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CATCH RATES OF SAILFISH FROM BRAZILIAN LONGLINE FISHERIES IN THE WESTERN ATLANTIC (1991-2022)

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SUMMARY

Catch and effort data performed by the Brazilian tuna longline fleet in a wide area of the South Atlantic Ocean from 1994 to 2020 were analyzed. The fishing effort was distributed over a wide area of the Atlantic Ocean. The CPUE of sailfish was standardized by a GLM using a Delta Lognormal approach. The factors used in the models were: year, quarter, vessels, clusters, hooks per float, hooks, and the lat-long reference for each 5 by 5 spatial square. The standardized CPUE series increases between 1996 and 2003, followed by a decreasing trend until the end of the time series.

RÉSUMÉ

Les données de prise et d'effort de la flottille palangrière thonière brésilienne dans une vaste zone de l'océan Atlantique Sud entre 1994 et 2020 ont été analysées. L'effort de pêche était réparti dans une large zone de l'océan Atlantique. La CPUE des voiliers a été standardisée par un GLM utilisant une approche delta-lognormale. Les facteurs utilisés dans les modèles étaient : l'année, le trimestre, les navires, les « grappes », les hameçons par flotteur, les hameçons et la référence lat-long pour chaque carré spatial de 5ºx5º. La série standardisée de la CPUE augmente entre 1996 et 2003, suivie d'une tendance à la baisse jusqu'à la fin de la série temporelle.

RESUMEN

Se analizaron los datos de captura y esfuerzo de la flota palangrera atunera brasileña en una amplia zona del océano Atlántico sur desde 1994 hasta 2020. El esfuerzo pesquero se distribuyó en una amplia zona del océano Atlántico. Se estandarizó la CPUE de pez vela mediante un GLM, utilizando un enfoque delta lognormal. Los factores utilizados en los modelos fueron: año, trimestre, buques, agrupaciones, anzuelos por flotador, anzuelos y la referencia lat-long para cada cuadrícula espacial de 5 por 5. La serie de CPUE estandarizada aumenta entre 1996 y 2003, seguida de una tendencia decreciente hasta el final de la serie temporal.

KEYWORDS

Delta Lognormal; billfish; Pelagic fisheries; Catch/Effort

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Introduction

In Brazil, sailfish are mostly caught as incidental bycatch by pelagic longline fisheries, while captures from gillnets are also documented. Sailfish are common off the Brazilian coast all year, primarily in tropical locations, with peak abundance from October to February on the southeast Brazilian coast (Mourato *et al.,* 2014a). Sailfish spawning in the western Atlantic have different northern and southern spawning distributions and peak seasons. Before the reproductive season in the southern hemisphere, sailfish migrate from the western central tropical Atlantic to the southwest Atlantic (Mourato *et al*., 2018). This movement pattern appears to be related to the shift of the 28°C surface isotherm towards the south (Mourato *et al*. 2014a) and matches with a pronounced preference for warmer mixed layer waters in the area examined (Mourato *et al*., 2014b).

The relationship between sailfish life cycle and migration pattern, combined with historical changes in fishing operations and strategies of Brazilian pelagic longline fisheries (Amorim and Arfelli, 1984; Hazin *et al*., 2007; Carvalho *et al*., 2010; Mourato *et al*., 2011), causes catchability oscillations, which may introduce significant errors in estimating abundance indices. Therefore, the CPUE standardization, which leads with the effects of factors other than the actual abundance of the stock on the CPUE is a crucial step in estimating an index of abundance for this species. In this study, therefore, to contribute with the assessment of the western Atlantic sailfish, a standardized series of CPUE for the species caught by the Brazilian longline fleet, including both national and chartered vessels, was updated from 1994 to 2021.

Material and methods

Catch and effort data

In the present study, catch and effort data from 127,740 tuna longline sets obtained from logbooks reported by the Brazilian tuna longline fleet, including national and foreign chartered vessels, from 1978 to 2022, were analyzed. The longline sets were distributed in a wide area of the equatorial and South Atlantic Ocean, ranging from 15° to 55º W of longitude and from 05º N to 40º S of latitude (**Figure 1**). The resolution of 5º x 5º, per fishing set, was used to analyze the geographical distribution of fishing effort and catches. The overall proportion of positive sets (fishing sets that caught at least one sailfish) for the whole period is about 81%. At the same time, the yearly variation showed a decrease in the last ten years of time series, while for the quarterly fluctuation a stable trend was observed (**Figure 2**).

Data cleaning was similar to those applied for other species (Sant'Ana *et al.,* 2018; Mourato *et al.,* 2022) and followed the approaches proposed by Hoyle *et al.* (2015), Hoyle *et al*. (2016), and Hoyle *et al.* (2018). All analyses were carried out in R version 4.0.0 (R Core Team, 2020). Vessels that had never caught a sailfish before were removed from the dataset at the first step. We also selected data for vessels that had fished for at least two quarters and reported at least 50 sets. Spatial cells and year-quarters were only included in the final dataset if it comprised at least five sets. Year-quarter * 5° cell strata with less than five sets were removed to avoid giving too much statistical weight to individual sets via the area-weighting process. These steps resulted in a considerable reduction in the original dataset, shrinking the time series to the most recent period between 1994 and 2022, comprising 94,527 fishing sets.

Cluster analysis

A cluster analysis was performed to investigate and identify effort groups with comparable species composition and, presumably, similar fishing method and targeting. The dataset was aggregated by vessel-month for this purpose. According to Hoyle *et al.* (2018), the set level data contains species composition fluctuation due to the randomness of chance interactions between fishing gear and schools of fish. This unpredictability causes some misallocation of sets when different fishing tactics are used, and aggregation tends to lessen the variability and thus the misallocation. The data were clustered using two methods, the first of which was based on the hierarchical Ward "hclust" method, which was implemented in R using the "hclust" function with the option "Ward.D." The second strategy was based on "kmeans" (Hartigan and Wong, 1979). Hoyle *et al.* (2015), Hoyle *et al*. (2016), and Hoyle *et al*. (2018) provide a more extensive discussion of these strategies.

CPUE standardization

CPUE standardization methods used a Generalized Linear Models (GLM) with a Delta Lognormal approach, as described by Hoyle *et al.* (2018) (https://github.com/hoyles/cpue.rfmo). For non-zero (positive) catch rates, delta lognormal analyses (Lo *et al.* 1992; Maunder & Punt 2004) employed a binomial distribution for the probability w of the catch rate being zero and a probability distribution f(y), where y was log(catch in number/hooks set)*1000. Year, quarter, cluster, hooks per float, hooks, and the lat-long reference for each 5°x5° spatial square were the factors included in the models. The predicted index for each year-quarter was the product of the two model components' year effects, $(1-w)*E(y|y\neq 0)$.

Year-quarter (yq) and 5° cell (latlong5) were fitted as categorical variables as covariates. The continuous variable hooks were fitted using a cubic spline function h with 3 degrees of freedom in the analyses. Hooks between floats (hbf) was also included using a cubic spline to fit it as a continuous variable, whereas cluster (cl) and vessel (vessid) were employed as a categorical variable (Hoyle *et al.,* 2018). As proposed by Hoyle *et al.* (2018), data in all models except the binomial model were 'area-weighted', with the weights of the sets adjusted so that the total weight per year-quarter in each 5° square would sum to 1.

Indices of abundance were obtained by applying the R function *predict.glm* to model objects. The datasets used for prediction included all year-quarter values, with all other variables fixed at either the median for continuous variables or the mode for categorical variables. Binomial time effects were obtained by a) generating logit time effects from the GLM, and b) adding a constant to these logit time effects so that the mean of the back-transformed proportions was equal to the proportion of positive sets across the whole dataset. The main aim of this approach is to obtain a CPUE that varies appropriately since variability for a binomial is more significant when the mean is at 0.5 than at 0.02 or 0.98, and the multiplicative effect of the variability is greater when the mean is lower. The outcomes were normalized and reported as relative CPUE with a mean of 1. Uncertainty estimates were provided by applying the R function predict.glm with type = "terms" and se.fit = TRUE and taking the standard error of the year-quarter effect. This process concerns only the uncertainty in the positive component. Residual distributions and Q-Q plots were produced for the lognormal positive analyses.

Results and discussion

The results of the cluster analyses showed an interesting pattern of targeting species. Five distinct groups were observed: Group 01, headed by albacore catches; Group 02, topped by the bigeye catches; Group 03, targeting blue shark; Group 04, for yellowfin; and Group 05 for swordfish. (**Figure 3**). Diagnostic plots for the Lognormal model showed that the lognormal distribution assumption for the positive dataset seems to be adequate, as indicated in the histogram (**Figures 4**). Residuals were homoscedastic, and no systematic bias were observed.

The annual influence of each explanatory variable in explaining the variation in the abundance index varied among the different covariates in the standardization model (**Figure 5**). The influence plot for the annual trend in vessel effect shows a stable pattern up to 2010, followed by a decreasing trend along the time series analyzed. The hook per float effect trend presented a decreasing trend up to 2002, followed by a stable trend until 2022. For the cluster effect, it was observed a continuously decreasing trend along the time series (**Figure 5**).

Overall time trends of standardized CPUE estimates presented an increasing between 1996 and 2003, followed by decreasing trend until the final of the time series (**Figure 6** and **Table 1**). The model appears to fit the observed data effectively, according to the model diagnostics (**Figure 4**), and the trend of the standardized catch rates appears to be plausible. As a result, we propose that our estimates could be taken to accurately reflect the stock's local relative abundance and advise that they be applied to assessment models.

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Table 1. Nominal and standardized index of relative abundance of sailfish caught by Brazilian pelagic longline fishery fleet between the years of 1994 to 2022.

Year	Scaled Index	C.V.
1994	1.12	14%
1995	1.21	11%
1996	0.43	15%
1997	0.79	6%
1998	0.79	7%
1999	1.06	5%
2000	0.96	5%
2001	1.25	5%
2002	1.25	6%
2003	1.50	6%
2004	0.96	6%
2005	0.85	5%
2006	1.11	6%
2007	0.83	5%
2008	0.89	6%
2009	1.28	5%
2010	1.06	6%
2011	1.02	5%
2012	0.89	7%
2013	1.45	16%
2014	0.81	11%
2015	0.63	13%
2016	0.61	10%
2017	0.67	14%
2018	0.63	8%
2019	0.94	9%
2020	1.15	8%
2021	0.89	12%
2022	0.82	10%

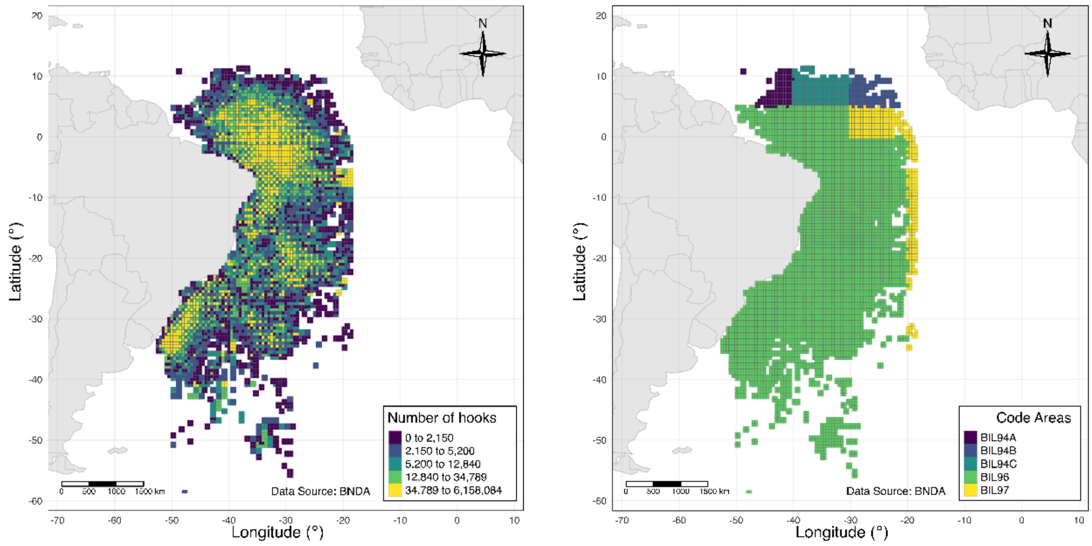

Figure 1. Spatial distribution of the total fishing effort done by the Brazilian tuna and Uruguayan longline fishing fleets in the Atlantic Ocean from 1978 to 2018 (left). Spatial representation of the ICCAT BIL sampling areas (right).

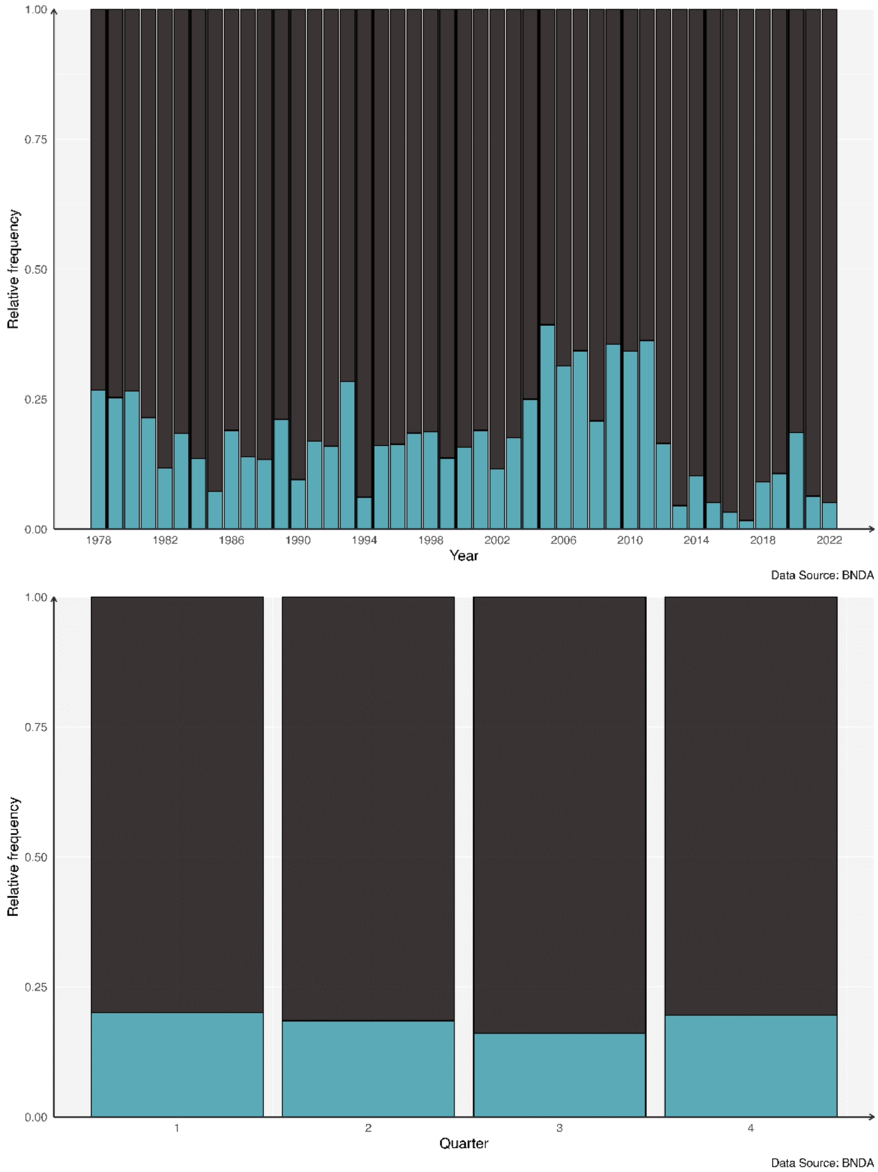

Figure 2. Proportion of positives for the sailfish caught by the Brazilian longline fishery in Atlantic Ocean (1978-2022).

Figure 3. Cluster analysis applied to the Brazilian longline fishery database in the Atlantic Ocean (1994-2022).

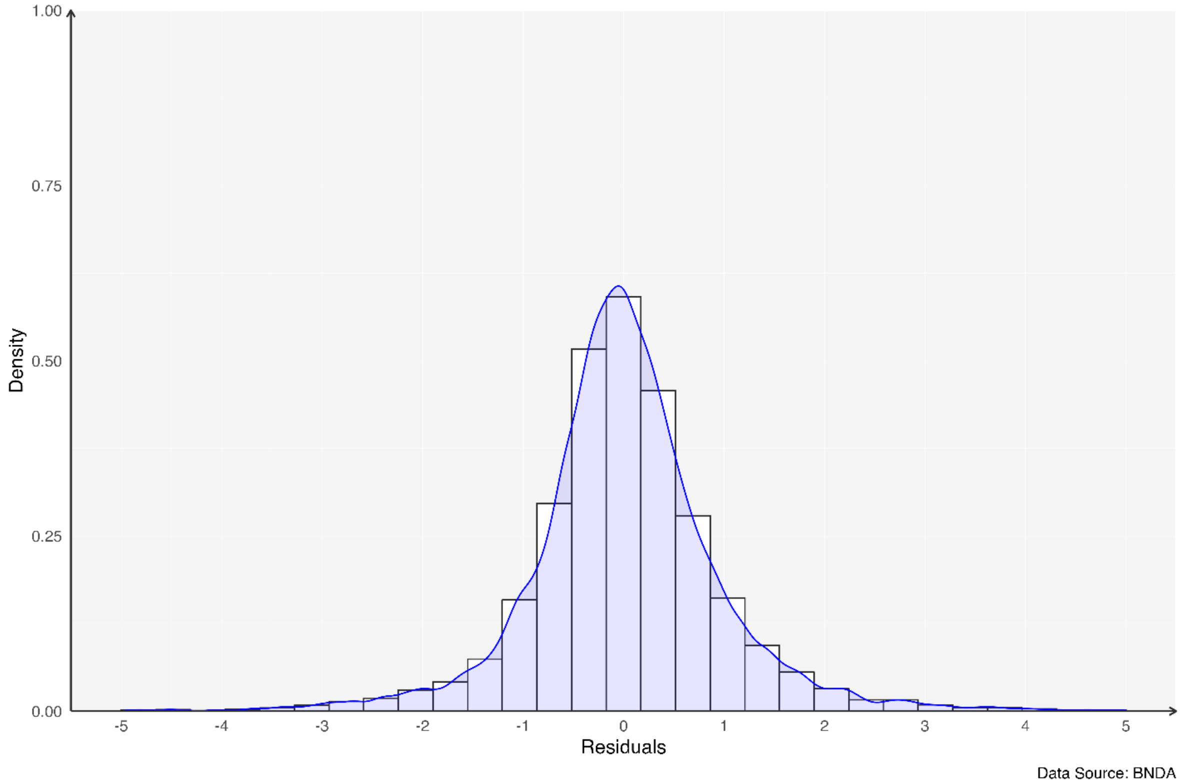

Figure 4. Diagnostics plot for the western sailfish delta lognormal model.

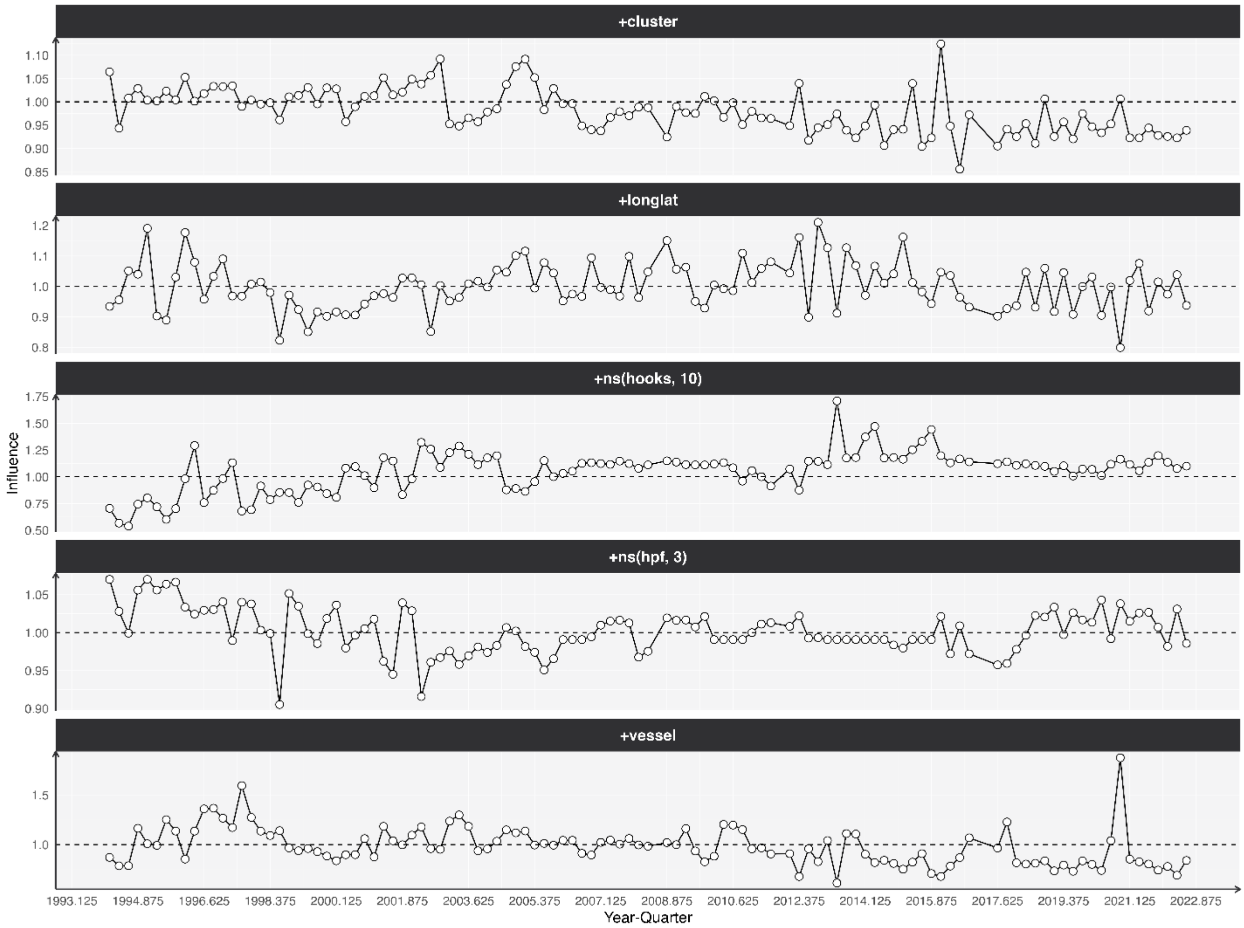

Figure 5. Annual and seasonal influence values for each explanatory variable in GLM model.

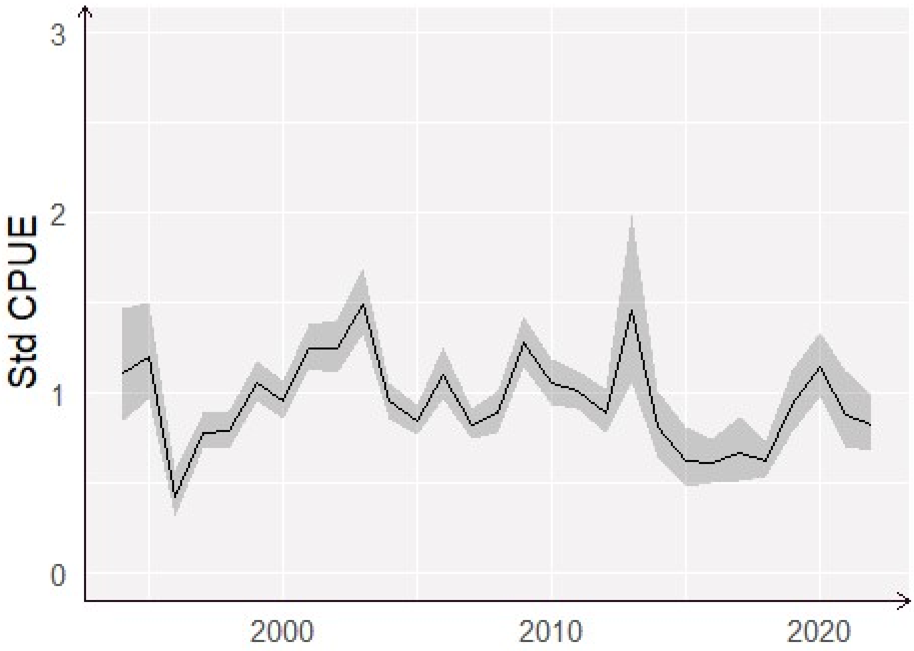

Figure 6. Scaled index for western Atlantic sailfish and respective 95% confidence intervals.