SWORDFISH CATCHES BY THE PORTUGUESE PELAGIC LONGLINE FLEET IN 1998-2016 IN THE INDIAN OCEAN: CATCH, EFFORT AND STANDARDIZED CPUES.

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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. This document analyses the catch and effort, size distribution and standardized CPUE trends for that period. Nominal annual CPUEs were calculated as kg/1000 hooks, and were standardized with Generalized Linear Mixed Models (GLMMs) using year, quarter, area, ratios and area:season interactions. The vessel effects were used as random variables. 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 show a general decreasing trend in the series, with an intermediate peak in the 2008 period. The results present an updated annual index of abundance for the swordfish captured by the Portuguese pelagic longline fleet in the Indian Ocean that can be integrated in stock assessment models for that species in the region.

KEYWORDS: Indian Ocean, swordfish, fishery indicators, CPUE standardization, GLMMs, 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 the 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.

Given the objective of conducting a swordfish stock assessment for the Indian Ocean in 2017, and following the working documents presented by the authors in 2012, 2013 and 2014 (Santos et al., 2012, 2013, 2014), this study provides an updated overview of the swordfish catches by the Portuguese pelagic longline fishery operating in the Indian Ocean between 1998 and 2016. Specific objectives are to present new information on the catch and effort, size distribution and CPUE trends (nominal and standardized) that can contribute to the stock assessment of swordfish 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 almost the entire 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 2016. The percentage of sets per year analyzed for this paper is also indicated. Note that the 2

first years of the series (1998 and 1999) were not used for the CPUE standardization analysis due to lower effort in the Indian Ocean.

Year	Sets (n)	Sets with effort (Hooks)	Sets with locations (VMS)	Sets used for analysis (%)
1998	113	113	113	100.0
1999	147	147	147	100.0
2000	275	275	275	100.0
2001	631	631	631	100.0
2002	687	687	647	94.2
2003	575	575	575	100.0
2004	370	370	370	100.0
2005	143	143	143	100.0
2006	1801	1801	1801	100.0
2007	1325	1325	1325	100.0
2008	238	238	238	100.0
2009	482	482	482	100.0
2010	457	457	457	100.0
2011	633	633	633	100.0
2012	516	516	516	100.0
2013	1312	1312	1312	100.0
2014	863	863	863	100.0
2015	1302	1302	1302	100.0
2016	1445	1445	1445	100.0
Total	**13315**	**13315**	**13275**	**99.7**

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 swordfish (SWO) 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.

2.2. CPUE standardization

The CPUE analysis was carried out using the official fisheries statistics collected by the Portuguese Fisheries authorities (DGRM), 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 swordfish captured per fishing set. The available catch data started in 1998 and was available until 2016. 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 CPUEs were estimated with Generalized Linear Mixed Models (GLMMs).

Santos et al. (2014) tested multiple sensitivity runs in SWO CPUE standardization models, including sensitivities to the model type, the use of ratio factor and the definition of the area effects. The base case used for the present work is based on the best model selected in that work. Additionally, Coelho et al. (2015a) tested targeting effects to this fleet by using ratios and cluster analysis, demonstrating that both had very similar behaviors in this particular fleet (fleet targeting mainly SWO but with BSH as a secondary target). Therefore, this update of the SWO CPUE is based on the base case from those previous studies.

There were some fishing sets with zero swordfish catches that result in a response variable of CPUE=0. As these zeros can cause mathematical problems for fitting the models, Coelho et al. (2014) tested three different methodologies, specifically tweedie, gamma and lognormal models. The best fit was achieved using lognormal models with the response variable defined as the nominal CPUE + constant (*c*), with *c* set to 10% of the overall mean catch rate (as recommended by Campbell, 2004), as that is the value that 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%, as is the case in this dataset), the method of adding a constant to the response variable performs relatively well.

Based on the sensitivities and tests reported by Coelho et al. (2014), the covariates considered and tested in the base case models for this work were:

- Year: analyzed between 2000 and 2016;
- Quarter of the year: 4 categories: 1 = January to March, 2 = April to June, 3 = July to September, 4 = October to December;
- Area: Using a GLM Tree area stratification based on Ichinokawa & Brodziak (2010) approach;
- Ratio: based on the SWO/SWO+BSH ratio of captures;
- Interactions: first order interactions were tested and used if significant with the AIC criteria;
- Vessel ID: used as a random variable in the GLMM.

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). 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 ratio factor 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 *versus* a more diffuse fishing strategy aimed at the two main species (SWO and BSH). Moreover, it has been 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, Coelho et al., 2015a). The ratio factor was calculated for each set and then divided into ten categories using the 0.1 quantiles. However, recent works have also suggested the use of cluster analysis to define target effects as explanatory variables in the standardization models (He et al., 1997). This approach has been used with success in the Indian Ocean by Wang and Nishida (2014) for swordfish, and has also been tested in blue shark both in the North Atlantic by Coelho et al. (2015b) and Indian Ocean by Coelho et al. (2015a). In those later studies, this approach was tested as a sensitivity analysis but not selected in the final model as the EU.Portugal fleet consistently targets SWO and to a less extent BSH, and as such the information obtained with the cluster analysis is very similar to using SWO/BSH ratios.

All statistical analysis for this paper was carried out with the R Project for Statistical Computing version 3.4.0 (R Core Team, 2016) using several additional libraries (Wickham, 2007, 2009; Fox and Weisberg, 2011; Højsgaard and Halekoh, 2012; Bivand and Lewin-Koh, 2013; Bates et al., 2014; Lenth, 2014).

3. Results and Discussion

3.1. Spatial distribution in 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 2016 are 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**).

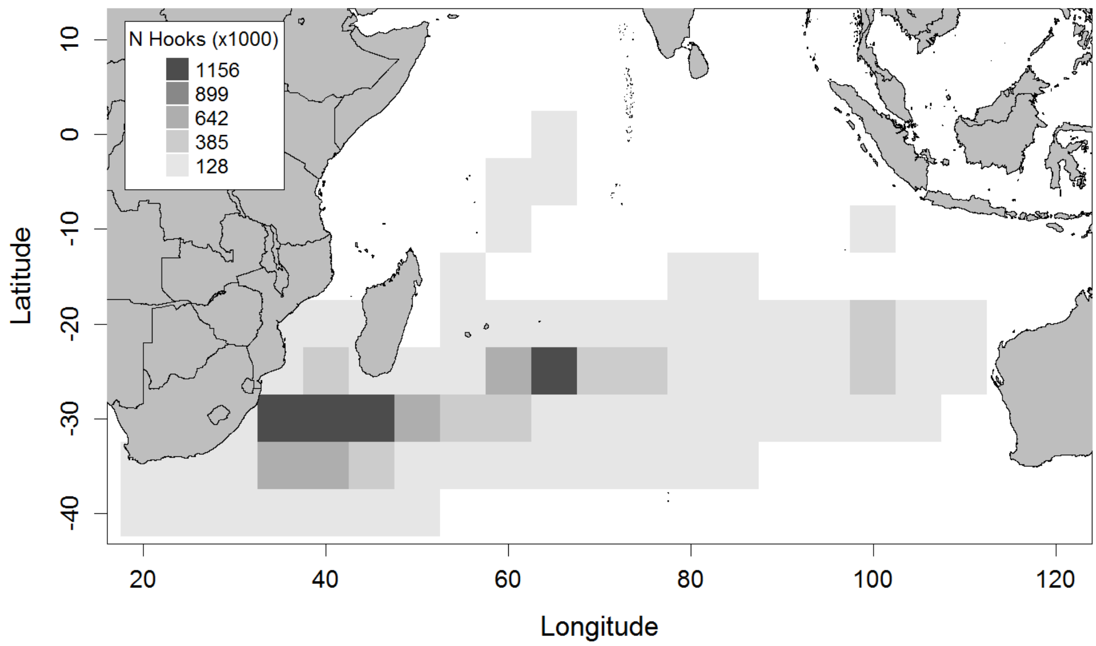

Figure 1. Effort distribution of the Portuguese pelagic longline fleet for the 1998-2016 period in the Indian Ocean. The effort is represented in 5x5 grids with darker and lighter colors representing respectively to areas with more and less effort in number of hooks.

The SWO catches are also spread throughout the southern Indian Ocean region. However, there seems to be a higher concentration particularly in the SE Indian Ocean, as well as in some areas of the SW IO (**Figure 2**).

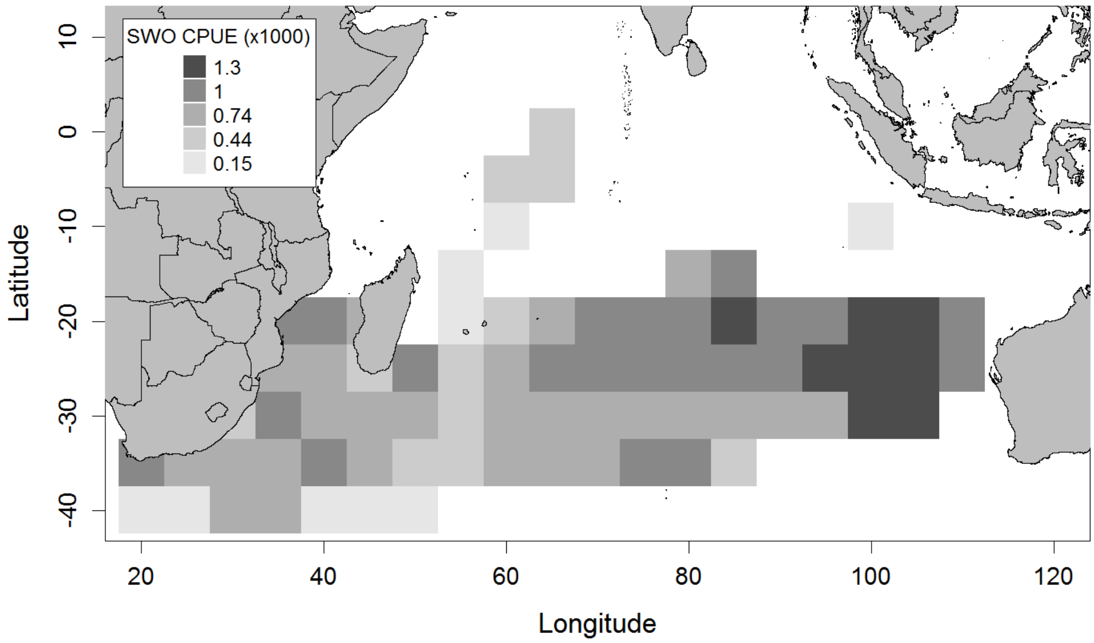

Figure 2. SWO CPUE distribution for the Portuguese pelagic longline fleet for the 1998-2016 period in the Indian Ocean. The CPUEs are represented in 5x5 grids with darker and lighter colors representing respectively areas with higher and lower SWO CPUE mean values.

3.2. 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 2006-2007 and then a sharp decrease in the 2008 (**Figure 3**). Since then, and for the most recent years (2009 to 2016) 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 swordfish 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 most 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.

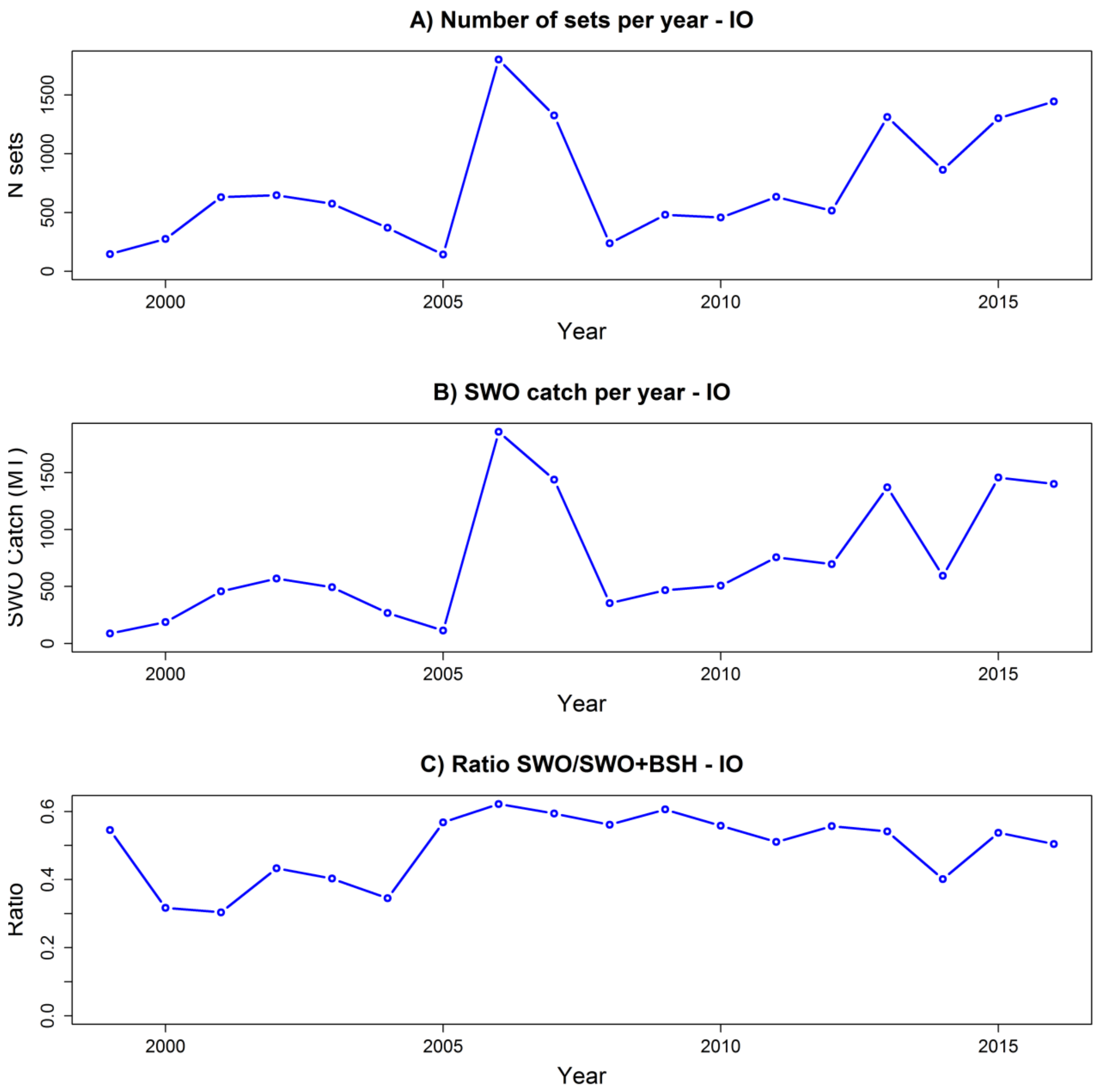

Figure 3: Descriptive plots of the total effort in sets (A), the total catch of swordfish (B), and the ratio of swordfish compared to the swordfish and blue shark catches (C), for the Portuguese longline fleet operating in the Indian Ocean.

No major pattern or trend was observed in the swordfish CPUE along the quarters of the year, and a high inter- and intra-annual variability was noticed (**Figure 4**).

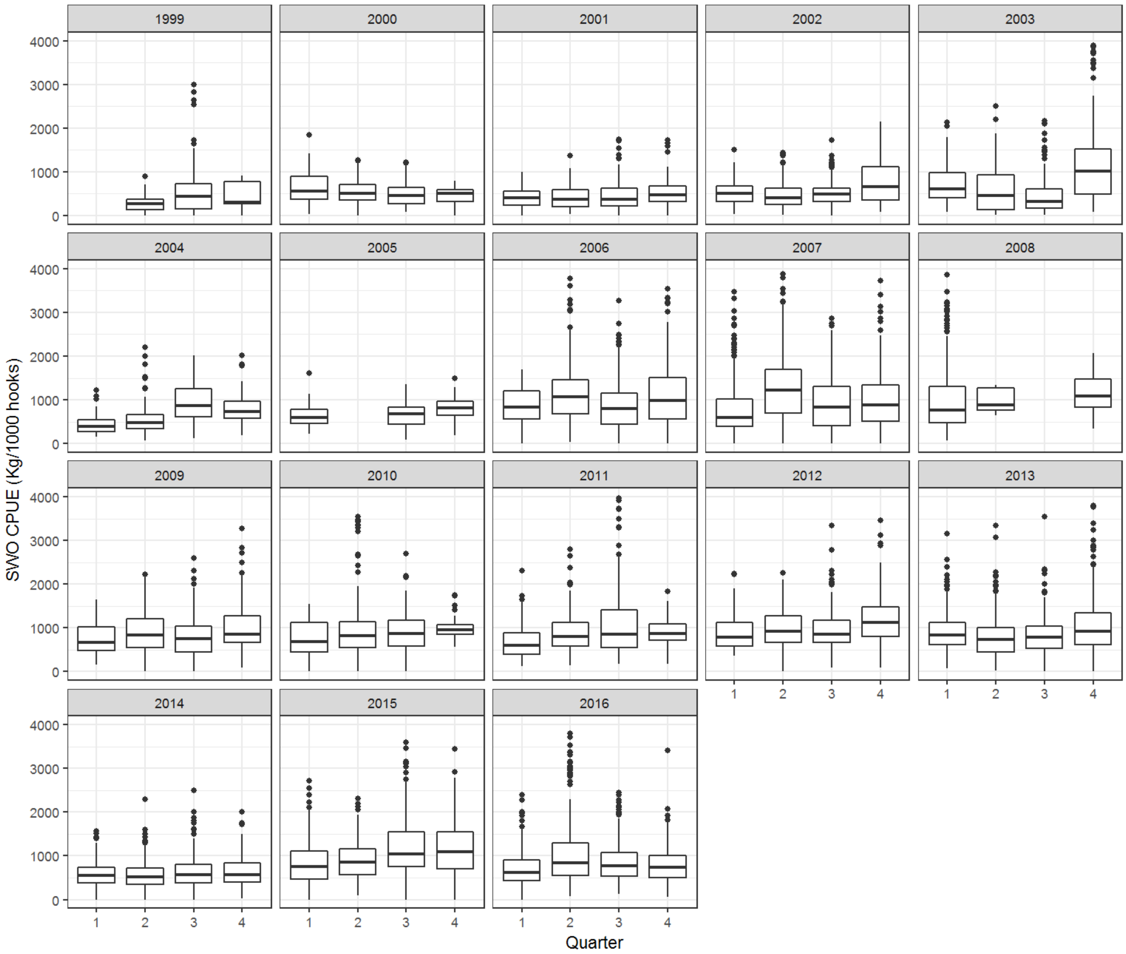

Figure 4. Quarterly swordfish CPUE (kg/1000 hooks) by the Portuguese pelagic longline fleet in the Indian Ocean, per year. In the boxplots the middle lines represents the median, the box the quartiles, the whiskers the non-outlier range and the points the outliers.

3.3. CPUE data characteristics

The nominal time series of the swordfish CPUE for the Portuguese pelagic longline fleet operating in the Indian Ocean is presented in **Figure 5**. There was a tendency for the CPUE to increase substantially in the first years of the fishery between 2000 and 2008, followed by a decrease until 2014, and then another increase in the most recent years, with current CPUEs similar to the period 2009-2013 (**Figure 5**).

The lower nominal CPUE in the early years of the time series was most probably related to the use of the traditional Spanish style longline gear in the period. It is known that the currently used monofilament gear (Florida style) is more efficient (see Vega and Licandeo, 2009; and references therein). It is worth noting that the entire Portuguese fleet shifted to the new gear by the mid-2000.

The percentage of fishing sets with zero catches of SWO in the Indian Ocean was very low, specifically 0.5%. This level of low percentages of fishing sets with zero SWO catches are similar, for example, to what has been previously reported by the Spanish fleet targeting swordfish in the same area, which reported values of fishing sets with zero catches generally lower than 1% (Ramos-Cartelle et al., 2011), and also for the Portuguese fleet operating along wider areas of the Indian Ocean (Santos et al., 2013). The nominal swordfish CPUE distribution was highly skewed to the right and became more normal shaped in the log-transformed scale (**Figure 6**).

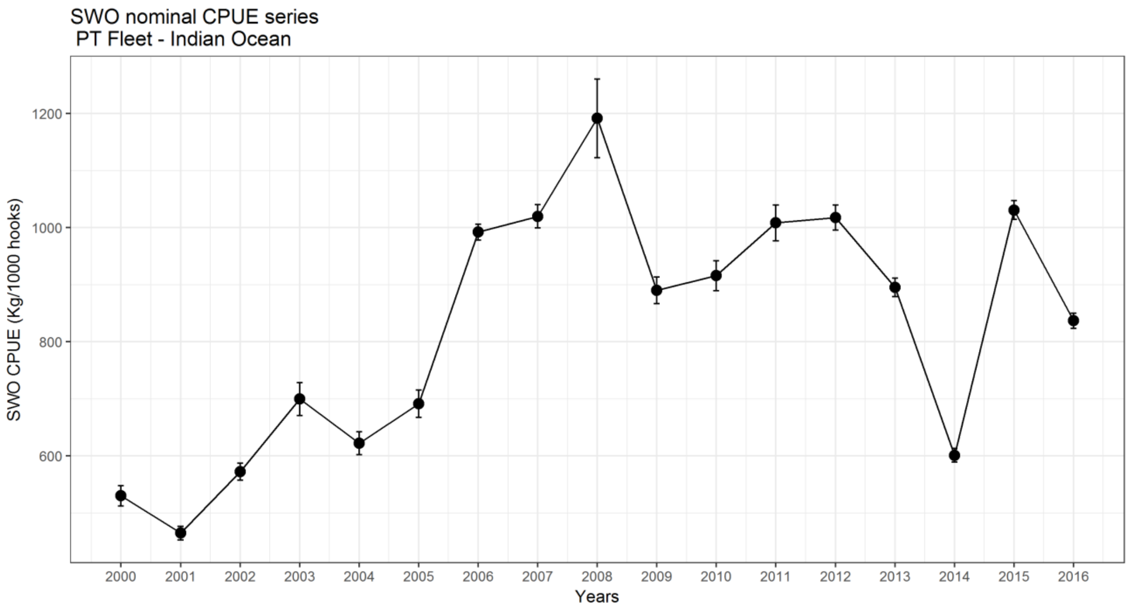

Figure 5. Nominal CPUE series (kg/1000 hooks) for swordfish caught by the Portuguese pelagic longline fishery in the Indian Ocean, between 2000 and 2016. The error bars refer to the standard errors.

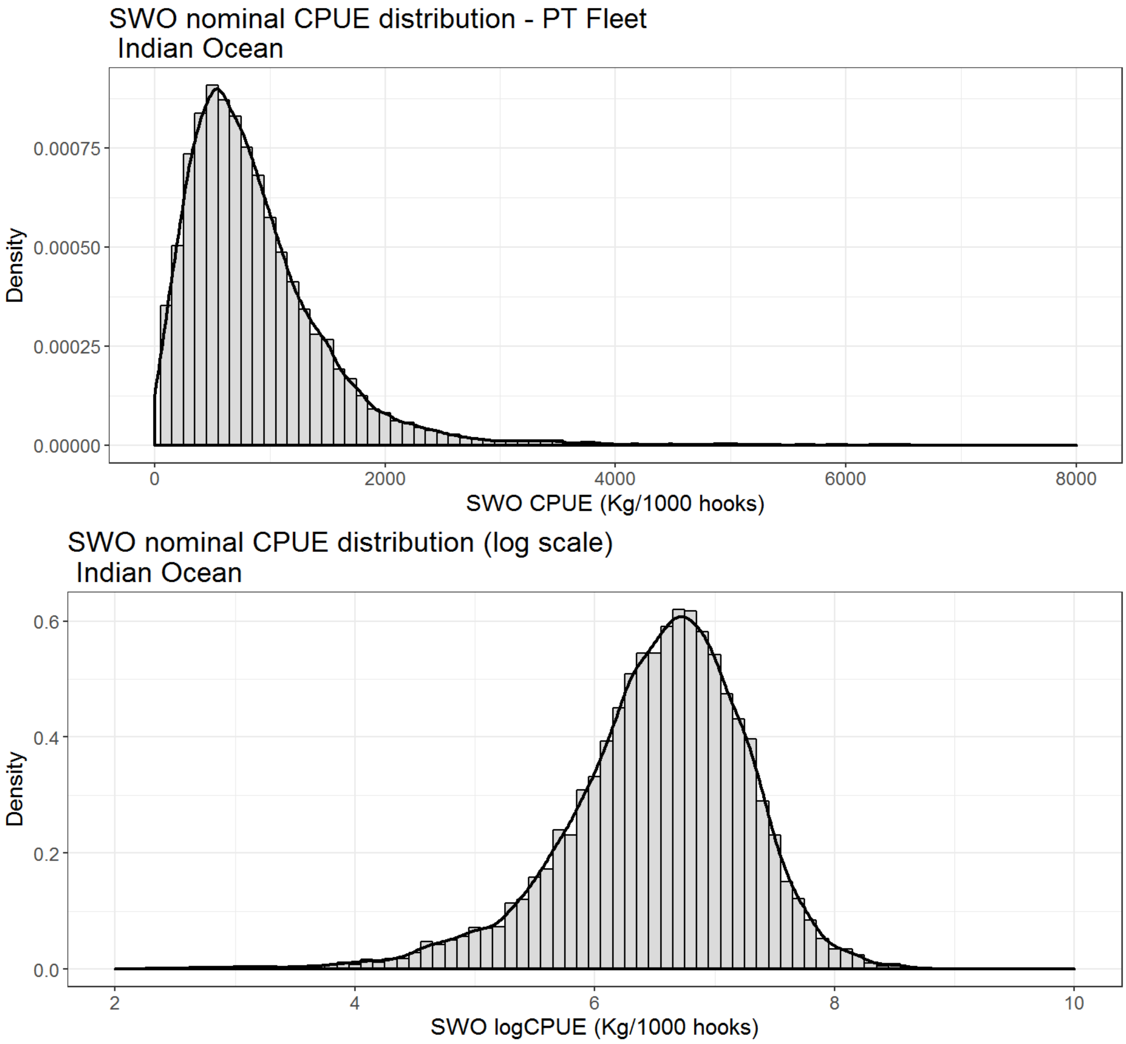

Figure 6: Distribution of the nominal swordfish CPUE captured by the Portuguese longline fleet in the Indian Ocean in non-transformed (top plot) and log-transformed (bottom plot) scales.

3.4. CPUE standardization

For the base case lognormal models (based on Santos et al. (2014) final selected model) and with further testing in the GLMMs (using vessel as random), it was concluded that all the explanatory variables tested for the swordfish CPUE standardization were significant and contributed significantly for explaining part of the deviance. The area stratifications followed a GLM tree approach for optimization based on the AIC drop. The final areas selected (6 areas) are shown in **Figure 7**. 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 2**).

The factors that contributed most for the deviance explanation were the ratio factor followed by year and then the area effects (**Table 2**). In terms of model validation both models seemed adequate for this particular situation with a low quantity of zeros, as the residual analysis, including the residuals distribution along the fitted values, the QQ plots and the residuals histograms, did not identified any major problems in the models (**Figure 8**).

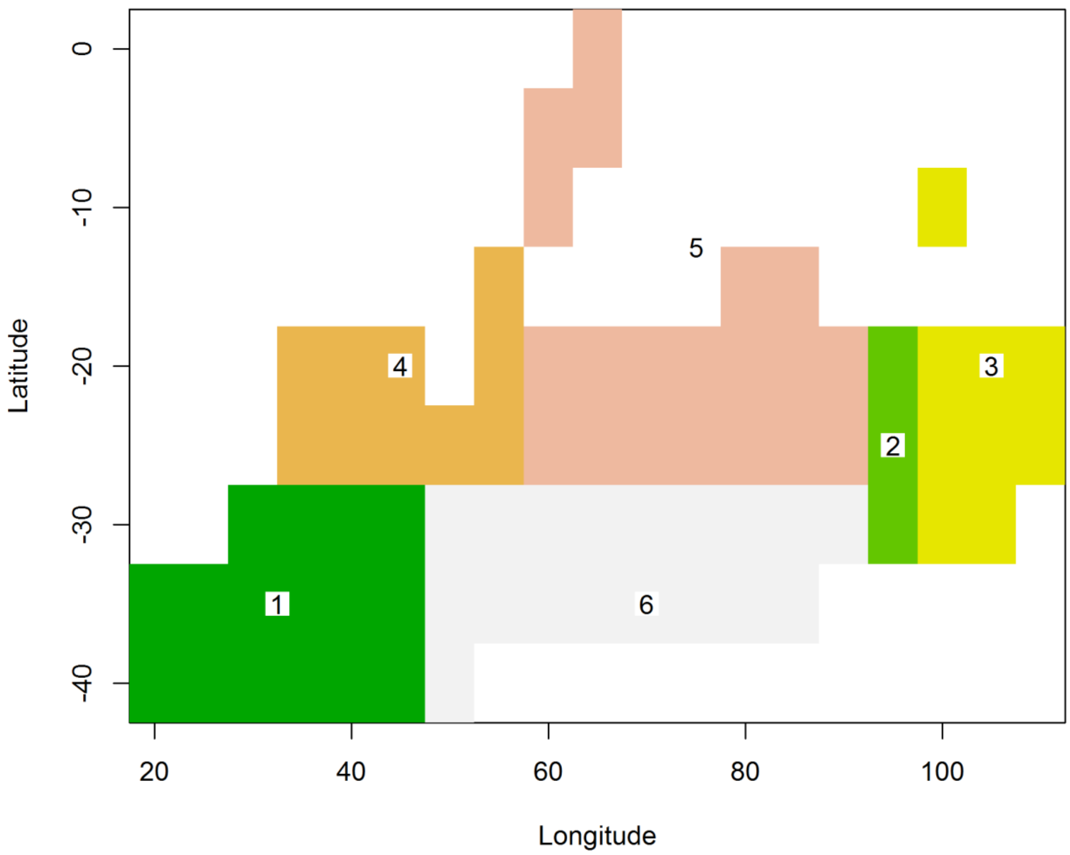

Figure 7: Spatial area stratification for the SWO CPUE captured by the Portuguese longline fleet in the Indian Ocean.

Table 2. Deviance table of the parameters used for the swordfish CPUE standardization models in the Indian Ocean. For each parameter it is indicated the degrees of freedom used (Df), the deviance explained, 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.

Variables	**Df**	**Deviance**	**Resid DF**	**Resid Dev**	**F-stat.**	***p-value***
Intersept only			13014	5256		
Year	16	602.3	12998	4653.7	175.09	< 0.001
Quarter	3	76.9	12995	4576.7	119.3	< 0.001
Area	5	204.5	12990	4372.2	190.26	< 0.001

Ratio	9	1541.9	12981	2830.3	796.87	< 0.001
Quarter : Area	15	42.7	12966	2787.6	13.23	< 0.001

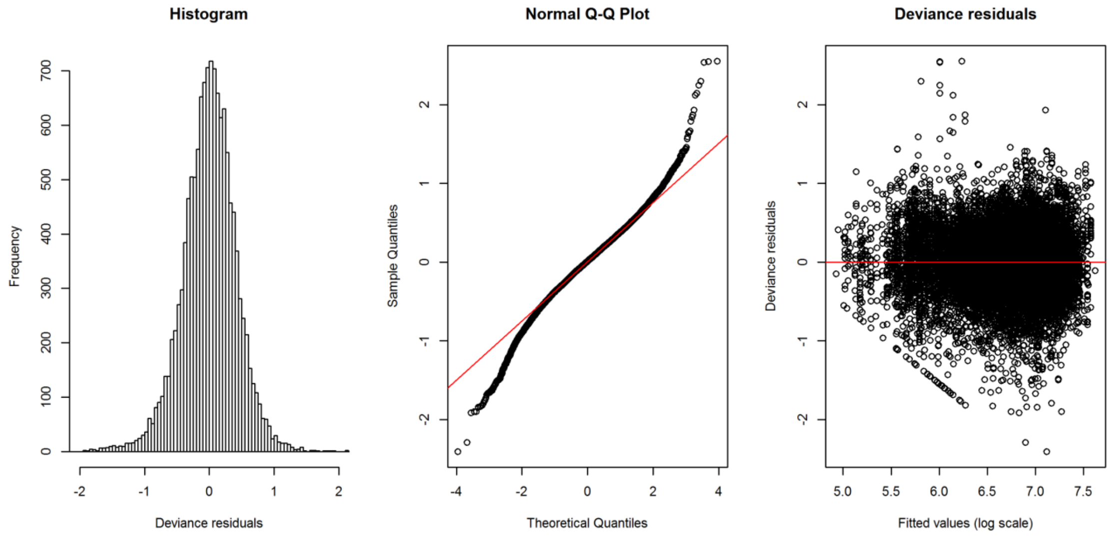

Figure 8. Residual analysis for the final lognormal GLMM model used for the swordfish CPUE standardization in the Indian Ocean. It is presented the residuals along the fitted values on the log scale (graphics on the left), the QQPlot (graphics on the middle) and the histogram of the distribution of the residuals (graphics on the right).

3.5. Final standardized SWO CPUE series

Given the many sensitivity tests run in Santos et al. (2014) with comparison for model type, use of the ratio factor, and area effects, and the new tests run now, the final standardized CPUE series recommended to be used for the SWO assessment in the Indian Ocean is based on a lognormal GLMM. Besides the main simple effects Year, Quarter, Area and Ratio, this model uses vessels as random effects and also accounts for a Quarter:Area interactions, allowing for different seasonal effects in the CPUEs to take place within each of the areas considered.

The standardized swordfish CPUE index (in kg/1000 hooks) for the Portuguese pelagic longline fishery in the Indian Ocean between 2000-2016, suggested to be used in the SWO stock assessments is presented in **Figure 9** and **Table 3**. Overall, the standardized CPUE series showed a general decrease, with a partial increase in 2008. There are large differences between the nominal and standardized series, meaning that the variables included in the models (other than year) seem to be accounting for the variability in CPUEs, which is the objective of the standardization process, i.e., to remove fishery-dependant effects to account only for the relative biomass change through time.

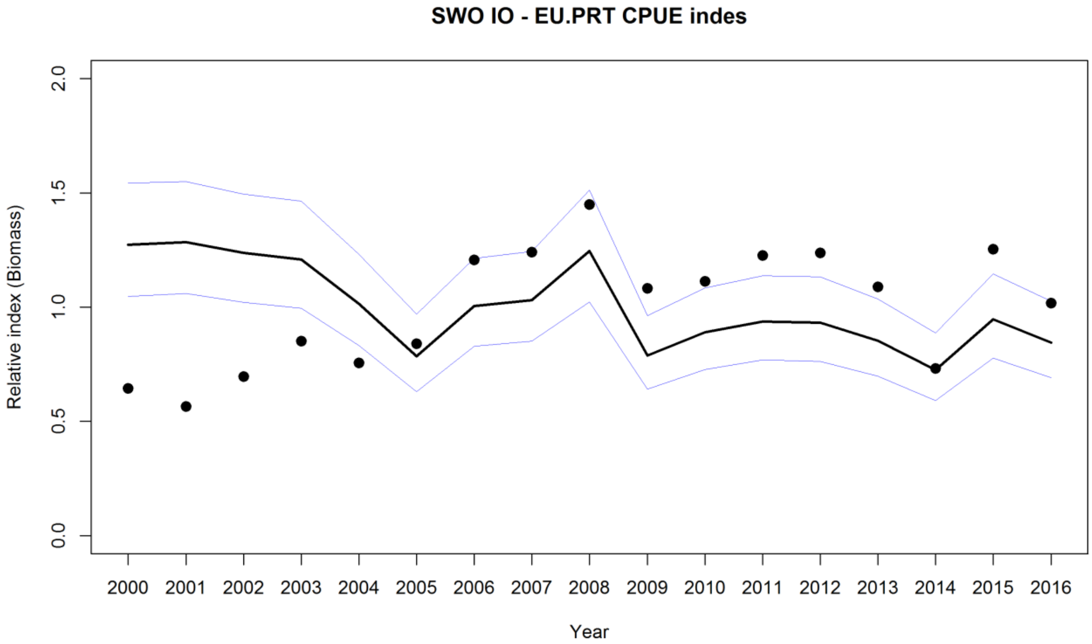

Figure 9. Standardized CPUE series for SWO captured by the Portuguese pelagic longline fleet in the Indian Ocean using a lognormal GLMM for the final selected model. The solid line refers to the standardized index and the black dots to the nominal CPUE series.

Table 3: Standardized SWO CPUE index (kg/1000 hooks) for the Portuguese pelagic longline fleet in the Indian Ocean between 2000 and 2016, suggested to be used in future stock assessments. This table includes the index value (original scale and scaled by the overall mean), the 95% confidence intervals (CI) and the coefficient of variation (CV, %).

Year	Nominal CPUE	Standardized CPUE index (Kg/1000 Hooks)				
		Stdz CPUE	Upper CI (95%)	Lower CI (95%)	CV (%)	Scaled index
2000	530.1	835.1	1012.1	686.6	21.66	1.27
2001	464.7	841.9	1016.5	694.9	32.05	1.28
2002	572.4	811.9	980.5	670.0	32.36	1.24
2003	699.7	793.0	959.5	653.0	30.82	1.21
2004	622.2	665.2	807.4	545.6	24.71	1.01
2005	691.4	514.4	635.8	413.4	16.49	0.78
2006	992.3	659.3	796.1	543.7	52.60	1.01
2007	1019.8	676.0	815.8	557.9	45.11	1.03
2008	1191.6	817.2	991.4	671.1	20.23	1.25
2009	890.3	516.8	631.3	420.5	28.31	0.79
2010	915.7	583.4	710.7	476.4	27.60	0.89
2011	1008.3	614.5	746.0	503.8	32.00	0.94

2012	1017.7	611.0	743.1	499.9	29.22	0.93
2013	895.5	559.1	678.7	458.2	45.43	0.85
2014	601.2	476.2	581.3	387.7	37.18	0.73
2015	1030.8	620.4	751.4	510.0	45.25	0.95
2016	836.9	553.9	672.8	453.6	47.80	0.84

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