[IOTC-2026-WPB24-18]

UPDATED STANDARDIZED CPUE INDICES FOR SWORDFISH CAUGHT BY THE PORTUGUESE PELAGIC LONGLINE FLEET IN THE INDIAN OCEAN, 2000–2024.

RUI COELHO[1,2,*], DANIELA ROSA[1,2], PEDRO G. LINO[1]

Discussions: The purpose of the paper is to inform the WPB that the standardized CPUE index for swordfish caught by the Portuguese pelagic longline fleet in the Indian Ocean has been updated to cover the period 2000-2024 using a Tweedie GLMM.

Feedback: The authors of the paper request review and comments from the WPB that the standardization approach used, the model configuration, validation and sensitivity analysis presented, are adequate for the intended use of the index.

Conclusion: The authors seek endorsement that this updated standardized CPUE series from the EU.Portugal pelagic longline fleet can be used as an index of relative abundance for the 2026 IOTC swordfish stock assessment.

[1] Portuguese Institute for the Ocean and Atmosphere (IPMA), Av. 5 de Outubro s/n, 8700-305 Olhão, Portugal.
[2] Centro de Ciências do Mar do Algarve (CCMAR/CIMAR LA), Campus de Gambelas, Univ. Algarve, 8005-139 Faro, Portugal.
* Corresponding author: Rui Coelho (rpcoelho@ipma.pt)

Contents

Abstract

The Portuguese pelagic longline fishery in the Indian Ocean started in the late 1990's, targeting mainly swordfish in the southwest. This document updates that analysis with regards to catch, effort and standardized CPUE trends for the Portuguese fleet operating in the Indian Ocean. Nominal annual CPUEs were calculated as kg/1000 hooks and were standardized with Tweedie Generalized Linear Mixed Models (GLMMs) using year, quarter, area and targeting ratios as fixed factors, and the vessel effect as a random variable. Model goodness-of-fit and validation was carried out with AIC, deviance explained and residual analysis. Overall, the standardized CPUE series showed an initial high level in 2000–2003, a decline through the mid-2000s with a partial recovery in 2007–2008, a lower and relatively stable period between 2009 and 2021, and an increase in the most recent years (2022–2024), though potential gear-related effects may contribute to this recent pattern and warrant further investigation. 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.

Key-words

CPUE standardization, fishery indicators, Indian Ocean, pelagic longline fisheries, swordfish, Tweedie GLMM

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, 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. 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 years, the active vessels in the convention area decreased to 3 in 2018, and only 2 in the more recent years.

Given the objective of conducting a swordfish stock assessment for the Indian Ocean in 2026, and following previous working documents presented by the authors in previous years for previous assessments and other swordfish related work (Santos et al., 2012, 2013, 2014, Coelho et al., 2017, 2020, 2023), this study provides an updated overview of the swordfish catches by the Portuguese pelagic longline fishery operating in the Indian Ocean between 1998 and 2024. Specific objectives are to present new information on the catch, effort and standardized CPUE trends that can contribute to the 2026 stock assessment of swordfish in the Indian Ocean.

2. Material and methods

2.1. Catch and effort

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 contains almost the entire time series for the Portuguese pelagic longline fleet operating in Indian Ocean.

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.

Table 1: Effort (number of fishing sets and hooks) with catch, effort and location information carried out by the Portuguese pelagic longline fleet in the Indian Ocean between 2000 and 2024 and used for this analysis.

Year	Sets	Hooks
2000	275	355200
2001	631	1080400
2002	647	1109900
2003	575	837650
2004	370	457800
2005	143	164200
2006	1801	1953620
2007	1325	1477170
2008	238	299800
2009	482	524150
2010	457	556854
2011	633	782000
2012	516	689343
2013	1312	1557998
2014	863	977752
2015	1302	1418400
2016	1449	1703550
2017	1413	1621500
2018	833	893600
2019	767	811000
2020	564	593800
2021	584	648200
2022	534	591200
2023	592	655400
2024	569	682800
Total	**19022**	**22615887**

2.2. CPUE standardization

The CPUE analysis was carried out using the official fisheries statistics collected by the Portuguese Fisheries authorities (DGRM), that is composed mostly of electronic logbook data to which VMS data was added for spatial locations. 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 data series begins in 1998 but the standardization model used data from 2000 onwards because of limited information in the initial two years of the fishery.

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).

There were some fishing sets with zero swordfish catches that resulted in a response variable of CPUE=0. Those zeros for SWO catches are minimal in the dataset given it is a main target species, but they were used in the models and need specific models specification and error distributions to not cause mathematical problems when fitting the models. Coelho et al. (2014) tested three different methodologies, specifically Tweedie, Gamma and Lognormal models. At the time, the Lognormal with an added constant was used, given that it is a simpler model to fit and the low percentage of zeros allows such type of approach (Campbell, 2004; Shono, 2008).

For this update, we run both Tweedie and Lognormal models, the Tweedie because it has the advantage of being a single model that can fit both the mass of zeros and the continuous positives, and the Lognormal with an added constant to provide a continuity of the previous CPUE standardization procedure used. The Tweedie distribution is a member of the exponential dispersion family, defined by a power parameter (p). When this takes values $1 < p < 2$, it allows to fit a continuous response with a mass at zero in the same model, which is appropriate for CPUE data that can include zero-catch sets without requiring an additive constant (Shono, 2008; Foster and Bravington, 2013). The Lognormal model with an added constant (c = 10% of the mean nominal CPUE; Campbell, 2004) was retained as a sensitivity to provide continuity with previous CPUE standardization procedures.

Santos et al. (2014) tested multiple sensitivity runs in the SWO CPUE standardization, including sensitivities to the model type, the use of ratio factor and the definition of the area effects. Additionally, Coelho et al. (2015) tested targeting effects to this fleet by using ratios and cluster analysis, demonstrating that both had very similar behaviors in this 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. As such, based on the sensitivity analysis and the previous CPUE standardizations provided by Coelho et al. (2017, 2020, 2023), the covariates considered and tested in the base case models for this work were:

- <u>Year</u>: analyzed between 2000 and 2024;
- <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 a GLM Tree area stratification based on Ichinokawa & Brodziak (2010) approach;
- <u>Ratio</u>: based on the SWO/SWO+BSH ratio of captures;
- <u>Interactions</u>: first order interactions were tested and used if significant with the AIC criteria;
- <u>Vessel ID</u>: used as a random variable in the GLMM.

The significance of each explanatory variable was assessed with likelihood-ratio tests on sequential model additions (each variable tested against the previous, simpler model), and by analyzing the deviance reduction (and proportion of total 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 indices of abundance were calculated as estimated marginal means (Lenth, 2024) for the year factor.

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 Nishida and Wang (2014) for swordfish, and has also been tested in blue shark both in the North Atlantic by Coelho et al. (2016) and Indian Ocean by Coelho et al. (2015). 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.

2.3. Software

All statistical analysis for this paper was carried out with the R Project for Statistical Computing version 4.5.1 (R Core Team, 2025) using several additional libraries: tidyverse (Wickham et al., 2019), ggplot2 (Wickham, 2016), glmmTMB (Brooks et al., 2017), lme4 (Bates et al., 2015), emmeans (Lenth, 2024), DHARMa (Hartig, 2024), car (Fox and Weisberg, 2019), sf (Pebesma, 2018), and rnaturalearth (Massicotte and South, 2024).

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 2024 are shown in **Figure 1**. Most of the effort took place in the south and southwest regions (**Figure 1**).

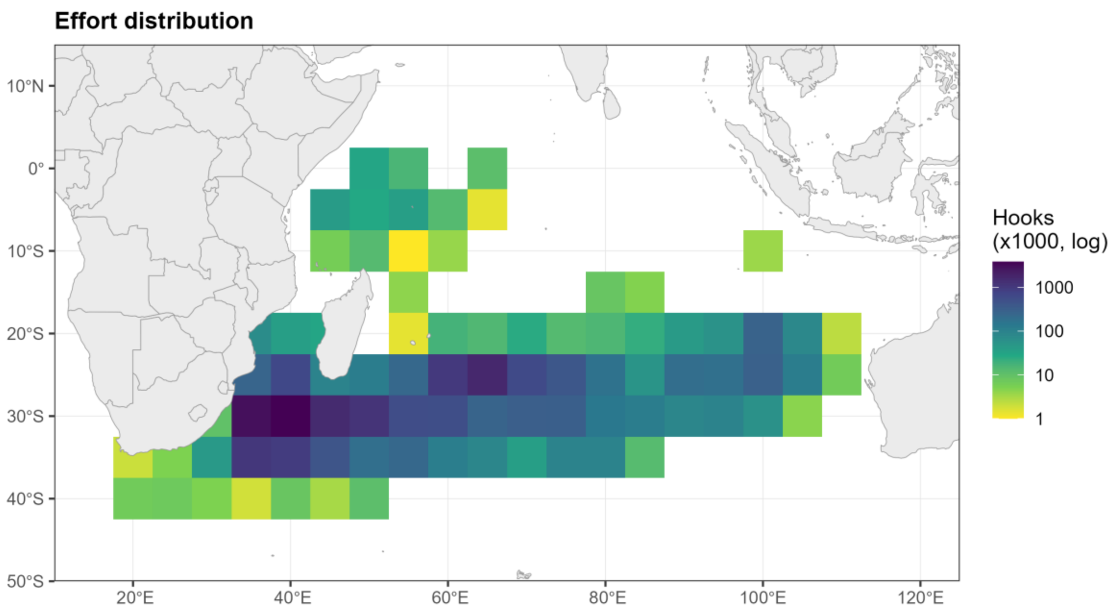

Figure 1. Effort distribution of the Portuguese pelagic longline fleet for the 1998-2024 period in the Indian Ocean. The total effort over that period is represented in 5x5 grids with darker colors representing areas with more effort in number of hooks.

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

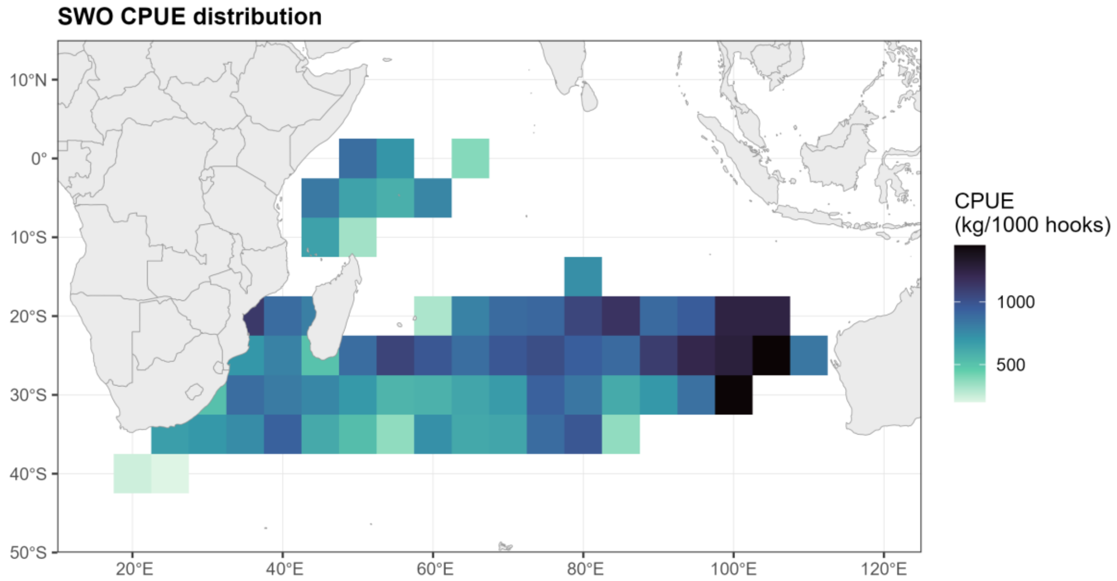

Figure 2. SWO CPUE distribution for the Portuguese pelagic longline fleet for the 1998-2024 period in the Indian Ocean. The mean CPUEs are represented in 5x5 grids with darker colors representing areas with higher SWO CPUE mean values. Only cells with >= 5 sets are represented.

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, between 2009 and 2016 the effort increased again to values higher than in the early 2000's and closer to the 2006-2007 period. Since 2018 there has been a decrease that has been relatively stable from then until 2024 (**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 until 2017, and then a decrease but stable period since 2018 until the present (**Figure 3**). In terms of ratios of swordfish compared to the swordfish + blue shark catches, the ratios were lower in the first years of the fishery, and higher in the most recent period since 2005, with a slight progressive decreasing trend until the present (**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., 2011) have demonstrated that higher blue shark catch rates are obtained when wire leaders are used.

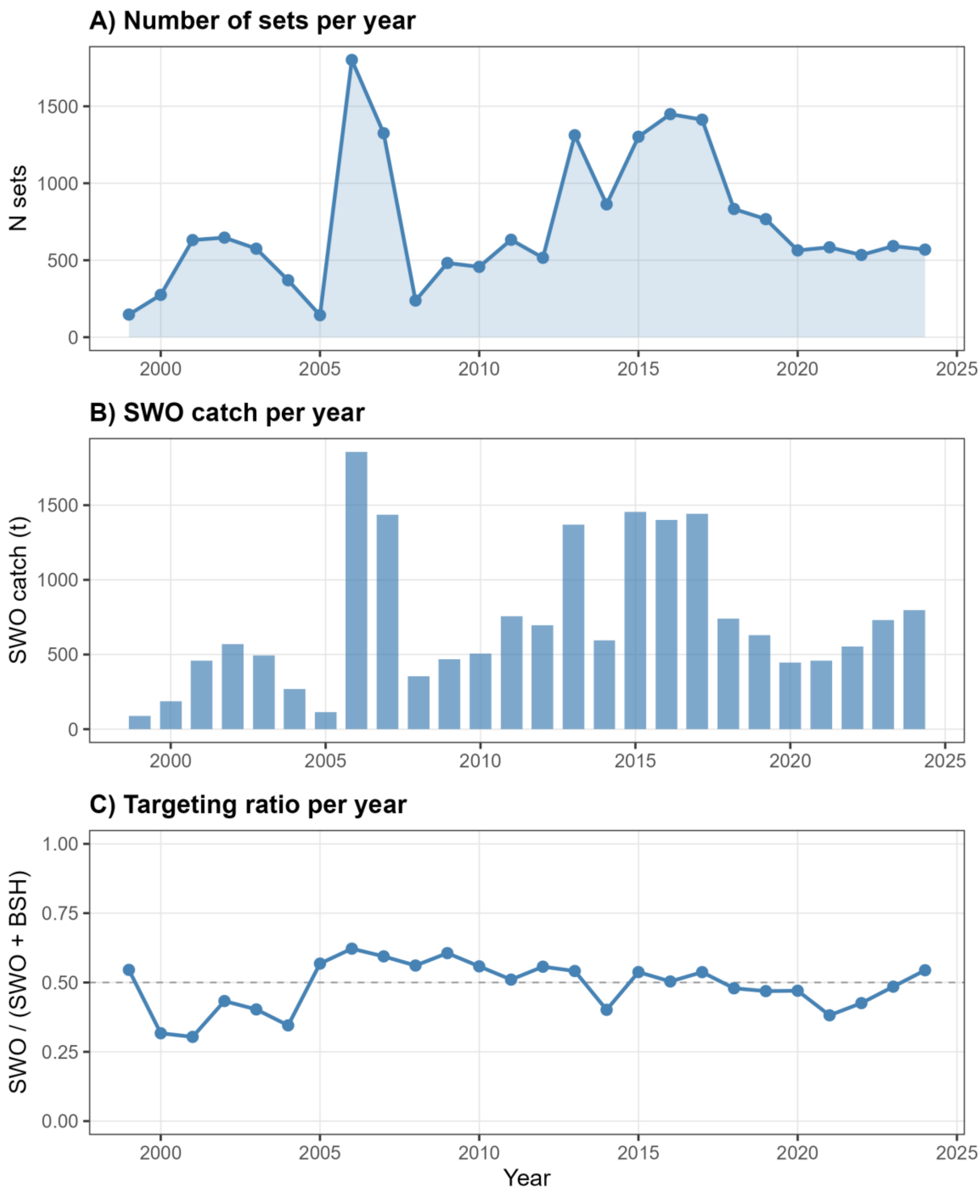

Figure 3: Descriptive plots of the total effort in sets (A), the total catch of swordfish (B), and the ratio of swordfish compared to the swordfish and blue shark catches (C), for the Portuguese longline fleet operating in the Indian Ocean.

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**).

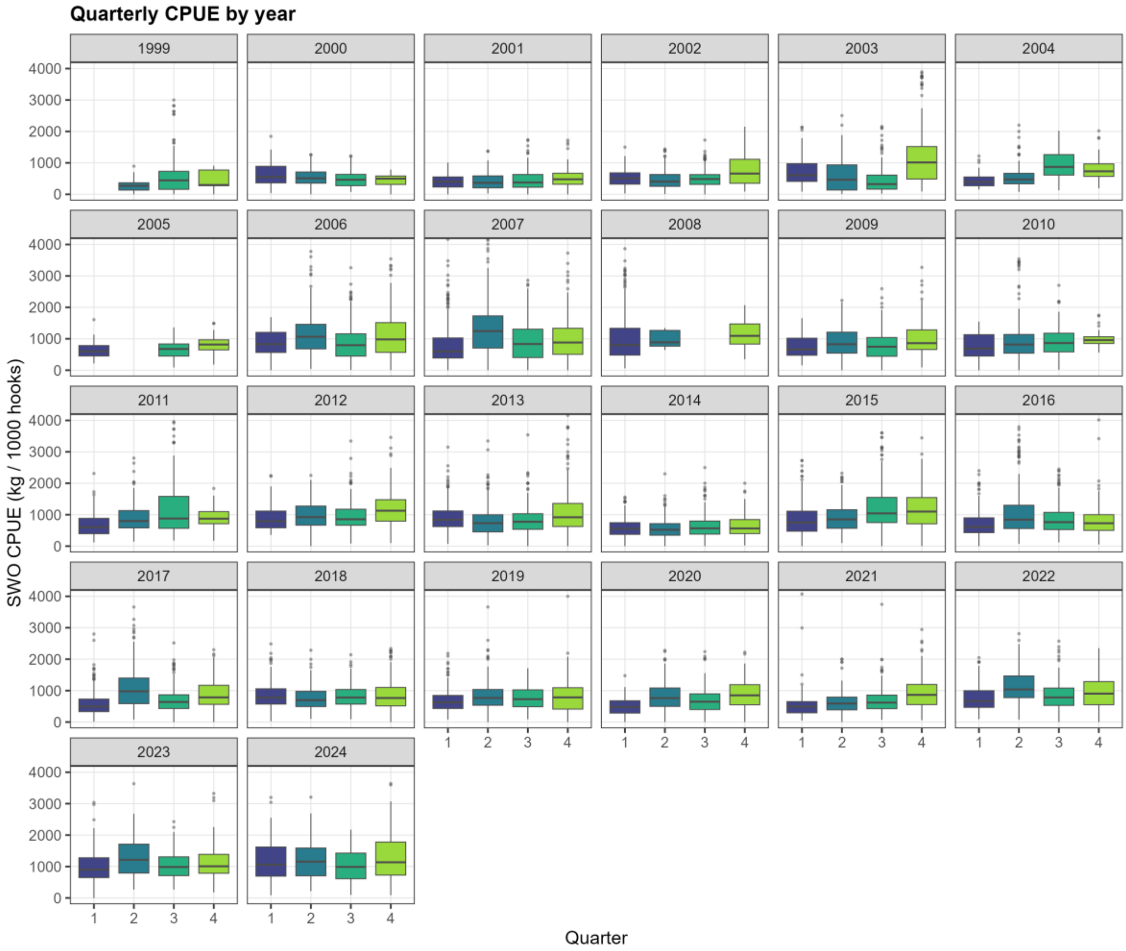

Figure 4. Quarterly swordfish CPUE (kg/1000 hooks) by the Portuguese pelagic longline fleet in the Indian Ocean, per year. In the boxplots the middle lines represent the median, the box the quartiles, the whiskers the non-outlier range and the points the outliers.

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. In the last year of the series, especially after 2022, the nominal CPUEs increased again (**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 0.49%. 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, Coelho et al. 2017). The nominal swordfish CPUE distribution was highly skewed to the right and became more normal shaped in the log-transformed scale (**Figure 6**).

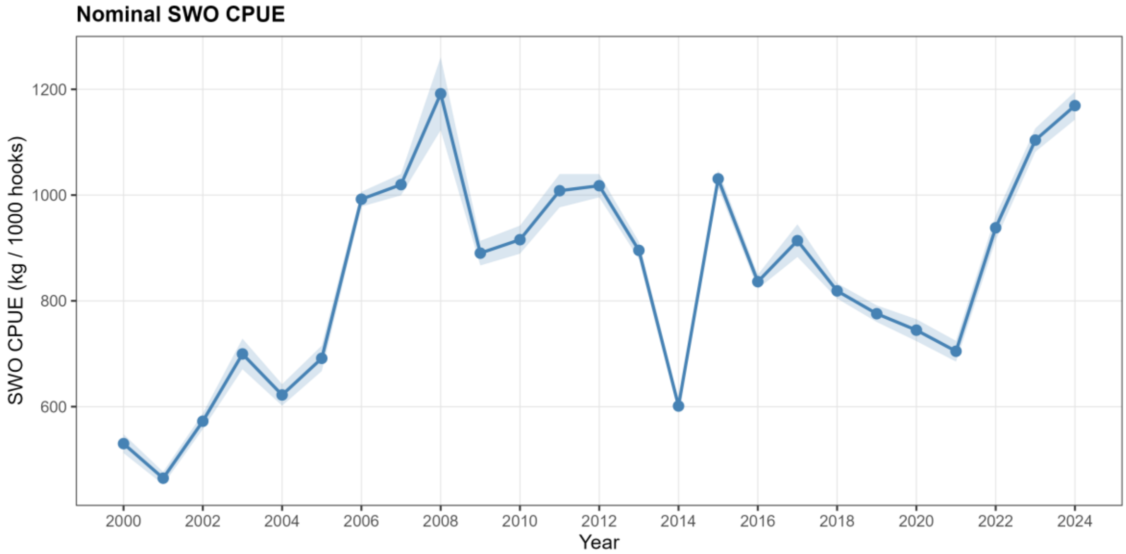

Figure 5. Nominal CPUE series (kg/1000 hooks) for swordfish caught by the Portuguese pelagic longline fishery in the Indian Ocean, between 2000 and 2024. The shaded band represents ± 1 standard error.

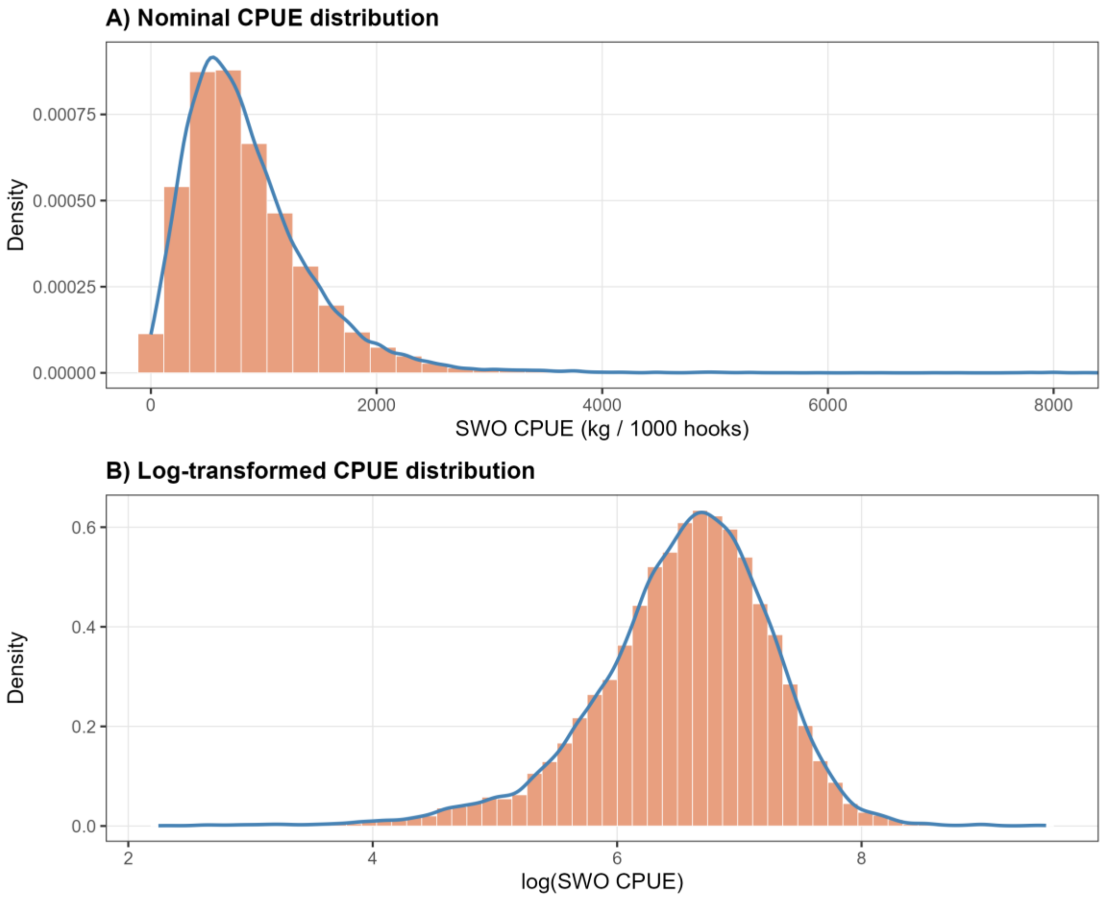

Figure 6: Distribution of the nominal swordfish CPUE captured by the Portuguese longline fleet in the Indian Ocean in non-transformed (top plot) and log-transformed (bottom plot) scales.

3.4. Spatial area stratification

The area stratifications followed a GLM tree approach for optimization based on the AIC drop. The final areas selected (5 areas) are shown in **Figure 7**.

There are some differences in the SWO nominal CPUE in those areas, in general with higher values in the SE Indian Ocean, followed by the more tropical regions and then the remaining areas (**Figure 8**).

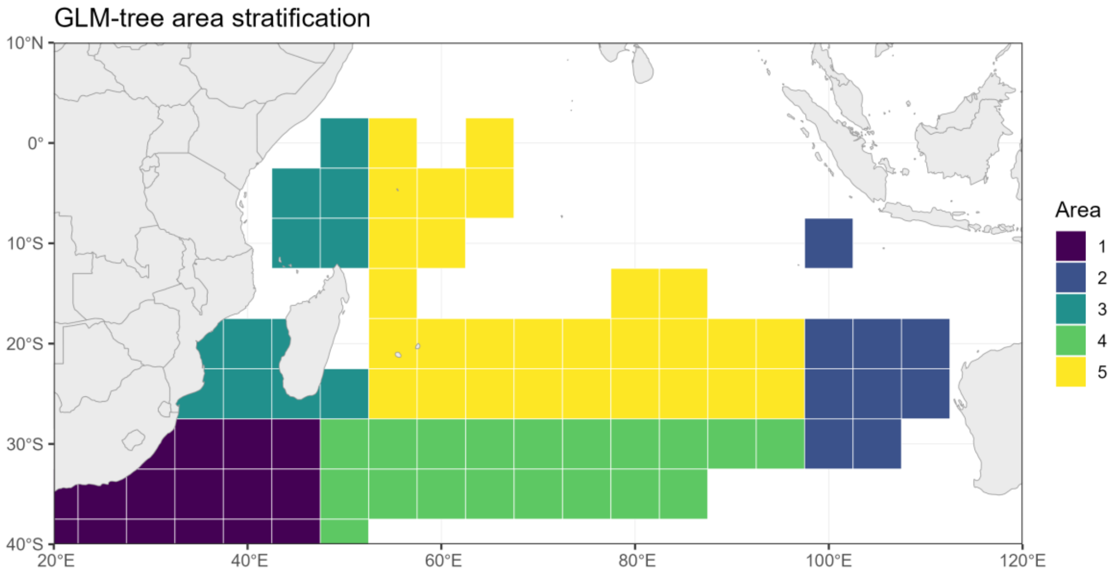

Figure 7: Spatial area stratification for the SWO CPUE captured by the Portuguese longline fleet in the Indian Ocean.

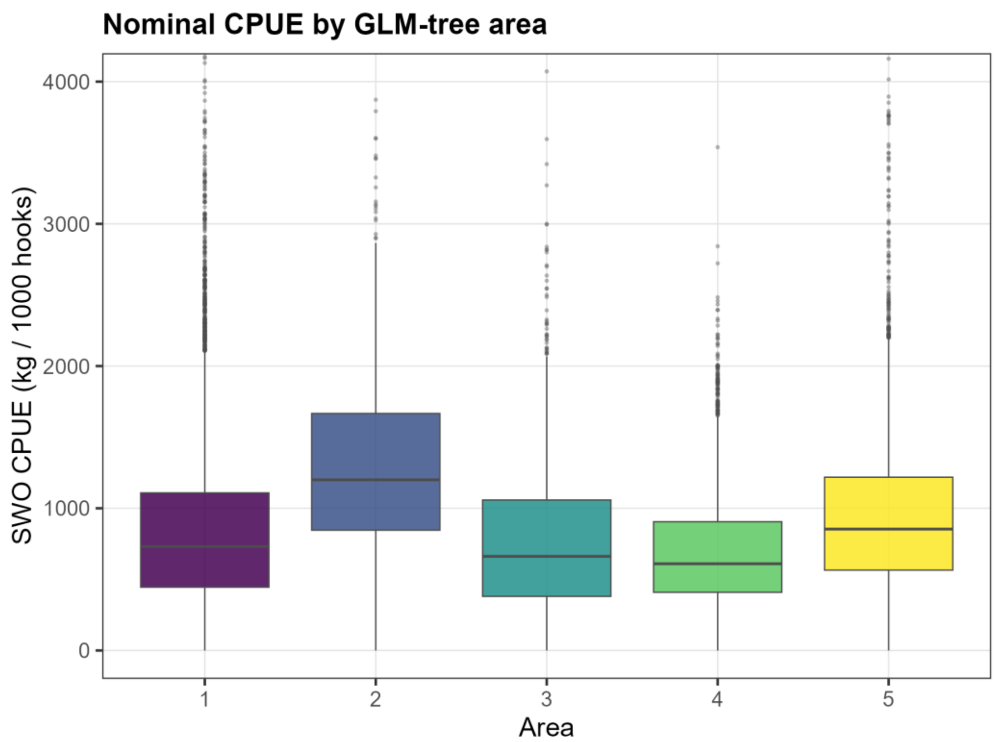

Figure 8: CPUE (median, interquartile range and dispersion) in each of the spatial areas defined by the GLM tree stratification procedure for the SWO CPUE captured by the Portuguese longline fleet in the Indian Ocean.

3.5. CPUE base model

The model explained a substantial portion of the variability in CPUE, with a marginal R^2 of 0.33 (variance explained by the fixed effects alone) and a conditional R^2 of 0.67 (variance explained by fixed and random effects combined). The contribution of the vessel random effect to the total variance explained therefore reflects relevant between-vessel differences in catchability that are accounted for in the standardization. All four fixed explanatory variables in the final model were highly significant and contributed to explaining part of the deviance (**Table 2**). The variable that contributed most was the ratio, followed by year, and then the season and spatial area effects.

First-order interactions between Quarter, Area and Ratio were tested as additions to the simple-effects model. None of the candidate interactions reached stable convergence, even with extended iteration limits, and the simple-effects model was therefore retained as the base case. This is consistent with the structure used in previous assessment cycles for the SWO CPUE standardization (Coelho et al., 2017, 2020, 2023).

The Tweedie power parameter (p) was estimated at 1.54, noting that when $1 < p < 2$ the distribution is a compound Poisson-Gamma that is appropriate for continuous positive data with a fraction of zeros.

Table 2. Sequential analysis of deviance for the Tweedie GLMM standardizing SWO CPUE for the Portuguese pelagic longline fleet in the Indian Ocean (2000–2024). Variables were added cumulatively. Df: total parameters; dDf: parameters added; dDeviance: deviance reduction; Chisq and P-value: likelihood-ratio test for each addition; AIC and dAIC: Akaike Information Criterion and its change (delta) versus the previous model. Note: all models use vessel effect as a random variable.

Model	df	dDf	dDeviance	deviance	Chisq	P_value	AIC	dAIC
Null	3	NA	NA	287777.7	NA	NA	287783.7	NA
add_Year	27	24	2090.1	285687.6	2090.1	0	285741.6	-2042.1
add_Quarter	30	3	584.8	285102.9	584.8	2E-126	285162.9	-578.8
add_AreaCat	34	4	529.8	284573.1	529.8	2E-113	284641.1	-521.8
add_RatioFac	43	9	7663.3	276909.8	7663.3	0	276995.8	-7645.3

3.6. Model validation

The model was validated based on simulation-based residuals (DHARMa residuals) and the diagnostic plots indicated that the Tweedie GLMM provided an adequate fit. The dispersion test was non-significant (p = 0.95), confirming that the Tweedie family correctly accommodated the variance structure of the response. The Kolmogorov–Smirnov goodness-of-fit test and the outlier test were formally significant (p < 0.01). However, both tests are highly sensitive to large sample sizes and detect even minor departures from the theoretical distribution, which is expected in this case when using a large dataset in the models. The visual analysis of the residuals against fitted values showed no systematic patterns (**Figure 9**), supporting the model's adequacy for the standardization.

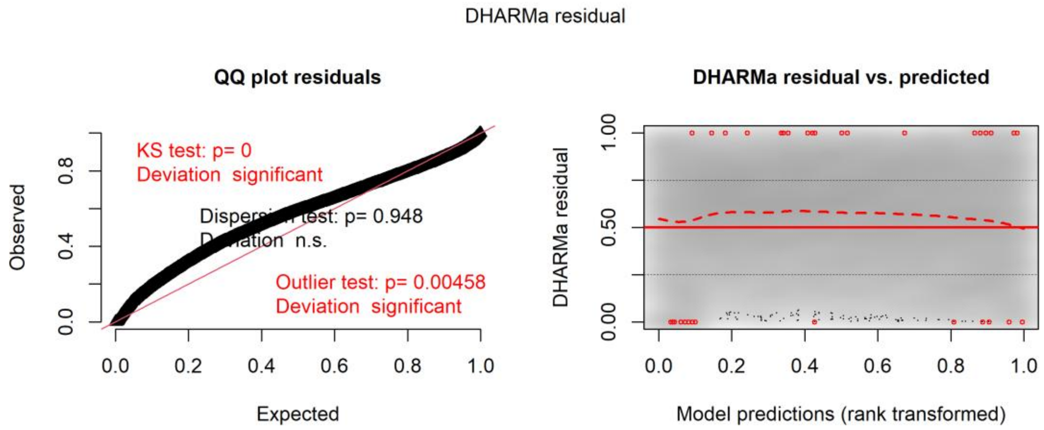

Figure 9. Residual analysis (based on simulation-based DHARMa residuals) for the final Tweedie GLMM model used for the swordfish CPUE standardization in the Indian Ocean.

3.7. Sensitivity analysis

The sensitivity analysis comparing model error distributions (Tweedie vs Lognormal+c) demonstrates that the differences in the final standardized CPUE are minimal. The two indices were strongly correlated (r = 0.91), with the Tweedie index slightly higher in years of higher CPUE and slightly lower in years of lower CPUE. The overall trend, however, is consistent between the two model structures (**Figure 10**)

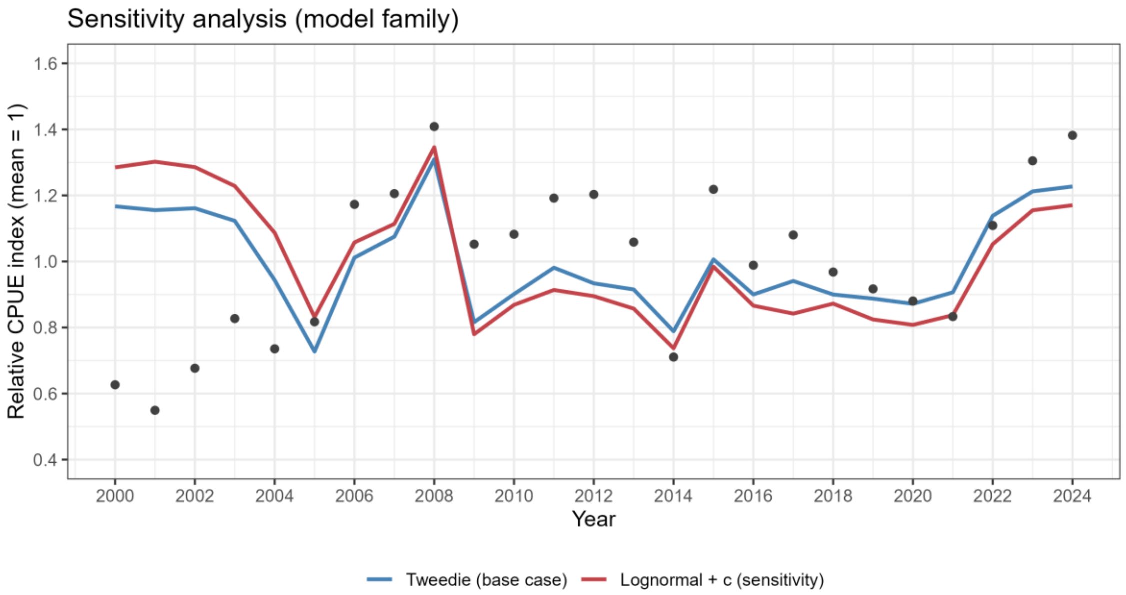

Figure 10. Sensitivity analysis comparing model error structures for the SWO CPUE standardization in the Indian Ocean. Both models are scaled to mean = 1 over their own series. The points represented in the plot are the nominal CPUEs.

3.8. Final standardized SWO CPUE series

The standardized swordfish CPUE index (in kg/1000 hooks) for the Portuguese pelagic longline fishery in the Indian Ocean between 2000-2024, suggested to be used in the SWO stock assessments is presented in **Figure 11** and the detailed values in **Table 3**.

Overall, the standardized CPUE series showed an initial high level in 2000–2003, a decline through the mid-2000s with a partial recovery in 2007–2008, a lower and relatively stable period between 2009 and 2021, and an increase in the most recent years (2022–2024). There are large differences between the nominal and standardized series, especially in the earlier years, 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-dependent effects to account only for the relative biomass change through time.

It is important to highlight that the 2022–2024 period shows a marked increase in the standardized index, with values approaching those observed at the beginning of the series and exceeding the 2009–2021 average.

Recent technological developments in pelagic longline fleets, namely the adoption of trapline-equipped longline gear by some vessels, have been shown to substantially increase swordfish catch rates per unit of effort deployed (Coelho et al., 2025, 2026). This represents a fishery-dependent effect that is not currently accounted for in the standardization model, and may therefore inflate recent CPUE values relative to what would reflect a true change in stock abundance. At this stage there is data collection procedures in place for the Portuguese pelagic longline fleet in the Indian Ocean, but the data collected so far is still limited and it is not fully known when this practice stared, so how much it can potentially affect this CPUE standardization

Future updates of this index should consider explicitly modelling the trapline effect as an additional covariate, once sufficient data on gear configuration becomes available across the fleet

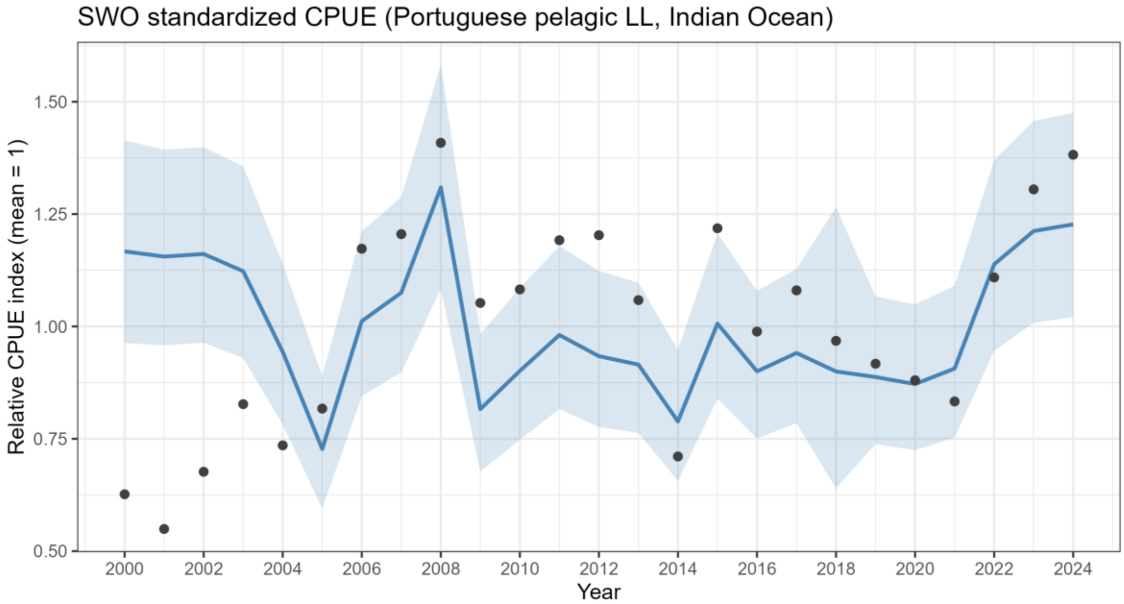

Figure 11. Final standardized CPUE series for SWO captured by the Portuguese pelagic longline fleet in the Indian Ocean using a Tweedie GLMM. The solid blue line refers to the standardized index, and the solid points are the nominal CPUEs. The blue band represents the 95% confidence interval.

Table 3: Standardized SWO CPUE index (kg/1000 hooks) for the Portuguese pelagic longline fleet in the Indian Ocean between 2000 and 2024, suggested to be used in future stock assessments. This table includes the nominal CPUEs and the index values (standardized in kg/1000 hooks), with the respective 95% confidence intervals (CI) and coefficient of variation (CV, %).

Year	Nominal CPUE	Standardized CPUE			
		Stdz CPUE	Lower 95%CI	Upper 95%CI	CV
2000	530.1	799.1	659.4	968.4	9.8
2001	464.7	791.2	656.2	954.0	9.5
2002	572.4	795.1	660.1	957.8	9.5
2003	699.7	768.9	636.6	928.8	9.6
2004	622.2	646.1	535.5	779.7	9.6
2005	691.4	498.0	407.1	609.2	10.3
2006	992.3	692.8	578.6	829.4	9.2
2007	1019.8	736.2	614.7	881.6	9.2
2008	1191.6	896.6	742.2	1083.2	9.6
2009	890.3	558.8	463.9	673.2	9.5
2010	915.7	617.1	512.1	743.5	9.5
2011	1008.3	671.7	559.1	807.1	9.4
2012	1017.7	639.4	531.5	769.3	9.4
2013	895.5	626.7	522.6	751.4	9.3
2014	601.2	540.0	449.5	648.7	9.4
2015	1030.8	689.1	574.7	826.2	9.3
2016	836.3	616.3	514.1	738.9	9.3
2017	913.9	644.3	537.5	772.4	9.2

2018	818.9	616.2	438.3	866.3	17.4
2019	775.8	607.7	505.7	730.3	9.4
2020	744.7	597.0	496.2	718.2	9.4
2021	704.8	620.6	515.8	746.7	9.4
2022	938.2	779.4	647.8	937.6	9.4
2023	1104.0	830.1	690.5	998.0	9.4
2024	1169.2	840.3	699.0	1010.1	9.4

4. Acknowledgments

The data used for this paper was collected within the PNAB/EU-DCF (Programa Nacional de Amostragem Biológica / EU Data Collection Framework). Special thanks are due to all skippers that voluntarily provided data from their fishing activities in the IOTC convention area. R.Coelho (CCMAR) receives Portuguese national funds from FCT - Foundation for Science and Technology through contracts UID/04326/2025 (DOI https://doi.org/10.54499/UID/04326/2025), UID/PRR/04326/2025 (DOI https://doi.org/10.54499/UID/PRR/04326/2025) and LA/P/0101/2020 (DOI:10.54499/LA/P/0101/2020).

5. References

Afonso, A.S., Hazin, F.H.V., Carvalho, F., Pacheco, J.C., Hazin, H., Kerstetter, D.W., Murie, D., Burgess, G.H. 2011. Fishing gear modifications to reduce elasmobranch mortality in pelagic and bottom longline fisheries off Northeast Brazil. *Fisheries Research*, 108: 336–343.

Brooks, M.E., Kristensen, K., van Benthem, K.J., Magnusson, A., Berg, C.W., Nielsen, A., Skaug, H.J., Mächler, M., Bolker, B.M. 2017. glmmTMB balances speed and flexibility among packages for zero-inflated generalized linear mixed models. The R Journal, 9(2), 378–400.

Bates D., Mächler M., Bolker B., Walker S., 2015. Fitting Linear Mixed-Effects Models Using lme4. Journal of Statistical Software, 67(1), 1–48

Campbell, R.A. 2004. CPUE standardisation and the construction of indices of stock abundance in a spatially varying fishery using general linear models. *Fisheries Research*, 70: 209–227.

Coelho, R., Santos, M.N., Lino, P.G. 2014. Blue shark catches by the Portuguese pelagic longline fleet between 1998-2013 in the Indian Ocean: catch, effort and standardized CPUE. 10th Working Party on Ecosystems and Bycatch, 27-31 October, Yokohama, Japan. IOTC Document: IOTC–2014–WPEB10–24. 32pp.

Coelho, R., Lino, P.G. Rosa, D., Santos, M.N., 2015. Update of the blue shark catches and standardized CPUE for the Portuguese pelagic longline fleet in the Indian Ocean: exploring the effects of targeting. 11th Working Party on Ecosystems and Bycatch, 7-11 September, Olhão, Portugal. IOTC Document: IOTC–2015–WPEB11–26. 24pp.

Coelho R., Santos M.N., Lino P.G., 2016. Standardized CPUE of blue shark in the Portuguese pelagic longline fleet operating in the north Atlantic. Blue shark data preparatory meeting, 23-27 March 2015, Tenerife, Spain. Collect. Vol. Sci. Pap. ICCAT, 72 (4): 1044-1066.

Coelho, R., Lino, P., Rosa, D., 2017. Swordfish catches by the Portuguese pelagic longline fleet in 1998-2016 in the Indian Ocean: catch, effort and standardized CPUEs. IOTC-2017-WPB15-14.

Coelho, R., Rosa, D., 2020. Update of the swordfish catch, effort, and standardized CPUEs by the Portuguese pelagic longline fleet operating in the Indian Ocean, between 1998 and 2018. IOTC-2020-WPB18-11.

Coelho, R., Rosa, D., Lino, P.G., 2023. Update of the swordfish catch, effort and standardized CPUEs by the Portuguese pelagic longline fleet operating in the Indian Ocean, between 1998 and 2022. Working Party on Billfish (WPB), 6-9 September 2023, Hybrid / Reunion Island, France. IOTC Document: IOTC-2023-WPB21-12

Coelho, R., Barbosa, C., Rosa, D., Lino, P.G., 2025, Preliminary evaluation of the new trapline gear targeting swordfish in the Portuguese pelagic longline fishery in the Atlantic Ocean. ICCAT SCRS Document. ICCAT Species Groups Meetings (Swordfish), Madrid, Spain, 22-23 September, SCRS/2025/148

Coelho, R., Lino, P., Barbosa, C., Rosa, D., 2026. The use of traplines in the Portuguese pelagic longline fleet operating in the eastern Atlantic. ICCAT swordfish data preparatory meeting. Madrid, Spain, 23-27 March 2026. SCRS/2026/001.

Foster, S.D., Bravington, M.V., 2013. A Poisson–Gamma model for analysis of ecological non-negative continuous data. Environ Ecol Stat 20, 533–552. https://doi.org/10.1007/s10651-012-0233-0

Fox, J., Weisberg, S. 2019. An R Companion to Applied Regression, 3rd Edition. Sage, Thousand Oaks CA.

Hartig, F., 2024. DHARMa: Residual Diagnostics for Hierarchical (Multi-Level / Mixed) Regression Models. R package version 0.4.7. https://CRAN.R-project.org/package=DHARMa

He, X., Bigelow, K.A., Boggs, C.H., 1997. Cluster analysis of longline sets and fishing strategies within the Hawaii-based fishery. Fisheries Research, 31 (1-2): 147-158.

Ichinokawa, M., Brodziak, J. 2010. Using adaptive area stratification to standardize catch rates with application to North Pacific swordfish (Xiphias gladius). Fisheries Research, 106: 249-260.

Lenth, R.V., 2024. emmeans: Estimated Marginal Means, aka Least-Squares Means. R package version 1.10.x. https://CRAN.R-project.org/package=emmeans

Massicotte, P., South, A. (2024). rnaturalearth: World Map Data from Natural Earth. R package version 1.0.x. https://CRAN.R-project.org/package=rnaturalearth

Mejuto, J., García-Cortés, B., Ramos-Cartelle, A. 2008. Standardized catch rates in biomass for the swordfish (*Xiphias gladius*) caught by the Spanish longline fleet in the Indian Ocean for the period 1993-2007. IOTC Working Document. IOTC-2008-WPB-06.

Mejuto, J., García-Cortés, B., Ramos-Cartelle, A., De la Serna, J.M., González-González, I. 2012. Standardized catch rates of shortfin mako (*Isurus oxyrinchus*) caught by the Spanish surface longline fishery targeting swordfish in the Atlantic Ocean during the period 1990-2010. *ICCAT SCRS/2012/046*. 12pp.

Nishida, T., Wang, S-P., 2014. CPUE standardization of swordfish (*Xiphias gladius*) exploited by Japanese tuna longline fisheries in the Indian Ocean using cluster analysis for targeting effect. IOTC–2014–WPB12–21 Rev_1.

Pebesma, E., 2018. Simple Features for R: Standardized Support for Spatial Vector Data. The R Journal, 10(1), 439–446.

Ramos-Cartelle, A., García-Cortés, B., Fernández-Costa, J., Mejuto, J. 2011. Standardized catch rates for the swordfish (*Xiphias gladius*) caught by the Spanish longline in the Indian Ocean during the period 2001-2010. *IOTC Working Document*. IOTC-2011-WPB09-23. 19pp.

R Core Team, 2025. R: A Language and Environment for Statistical Computing. R Foundation for Statistical Computing, Vienna, Austria. <https://www.R-project.org/>.

Santos, M.N., Coelho, R., Lino, P.G. 2012. A brief overview of the swordfish catches by the Portuguese pelagic longline fishery in the Indian Ocean: catch, effort, CPUE and catch-at-size. *IOTC–2012–WPB10–11*: 14 p.

Santos, M.N., Coelho, R., Lino, P.G. 2013. Standardized CPUE for swordfish (*Xiphias gladius*) caught by the Portuguese pelagic longline fishery in the North Atlantic Ocean. *ICCAT SCRS/2013/104*: 11pp.

Santos, M.N., Coelho, R., Lino, P.G. 2014. Swordfish catches by the Portuguese pelagic longline fleet between 1998-2013 in the Indian Ocean: Effort, standardized CPUE and catch-at-size. IOTC Doc: IOTC–2014–WPB12–18.

Shono, H. 2008. Application of the Tweedie distribution to zero-catch data in CPUE analysis. *Fisheries Research*, 93: 154–162.

Vega, R, Licandeo R. 2009. The effect of American and Spanish longline systems on target and non-target species in the eastern South Pacific swordfish fishery. *Fisheries Research*, 98: 22-32.

Ward, P, Lawrence, E, Darbyshire, R, Hindmarsh, S. 2008. Large-scale experiment shows that nylon leaders reduce shark bycatch and benefit pelagic longline fishers. *Fisheries Research*, 90: 100-108.

Wickham, H., 2016. ggplot2: Elegant Graphics for Data Analysis. Springer-Verlag, New York.

Wickham, H., Averick, M., Bryan, J., Chang, W., McGowan, L.D., François, R., Grolemund, G., Hayes, A., Henry, L., Hester, J., Kuhn, M., Lin Pedersen, T., Miller, E., Bache, S.M., Müller, K., Ooms, J., Robinson, D., Seidel, D.P., Spinu, V., Takahashi, K., Vaughan, D., Wilke, C., Woo, K., Yutani, H., 2019. Welcome to the tidyverse. Journal of Open Source Software, 4(43), 1686.