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CATCH RATES OF SWORDFISH FROM BRAZILIAN LONGLINE FISHERIES IN THE SOUTH ATLANTIC (1994-2020)

B. Mourato[1], R. Sant'Ana[2], L. Gustavo Cardoso[3], P. Travassos[4]

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 in a wide area of the Atlantic Ocean. The CPUE of the swordfish was standardized by a GLM using a Delta Lognormal approach. The factors used in the models were: year, quarter, vessels, clusters, hooks per floats, hooks, and the lat-long reference for each 5 by 5 spatial squares. The standardized CPUE series presented a decreasing trend between 1996 and 2001, remained relatively stable up to 2015, and steadily decreased from 2016 to 2020.

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 de l'espadon 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 flotteurs, les hameçons et la référence lat-long pour chaque carré spatial de 5º sur 5º. La série de CPUE normalisées a présenté une tendance à la baisse entre 1996 et 2001, est restée relativement stable jusqu'en 2015 et a diminué régulièrement de 2016 à 2020.

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 del pez espada mediante un GLM, utilizando un enfoque delta lognormal. Los factores utilizados en el modelo fueron: año, trimestre, buques, conglomerados, anzuelos por flotador, anzuelos, y la referencia lat-long para cada una de las cuadrículas espaciales de 5 por 5. La serie de CPUE estandarizada presentó una tendencia a la baja entre 1996 y 2001, se mantuvo relativamente estable hasta 2015 y disminuyó de forma constante desde 2016 hasta 2020.

KEYWORDS

Delta Lognormal; billfish; Pelagic fisheries; Catch/Effort

[1] Instituto do Mar, Universidade Federal de São Paulo, Av. Doutor Carvalho de Mendonça, 144, 11070-100, Santos, Brazil. E-mail:Bruno.mourato@unifesp.br

2 Universidade do Vale do Itajaí, Escola do Mar, Ciência e Tecnologia, Laboratório de Estudos Marinhos Aplicados. Rua Uruguai, 458, Itajaí, SC, Brazil.

3 Fundação Universidade Federal de Rio Grande, Instituto de Oceanografia, Laboratório de Recursos Pesqueiros Demersais e Cefalópodes. Av. Itália km 8, Campus Carreiros, Rio Grande, RS, Brazil.

4 Universidade Federal Rural de Pernambuco, Departamento de Pesca e Aquicultura, Rua Dom Manoel de Medeiros, s/n – Dois Irmãos, 52171-900 Recife, PE, Brazil.

Introduction

Since 1956, when longline fishing operations began in the South Atlantic Ocean, several changes in fishing operations and strategies have been observed that directly affected catch composition (Amorim e Arfelli, 1984; Hazin et al., 2007; Carvalho et al., 2010; Mourato et al., 2011). Such variations lead to oscillations in catchability, which may introduce severe errors in estimating abundance indices. A common way to compensate for these interferences is to standardize the CPUE series by different methods to neutralize the effects of factors other than the actual abundance of the stock on the CPUE. In this study, therefore, to contribute information for the assessment of the swordfish in the South Atlantic Ocean, 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 2020.

Material and Methods

Catch and effort data

In the present study, catch and effort data from 116,231 tuna longline sets obtained from logbooks reported by the Brazilian tuna longline fleet, including national and foreign chartered vessels, from 1978 to 2020, 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.

Data cleaning was based on 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 swordfish 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 2020, comprising 85,687 fishing sets. The overall proportion of positive sets (fishing sets that caught at least one swordfish) for the whole period is about 80%. At the same time, the yearly variation showed a slight increase from 1994 to 2003, followed by a stable trend, with a substantial reduction in 2020 (prop. of positives < 0.5) (**Figure 2**).

Cluster analysis

A cluster analysis was used to explore factors contributing to these patterns and to identify effort groups with similar species composition and, therefore, presumably, similar fishing strategy and targeting. For this purpose, the dataset was aggregated by vessel-month. Hoyle et al. (2018) explain that the set level data contains variability in species composition due to the randomness of chance encounters between fishing gear and schools of fish. This variability leads to some misallocation of sets using different fishing strategies, and this aggregation tends to reduce the variability and therefore reduce this misallocation. The data were clustered using two approaches, the first based on the hierarchical Ward "hclust" method, implemented in R by the "hclust" function with the option "Ward.D". The second was based on "kmeans" method (Hartigan and Wong, 1979). A more detailed description of these methods can be found in Hoyle et al. (2015), Hoyle et al. (2016), and Hoyle et al. (2018).

CPUE standardization

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

Covariates included year-quarter (yq) and 5° cell (latlong5) fitted as categorical variables. Analyses including the continuous variable hooks fitted it using a cubic spline function h with 3 degrees of freedom. Analyses including hooks between floats (hbf) fitted it as a continuous variable using a cubic spline ϕ, while those including cluster (cl) fitted it 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.

In the binomial component of the model, fitted probabilities of 0 or 1 may occur, associated with categories of year-quarter and 5° cell. This is known as ‘perfect separation' and is problematic for uncertainty estimation (Venables & Ripley 2002). This is one of the reasons why the binomial component of the uncertainty is not used. Perfect separation should not bias prediction of the year-quarter effects, as long as a category at which separation occurs is not used in the predictor. Perfect separation in year-quarter results in an accurate prediction of 0 or 1 (Hoyle et al., 2018).

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. Four distinct groups were observed: Group 01, headed by albacore catches; Group 02, topped by the bigeye and yellowfin tuna catches; Group 03, targeting blue shark; and Group 04, 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 QQ-plots (**Figures 4**). Residuals were homoscedastic, and no systematic bias were observed.

Table 1 summarizes the deviance analysis for the two stages of the Delta model, with a description for Lognormal and Binomial models. All variables were significant and resulted in a decrease in residual deviance. The explanatory variable “yrqtr” was the most important in the total deviance in both models, for the lognormal model and cluster for the binomial models. Model coefficients and respective effects (**Figure 5**) for the lognormal model indicate that higher catch rates of swordfish are associated with a reduced number of hooks between float (<8) and related to Group 04 of the variable cluster. Spatial variables were also important as judged by the variation of the coefficients. For the Binomial model, the expected proportion of positives seems to be uniform during the period but lower in the final of the time series (**Figure 5**).

The standardized CPUE series presented a decreasing trend between 1996 and 2001, remained relatively stable up to 2015, and steadily decreased from 2016 to 2020 (**Figure 6** and **Table 2**). Overall time trends of nominal and standardized CPUE estimates were opposite between 1994 and 2010, with the nominal index increasing while the standardized catch rate presented a declining trend. After 2010, both indices were more related, showing a declining trend up to 2020 (**Figure 6**).

Overall, our results presented the same temporal pattern as the previous study (Carneiro et al., 2017) (**Figure 7**). In the last assessment of south Atlantic swordfish, the Brazilian time series was split into two parts (1978-2004 and 2005-2012). This time block approach was necessary because the fishing target of part of the fleet has changed across the years, the longline type has changed, and the quality of the data has also likely changed due to the onboard observer program for leased boats only. However, the updated time series do not need to be split into two-time blocks because our data cleaning process (see material and methods) removed the historical period of the database (1978-1993), characterized by high variability and a flat general pattern. Also, the American-type longline was introduced in the Brazilian fleet in 1994, when the swordfish became the target species, minimizing, at least partially, the impact of the target species change in the updated time series. Finally, this study used only logbook data, which differed from the used approach in the previous analysis (Carneiro et al., 2017). Therefore, there is no impact on the data quality change after the beginning of the Brazilian Observer Program. For these reasons, we suggest not splitting the present standardized catch rate time series as was done in the last assessment for the south Atlantic swordfish in 2017.

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Table 1. Deviance analysis table of positive catch rates (Lognormal) and proportion of positive sets (Binomial) models.

Lognormal model						
	Df	**Deviance**	**Resid. Df**	**Resid. Dev**	**F**	**Pr(>F)**
NULL			51446	2862.759		
yrqtr	105	387.8521	51341	2474.907	117.5083	$2.2*10^{-16}$
latlong	47	209.8291	51294	2265.077	142.0232	$2.2*10^{-16}$
ns(hbf 3)	2	294.7839	51292	1970.294	4688.84	$2.2*10^{-16}$
ns(hooks 10)	10	173.1441	51282	1797.149	550.807	$2.2*10^{-16}$
clust	3	185.2132	51279	1611.936	1964.004	$2.2*10^{-16}$
Binomial model						
	Df	**Deviance**	**Resid. Df**	**Resid. Dev**	**F**	**Pr(>F)**
NULL			65755	68894.29		
yrqtr	105	7073.815	65650	61820.48	67.36967	$2.2*10^{-16}$
latlong	47	2368.849	65603	59451.63	50.40104	$2.2*10^{-16}$
ns(hbf 3)	2	1515.309	65601	57936.32	757.6545	$2.2*10^{-16}$
ns(hooks 10)	10	1729.089	65591	56207.23	172.9089	$2.2*10^{-16}$
clust	3	3483.977	65588	52723.25	1161.326	$2.2*10^{-16}$

Table 2. Nominal and standardized index of relative abundance of swordfish caught by Brazilian pelagic longline fishery fleet between the years of 1994 to 2020.

Year	Std. CPUE	C.V.
1994	1.052	10.6%
1995	1.436	7.8%
1996	1.581	7.1%
1997	1.492	7.5%
1998	1.261	8.9%
1999	1.056	10.6%
2000	0.948	11.8%
2001	0.884	12.7%
2002	0.901	12.4%
2003	1.042	10.7%
2004	0.842	13.3%
2005	0.858	13.0%
2006	0.980	11.4%
2007	1.205	9.3%
2008	1.097	10.2%
2009	1.080	10.4%
2010	1.060	12.0%
2011	1.038	12.2%
2012	0.991	11.3%
2013	0.871	12.8%
2014	0.953	11.7%
2015	1.120	10.0%
2016	0.993	11.3%
2017	0.793	14.1%
2018	0.877	12.7%
2019	0.684	16.4%
2020	0.628	17.8%

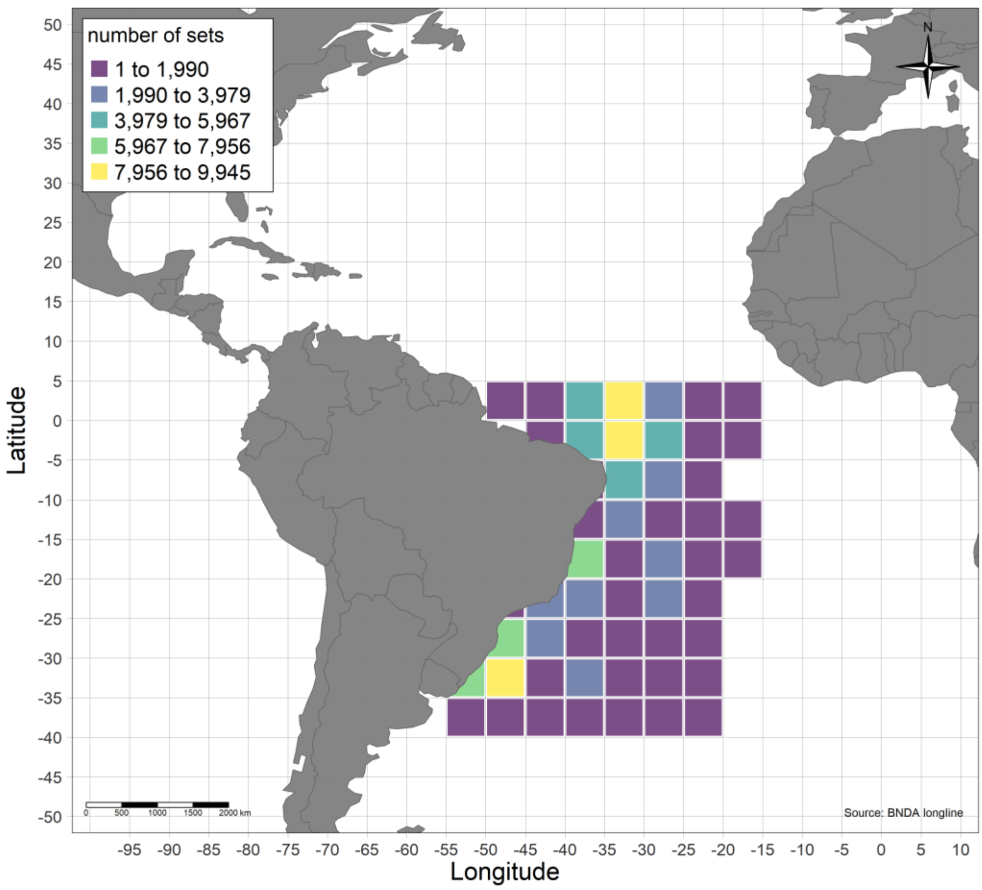

Figure 1. Spatial distribution of the total fishing effort (fishing sets) done by the Brazilian tuna longline fishery in the Atlantic Ocean from 1994 to 2020.

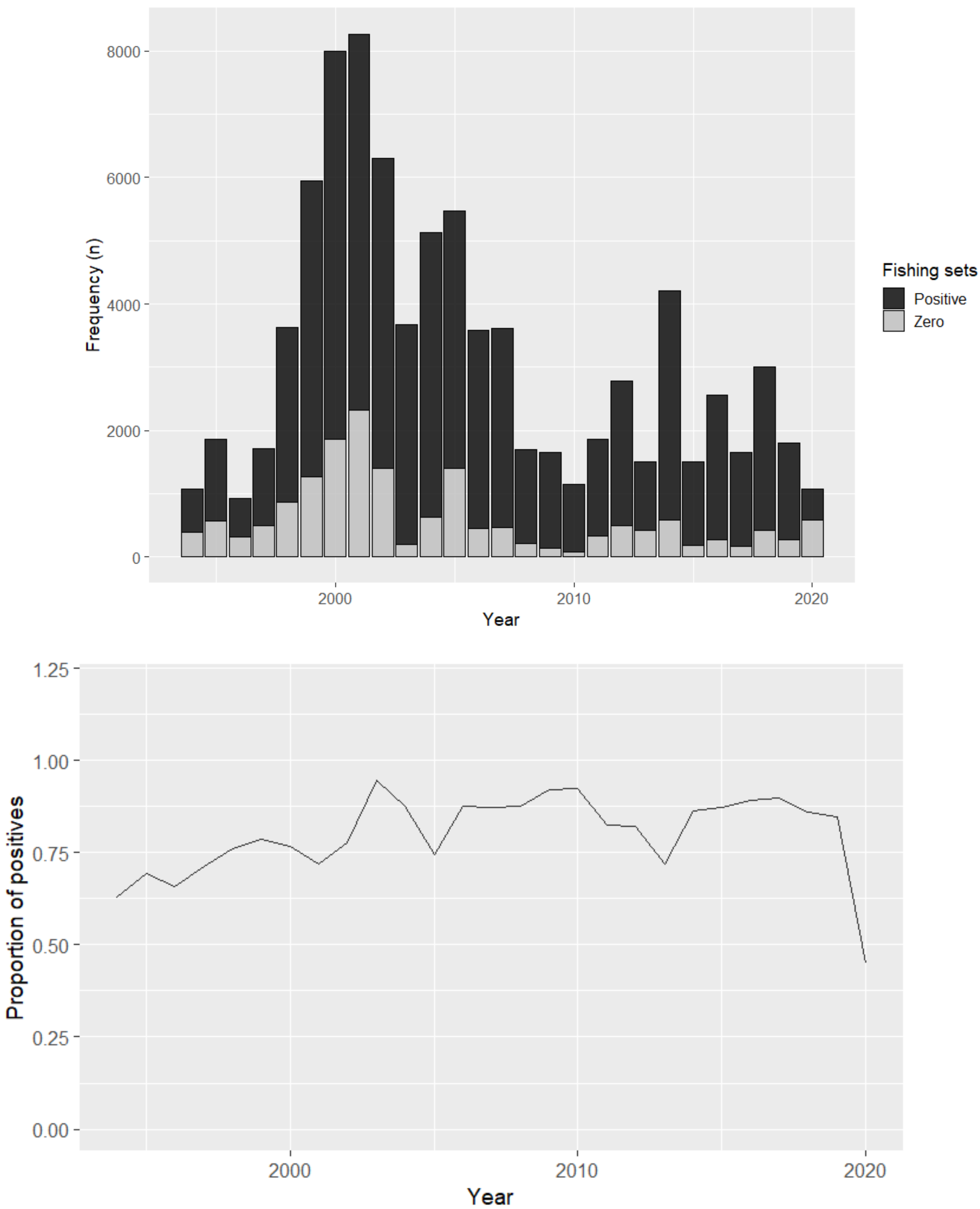

Figure 2. Number of sets and proportion of positive sets (with swordfish catch) of the Brazilian longline fleet from 1994 to 2020.

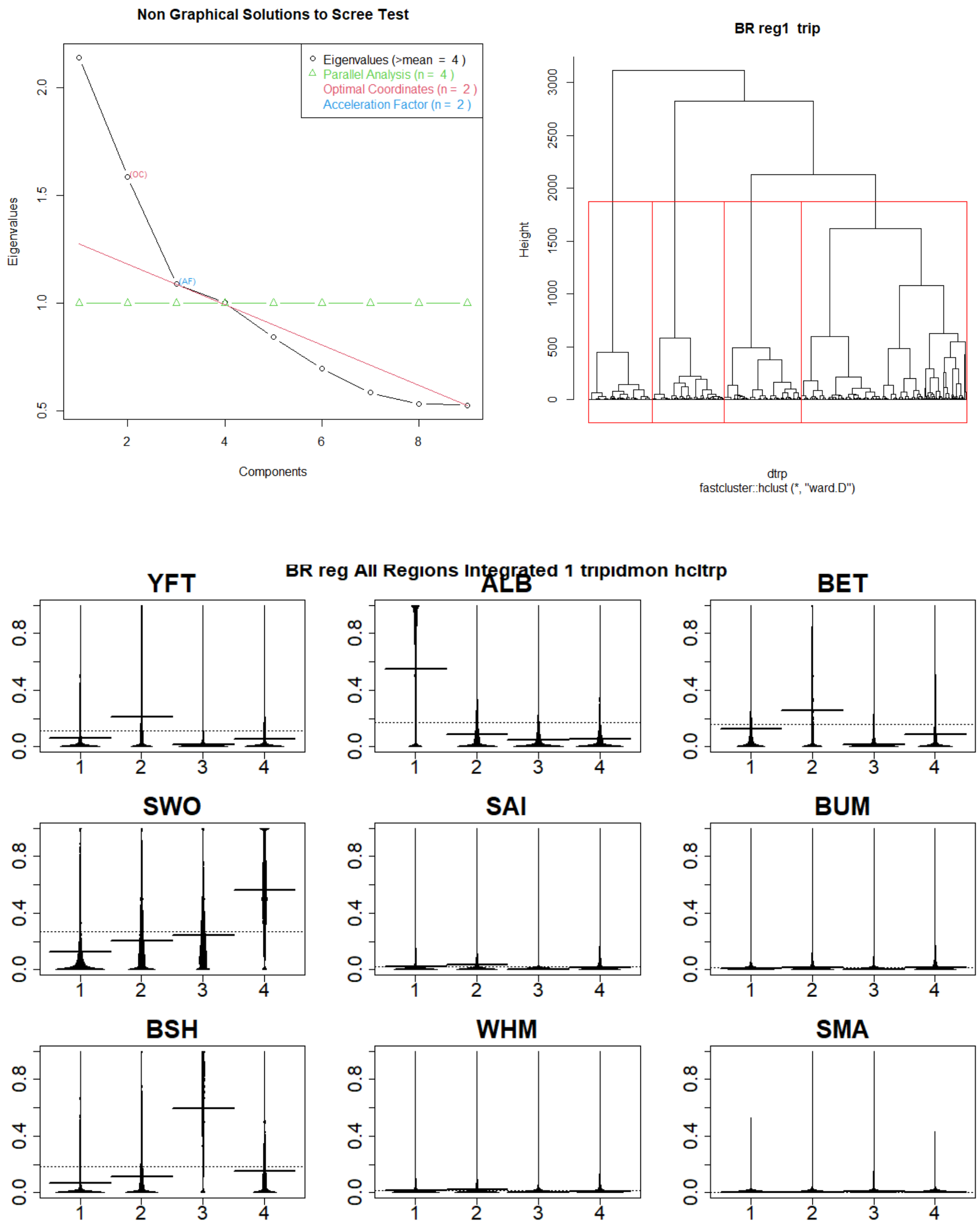

Figure 3. General diagram of the results obtained from cluster analysis. Top-left: results from the screen test applied to identify the number of groups in cluster analyses. Top-right: dendogram showing the results from cluster analyses. Bottom: contribution of each species for the groups formation.

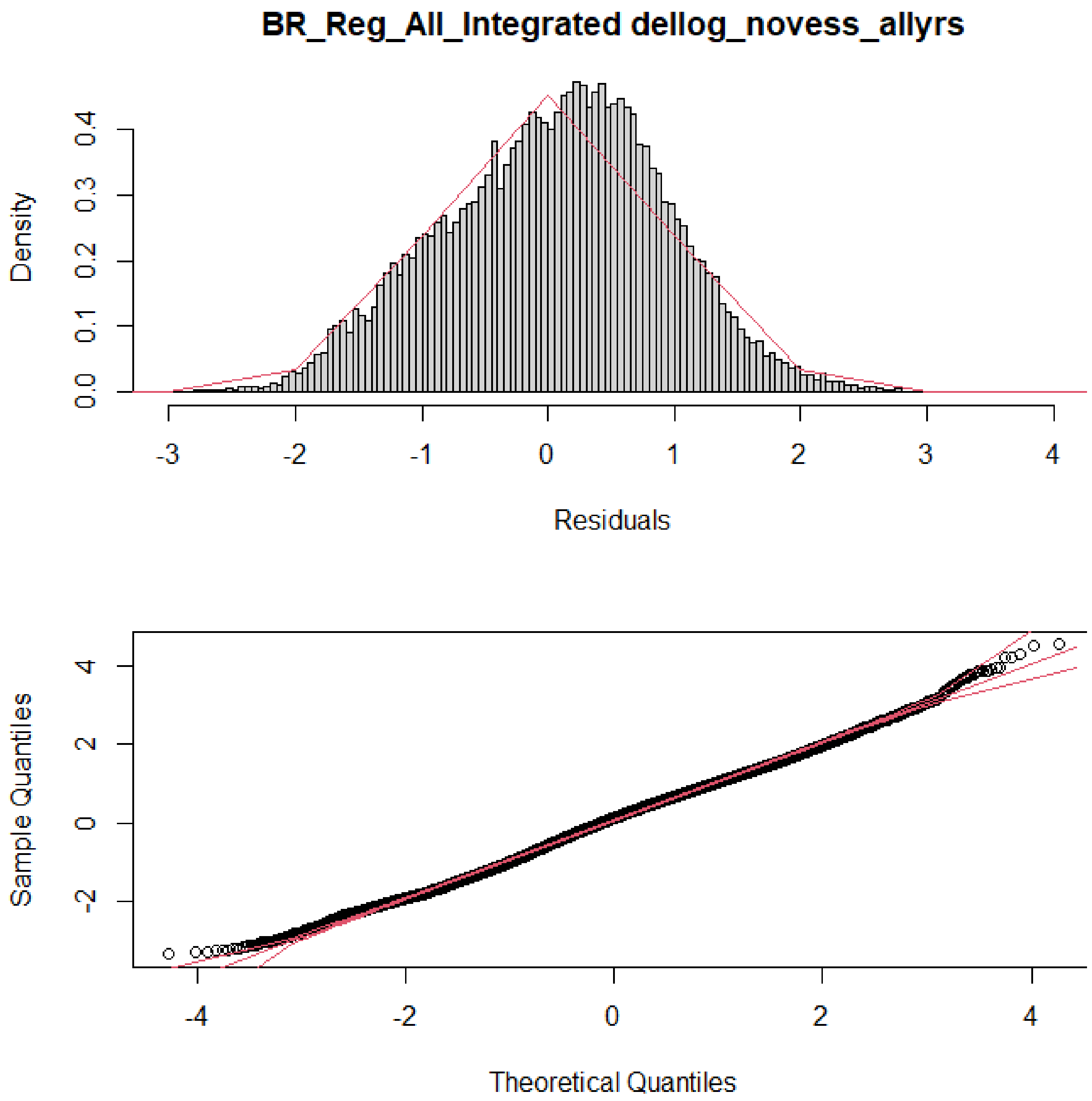

Figure 4. Diagnostics plots for the swordfish deltalog model - positive component.

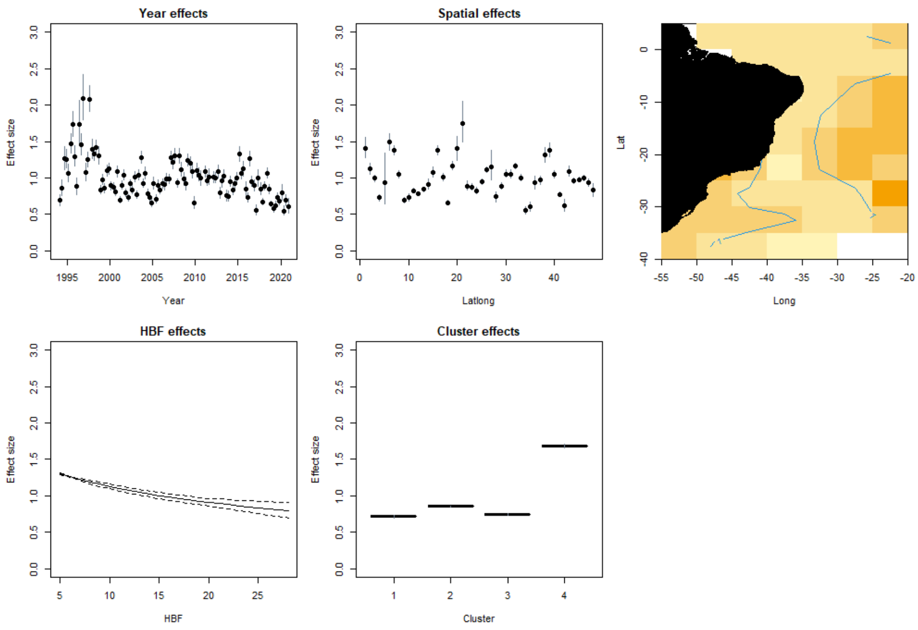

Figure 5. Covariate effects of the swordfish deltalog model - positive component

Figure 6. Catch rates of swordfish for Brazilian tuna longliners from 1994 to 2020. Black line represents the standardized catch rate and shaded area depicts the associated coefficient variation. White circles are the nominal catch rates.

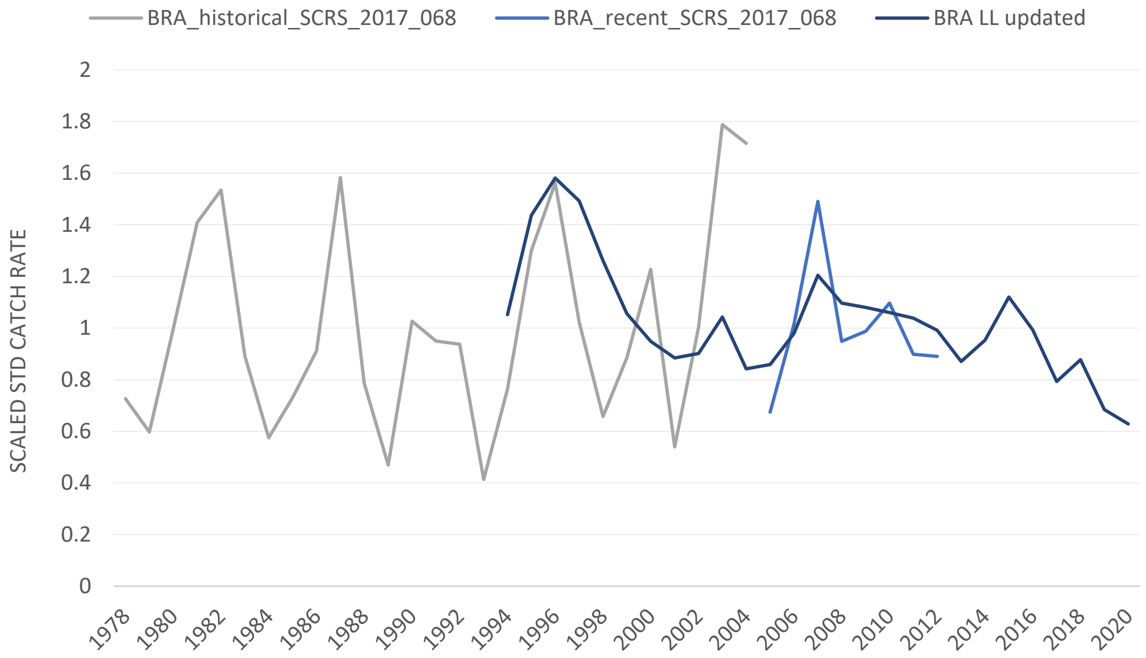

Figure 7. Comparison of updated (present study) and previous (Carneiro, et al., 2017) catch rates of swordfish for Brazilian tuna longliners from 1978 to 2020.