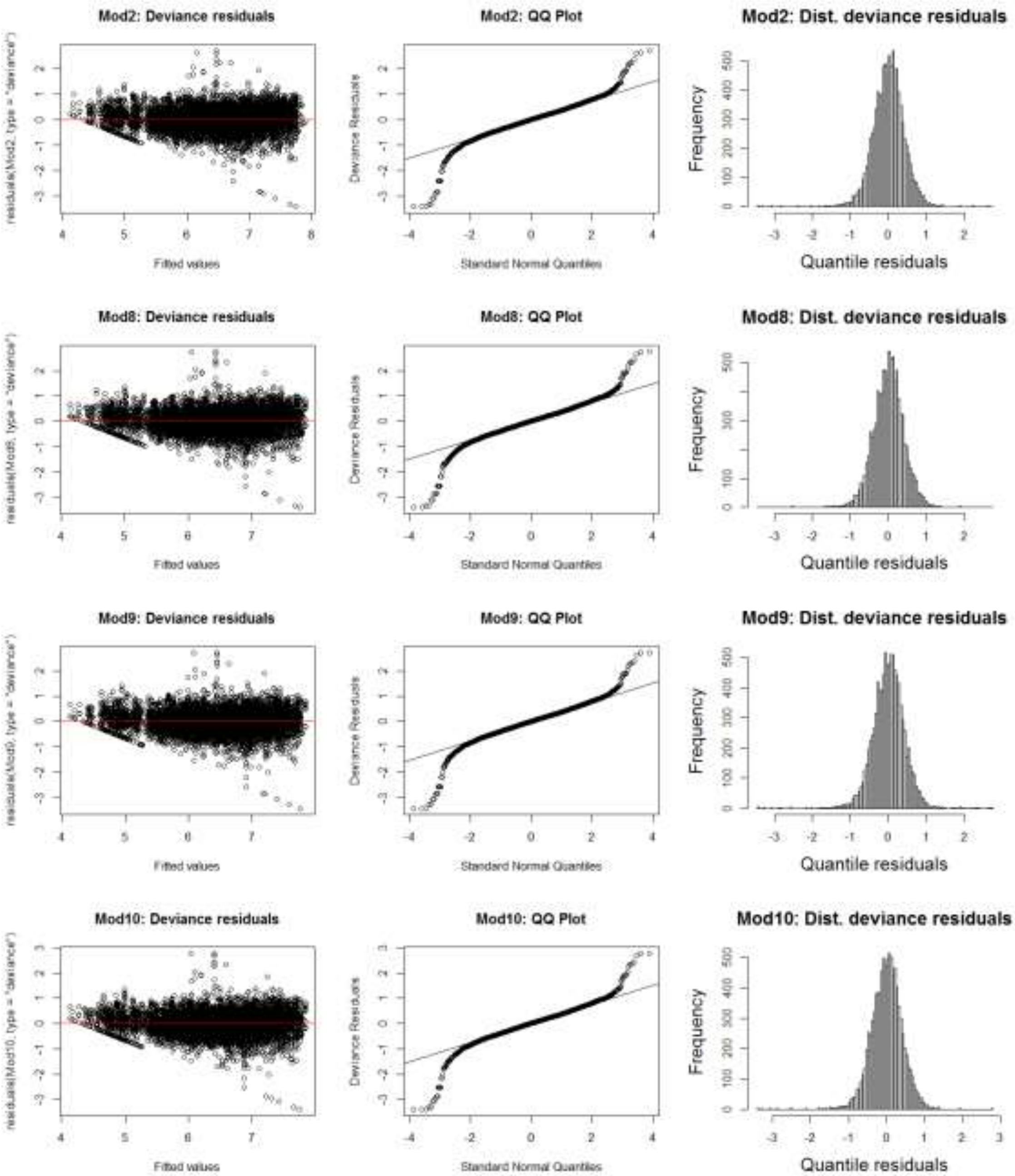

Figure 14. Residual analysis for the various model tested for the sensitivity to the area factor for the blue shark CPUE standardization in the Indian Ocean. Mod 2 is the base case model with Indian Ocean region divided into quadrants, Mod 8 uses the Longhurst ecological regions, Mod 9 uses the FAO subareas and Mod 10 does not include the area factor. For each model it is presented the residuals along the fitted values on the log scale (graphics on the left), the QQPlot (graphics on the middle) and the histogram of the distribution of the residuals (graphics on the right).

3.3.6. Final standardized CPUE series

Given the goodness-of-fit of the various candidate models and the comparisons from the sensitivity analysis for the model type, the use of the ratio factor, and the areas considered, the final standardized CPUE series recommended to be used is derived from Mod2. Besides the main simple effects Year, Quarter, Area, Vessel and Ratio, this model also accounts for a Quarter:Area interaction, allowing for different seasonal effects in the CPUEs to take place within each of the areas considered.

The standardized blue shark CPUE index (in kg/1000 hooks) for the Portuguese pelagic longline fishery in the Indian Ocean between 2000-2013, suggested to be used in future stock assessments is presented in **Table 7**. Overall, the general trend of the series followed the same general pattern of the nominal series, with an increase in the first years of the series, followed by a general decrease until 2005, then followed by a peak in 2008, and then a general decrease for the more recent years.

Table 7: Standardized BSH CPUE index (kg/1000 hooks) for the Portuguese pelagic longline fleet in the Indian Ocean between 2000 and 2013, suggested to be used in future stock assessments. This table includes the index value, the 95% confidence intervals (CI) and the coefficient of variation (CV, %).

Year	Estimate	Upper 95%CI	Lower 95%CI	CV (%)
2000	642.1	692.8	594.7	9.0
2001	702.5	749.6	658.1	11.9
2002	660.7	703.9	619.8	11.6
2003	634.4	678.7	592.7	11.8
2004	509.5	545.7	475.3	9.3
2005	418.3	465.6	375.1	8.8
2006	501.0	525.2	477.8	14.0
2007	508.3	532.0	485.6	11.5
2008	539.0	583.3	497.6	8.6
2009	393.8	425.9	363.8	11.6
2010	396.9	428.6	367.2	11.1
2011	422.7	453.2	393.8	12.0
2012	411.2	444.6	380.0	12.1
2013	380.6	405.5	356.9	15.4

4. Acknowledgments

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Annexes

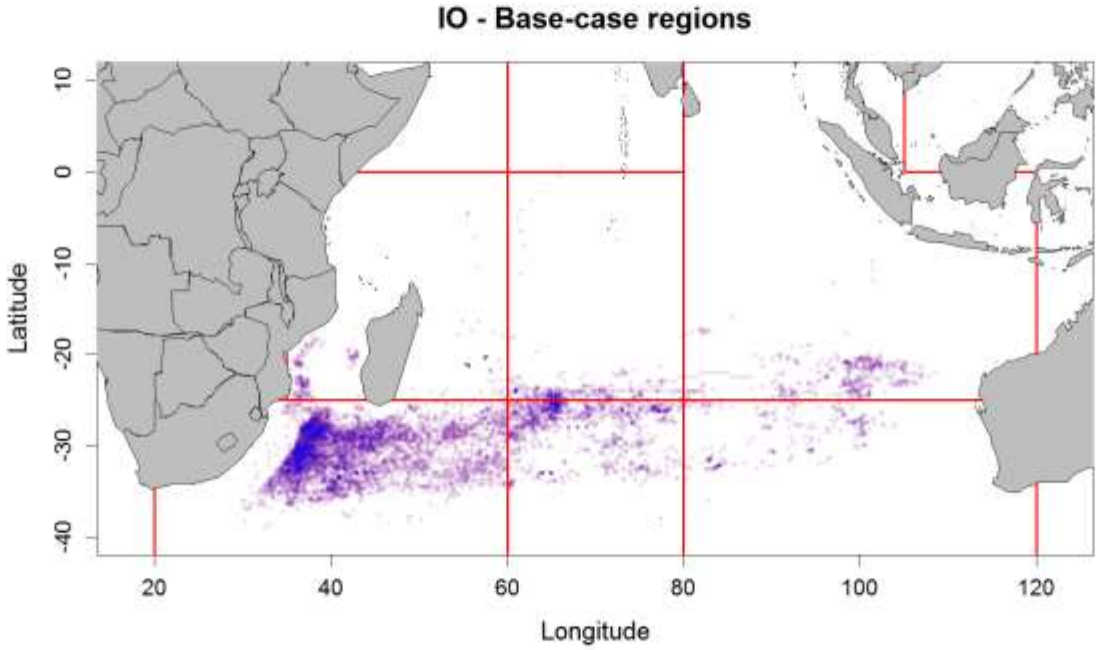

Figure 1: Area stratification in the Indian Ocean as defined in Mejuto et al. (2008) based on sea temperature at 50m depth, with the location of the Portuguese pelagic longline sets reported by the fleet with logbooks between 1998 and 2013. Full color saturation indicates higher blue shark CPUE while the lighter red color represents sets with zero BSH catches.

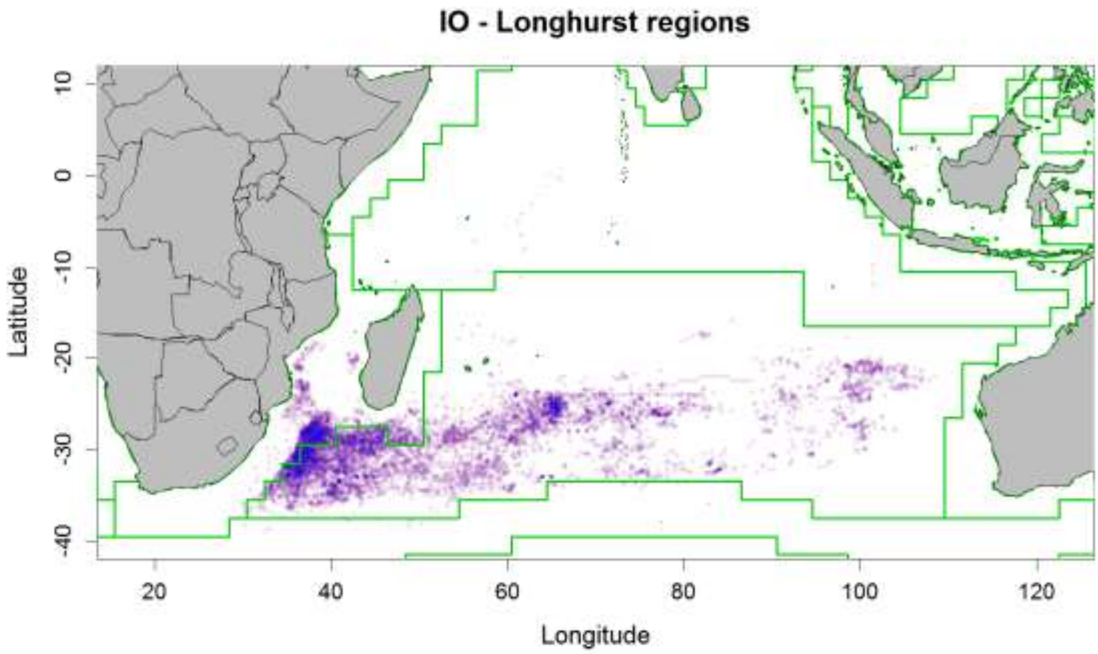

Figure 2: Longhurst ecological regions (Longhurst, 2007) in the Indian Ocean, with the location of the Portuguese pelagic longline sets reported by the fleet with logbooks between 1998 and 2013. Full color saturation indicates higher blue shark CPUE while the lighter red color represents sets with zero BSH catches.

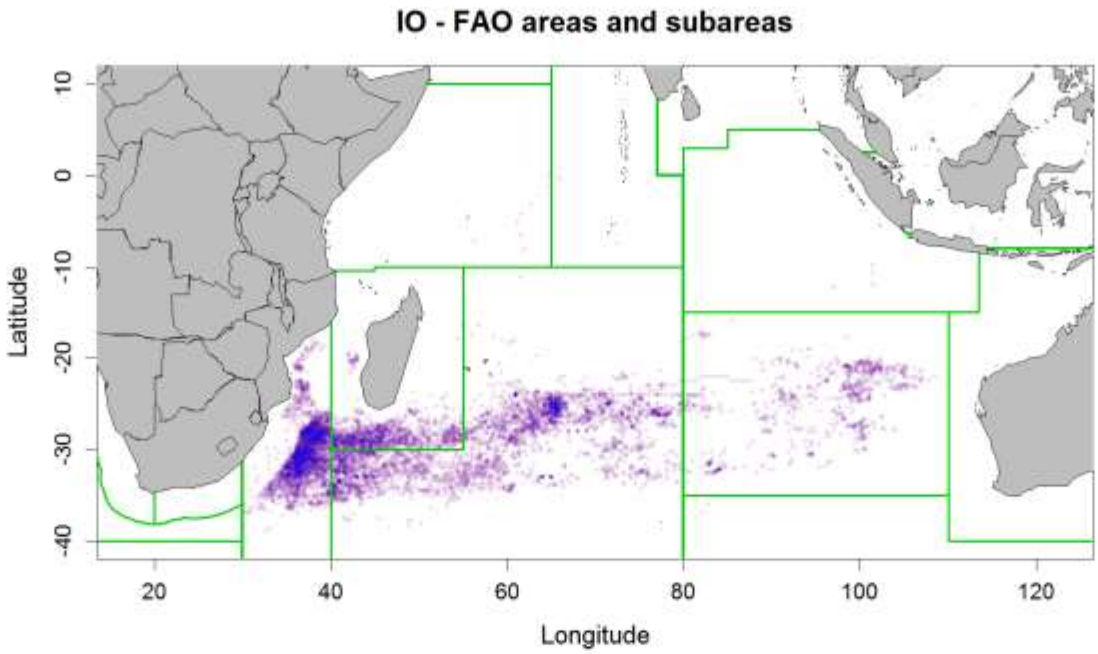

Figure 3: FAO areas and subareas in the Indian Ocean, with the location of the Portuguese pelagic longline sets reported by the fleet with logbooks between 1998 and 2013. Full color saturation indicates higher blue shark CPUE while the lighter red color represents sets with zero BSH catches.

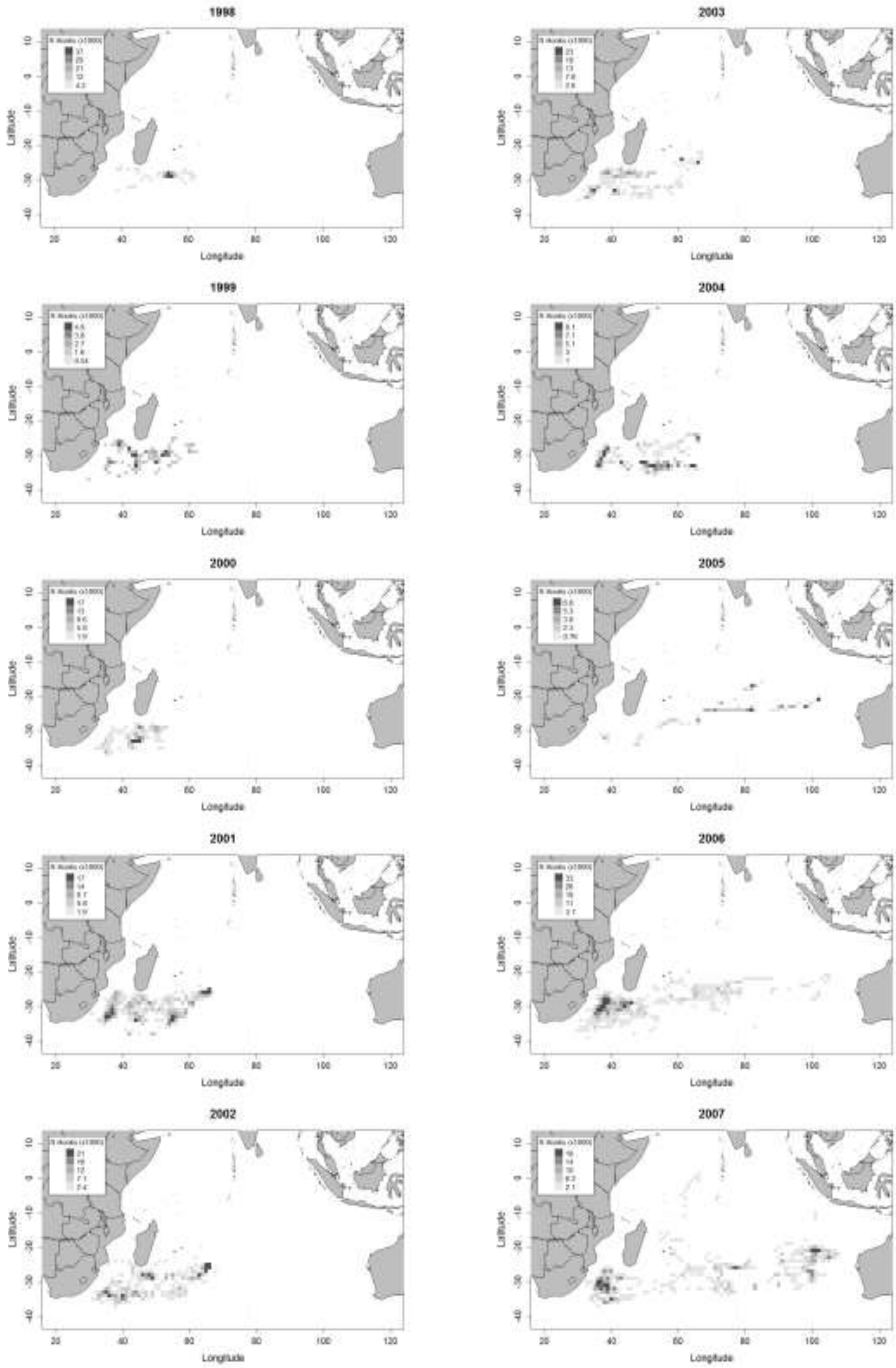

Figure 4: Effort distribution of the Portuguese pelagic longline fleet in the Indian Ocean between 1998 and 2013. The effort is represented in 1°x1° grids with darker and lighter colors representing respectively to areas with more and less effort in number of hooks.

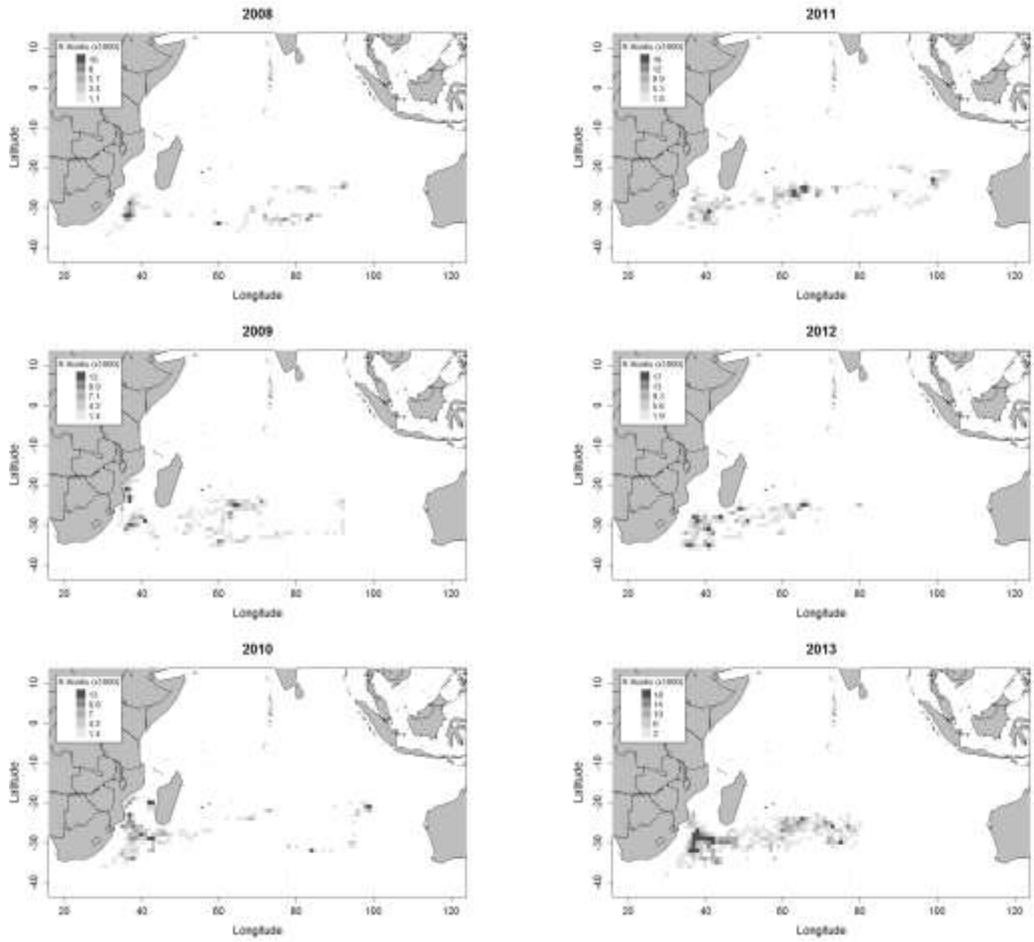

Figure 4: Continued.