BAYESIAN GENERALIZED LINEAR MODELS FOR STANDARDIZATION OF SKIPJACK CATCH RATES BASED ON BRAZILIAN HANDLINE ASSOCIATED SCHOOL FISHING (2010-2020) IN THE WESTERN EQUATORIAL ATLANTIC

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SUMMARY

In the present analysis, port sampling and logbook records from the Brazilian handline tuna fishery in associated schools in the western tropical Atlantic, from 2010 to 2020, were used to generate a standardized CPUE series by a Bayesian generalized linear model using Integrated Nested Laplace Approximation (INLA) approach. The standardized catch rate series shows a stable trend until 2016, followed by a sharp increase in 2017 and a decline up to 2020. The apparent rise in catch rates in 2017 might be related to unaccounted factors that could potentially increase the catchability, such as the increase of landings due to the demand for this species in the Brazilian canning company. Also, it was observed the entrance of larger fishing boats with more fishing capacity in this fleet in 2017. These changes directly might influence catchability and, consequently, the estimation of the relative abundance of skipjack tuna caught by this fleet. Although the results might be speculative because the data seems to be not the ideal, they might be considered when discussing the assessment of the western Atlantic skipjack tuna.

RÉSUMÉ

Dans la présente analyse, l'échantillonnage au port et les registres des carnets de pêche de la pêcherie brésilienne thonière à la ligne à main sur bancs associés dans l'Atlantique tropical occidental, de 2010 à 2020, ont été utilisés pour générer une série de CPUE standardisées par un modèle linéaire généralisé bayésien, en utilisant l'approche d'approximation de Laplace intégrée et imbriquée (INLA). La série de taux de capture standardisés montre une tendance stable jusqu'en 2016, suivie d'une brusque augmentation en 2017 et d'une chute jusqu'en 2020. L'augmentation apparente des taux de capture en 2017 pourrait être liée à des facteurs non pris en compte qui pourraient potentiellement augmenter la capturabilité, comme l'augmentation des débarquements due à la demande de cette espèce dans la conserverie brésilienne. De même, on a observé l'entrée de bateaux de pêche plus grands et dotés d'une plus grande capacité de pêche dans cette flottille en 2017. Ces changements pourraient influencer directement la capturabilité et, par conséquent, l'estimation de l'abondance relative du listao capturé par cette flottille. Bien que les résultats puissent être spéculatifs car les données ne semblent pas idéales, ils peuvent être pris en compte lors de l'évaluation du listao de l'Atlantique Ouest.

RESUMEN

En el análisis, se utilizaron los registros de los muestreos en puerto y de los cuadernos de pesca de la pesquería brasileña de túnidos con línea de mano en bancos asociados en el Atlántico tropical occidental, desde 2010 hasta 2020, para generar una serie estandarizada de CPUE, mediante un modelo lineal generalizado bayesiano, utilizando el enfoque de aproximación anidada integrada de Laplace (INLA). La serie de tasas de captura estandarizadas muestra una brusca tendencia estable hasta 2016, seguida de un marcado aumento en 2017 y un descenso hasta 2020. El aparente aumento de las tasas de captura en 2017 podría estar relacionado con factores no contabilizados que tendrían el potencial de aumentar la capturabilidad, como el

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aumento de los desembarques debido a la demanda de esta especie en la empresa conservera brasileña. Asimismo, se observó la entrada de buques pesqueros más grandes y con mayor capacidad de pesca en esta flota en 2017. Estos cambios podrían influir directamente en la capturabilidad y, en consecuencia, en la estimación de la abundancia relativa de listado capturado por esta flota. Aunque los resultados pueden ser especulativos, ya que los datos no parecen ser los ideales, podrían tenerse en cuenta a la hora de debatir la evaluación del stock de listado del Atlántico occidental.

KEYSWORDS

Tunas, Catch and effort, CPUE, INLA

1. Introduction

The Brazilian tropical tuna fishery in associated schools in the western tropical Atlantic started in 2012 (Silva et al., 2019) and grew rapidly between 2011 and 2017, with total catches reaching 28,309 t in 2017. From 2018 onwards, total catches have been decreased gradually and followed a stable trend in recent years (2019-2020) with total landings around 18,000 t. Yellowfin tuna was always the main species caught representing around 60% of the total catches, followed by bigeye tuna (22%) and skipjack tuna (10%) from 2010 to 2020 (**Figure 1**). The decreasing trend of the total landings in recent years can be explained by the implementation of several rules established by the Brazilian Government, which create measures and criteria for fishing in associated schools and prohibit any new fishing licenses for any modality of fishing methods targeting tunas or tuna-like species. In the present document, a Bayesian generalized linear model was developed to standardize the skipjack catch rate time series caught by the handline tuna fishery in the associated school (2010-2020) in the western tropical Atlantic to contribute to the stock assessment of the skipjack tuna in 2022.

2. Material and Methods

The monitoring of tropical tuna handline fishery in associated schools in the western equatorial Atlantic started in 2010, comprising port sampling and logbook records. The data set included a total of 746 fishing trips, comprising 13803 days at sea, from 2010 to 2020. Records for each fishing trip had boat names, dates, and catch in kilograms by species. Records of fishing area (latitude and longitude) are not available for the entire time series (only after 2017) and were not used as a candidate explanatory variable in the modeling exercise. However, during the developing process of this fishery, the fishing ground was restricted along the tropical zone of the SJ08 ICCAT area. After 2017, this fishing fleet expanded its operations eastwards, including the tropical zone of the SJ03 (but always close to the west boundary) and SJ08 ICCAT areas. For this reason, catch and effort data inside of the SJ03 ICCAT area were removed from the present analysis. **Figure 2** depicts the fishing effort (days at sea) for the period 2018-2020.

We used Bayesian generalized linear models to investigate how skipjack tuna catch rates respond to the explanatory variables. The expected values of the response variable Y_i, calculated as catch/effort (kg/days at sea) is assumed to follow a lognormal probability distribution, with mean $\mu_i = E(Y_i)$, which is linked to the linear predictor η_i by a link function $g(\mu_i) = \log(\eta_i)$ for each monitored fishing trip i, according to the general formulation:

$$\boldsymbol{\eta_i} = \boldsymbol{\beta_0} + \sum_{m=1}^{M} \boldsymbol{\beta_{m_i}} \boldsymbol{X_{m_i}} + \sum_{k=1}^{K} \boldsymbol{f_k}(\boldsymbol{z_{ik}}) = 1, \ldots, n$$

where β_0 is the intercept, M denotes the total number of covariates, β_m is the vector of the coefficients which determine the effect of the covariates X_m on the response variable $E(Y_i)$; The terms $f_k(.)$ represent a random effect for each fishing boat, $z = (z_1, \ldots, z_k)$. Two main parametric covariates (*i.e.* factors) were considered. The factor "year" included data from 2010 to 2010 and "month", with two 12 levels. Bayesian inference and parameter estimates in the form of marginal posterior distributions were obtained throughout the Integrated Nested Laplace Approximation approach (INLA), which is currently implemented in the R environment by the R-INLA package (http://www.r-inla.org). As recommend by Held et al. (2010), we used default priors for all fixed-effect parameters, which were defined by a vague zero-mean Gaussian prior distribution with a variance of 100 (except for the variance of intercept which the default value is zero). The selection of predictors and the decision on their entry or exclusion was based on the forward stepwise approach using the Deviance Information Criterion (DIC) and

Watanabe-Akaike Information Criterion (WAIC) (Gelman et al., 2014). Finally, the residual distribution was checked to evaluate the goodness of best fit model following the methodology of standard graphical checks (Ortiz and Arocha, 2004).

3. Results and Discussion

Table 1 depicts the stepwise forward selection of covariates of the model. The full model, including all covariates, resulted in the lowest values of DIC and WAIC. Model residuals and predictive model diagnostics (Figure 3) suggested no evidence of major problems with heteroscedasticity of model residuals. Predicted versus observed values were positively and significantly correlated (correlation coefficient = 0.66; $p < 0.01$). However, some outliers were observed, suggesting that some observed values are much higher (or lesser) than the model would predict. **Table 2** shows the statistics of marginal posterior distributions for the hyperparameters of the model.

The standardized catch rate series shows a stable trend until 2016, followed by a sharp increase in 2017 and a decline up to 2020 (**Table 3** and **Figure 4**). The skipjack tuna catches showed a similar trend with a peak of 5,293 t in 2017, followed by a decline and remaining around 2,200 t in the last two years (2019 and 2020). The apparent rise in catch rates in 2017 might be related to unaccounted factors (i.e., explanatory variables) that could potentially increase the catchability, such as the increase of landings due to the demand for this species in the Brazilian canning company. In fact, results also show that the importance of skipjack tuna in this fishery has been growing progressively over time since the skipjack proportion in the total catches has increased from 2017 on (**Figure 1**). Also, in 2017, it was observed the entrance of larger fishing boats with more fishing capacity in this fleet. These changes directly might influence catchability and, consequently, the estimation of the relative abundance of skipjack tuna caught by this fleet. Although the results might be speculative because the data seems to be not the ideal, they might be considered when discussing the assessment of the western Atlantic skipjack tuna.

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Table 1. Stepwise selection of covariates used in the of the Bayesian generalized linear model for skipjack tuna catch rates from handline fishery in associated schools in the western equatorial Atlantic (2010-2020).

Model	**Deviance**	**WAIC**	**DIC**
log.cpue ~ null	2782	2784	2784
log.cpue ~ Year	2537	2551	2549
log.cpue ~ Year+Month	2541	2566	2564
log.cpue ~ Year+Month + f(boat,'iid')	2292	2402	2394

Table 2. Marginal posteriors distributions for the precisions of the covariates of the Bayesian generalized linear model for skipjack tuna catch rates from handline fishery in associated schools in the western equatorial Atlantic (2010-2020).

Parameters	**mean**	**SD**	**2.5th percentile**	**50th percentile**	**97.5th percentile**
Precision for the Gaussian observations	1.387	0.081	1.233	1.386	1.552
Precision for boat	4.116	1.033	2.493	3.977	6.531

Table 3. Standardized index of relative abundance of the Bayesian generalized linear model for skipjack tuna catch rates from handline fishery in associated schools in the western equatorial Atlantic (2010-2020). Statistics are based on the marginal posterior distributions for year coefficients.

Year	**Index**	**2.5th percentile**	**97.5th percentile**
2010	0.159	0.054	0.299
2011	0.422	0.293	0.593
2012	0.355	0.233	0.515
2013	0.556	0.359	0.833
2014	1.270	0.758	2.042
2015	0.804	0.598	1.063
2016	0.568	0.401	0.773
2017	2.707	2.047	3.636
2018	1.861	1.449	2.393
2019	1.380	1.078	1.748
2020	0.918	0.649	1.273

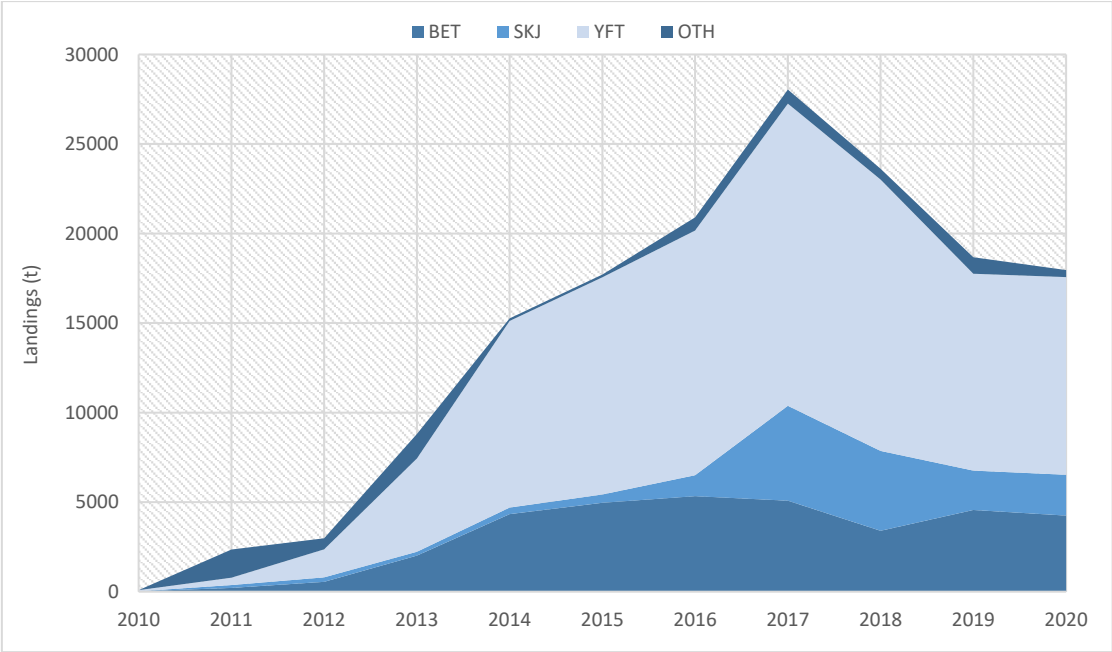

Figure 1. Landings (t) of tropical tuna's species caught by the Brazilian handline fishery in associated schools in the western equatorial Atlantic (2018-2020).

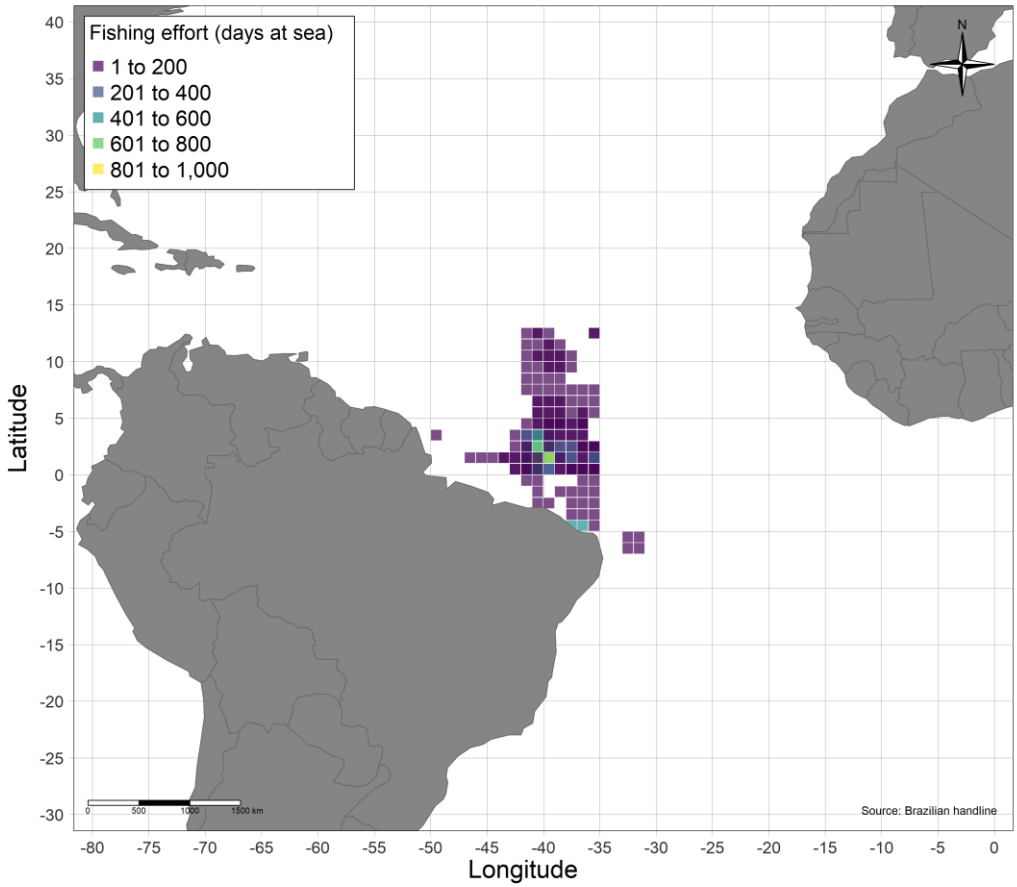

Figure 2. Distribution of fishing effort (days at sea) of the Brazilian handline fishery in associated schools in the western equatorial Atlantic (2018-2020).

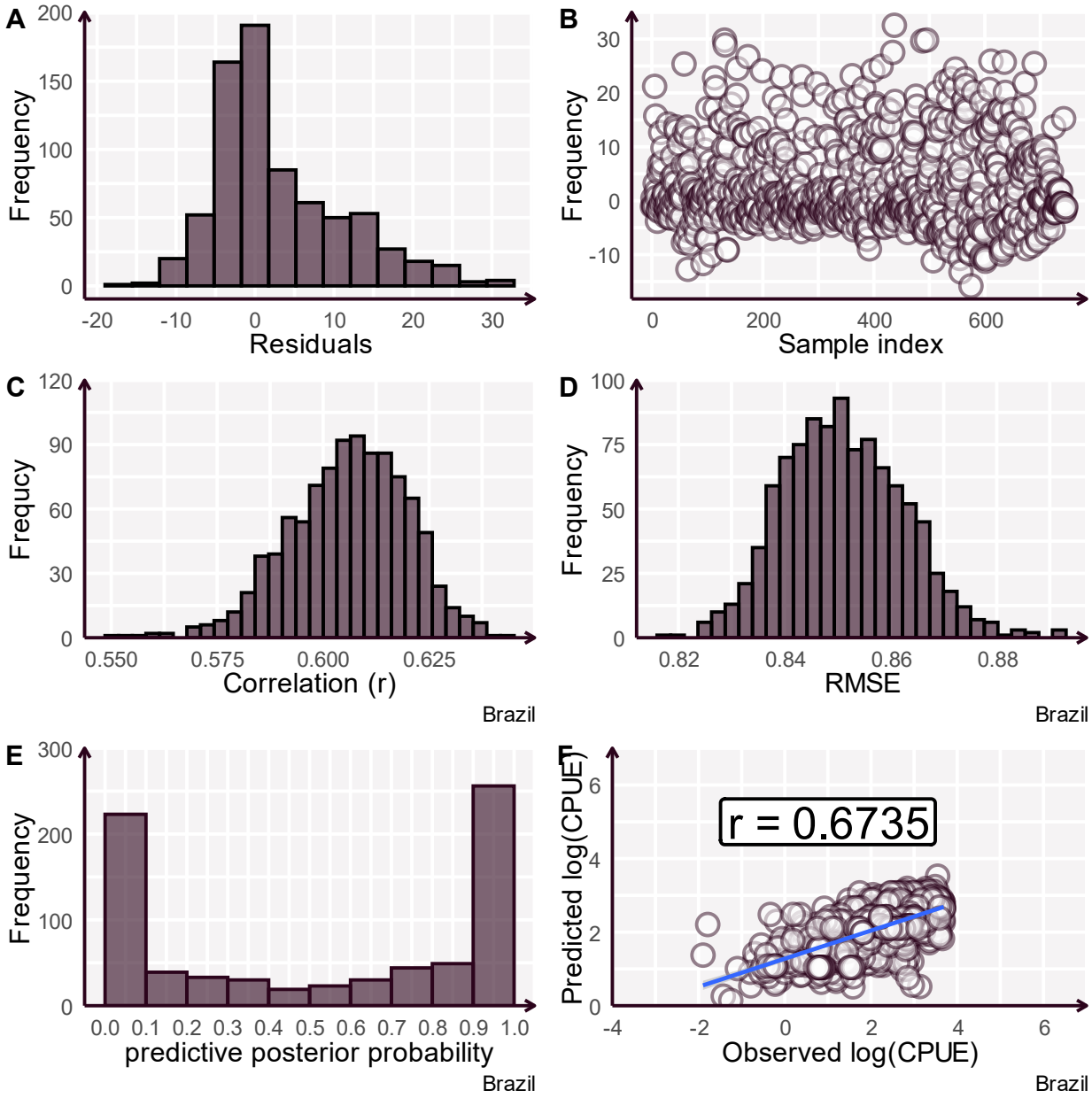

Figure 3. Residual analysis and predictive model diagnostics of the Bayesian generalized linear model for skipjack tuna catch rates from handline fishery in associated schools in the western equatorial Atlantic (2010-2020).

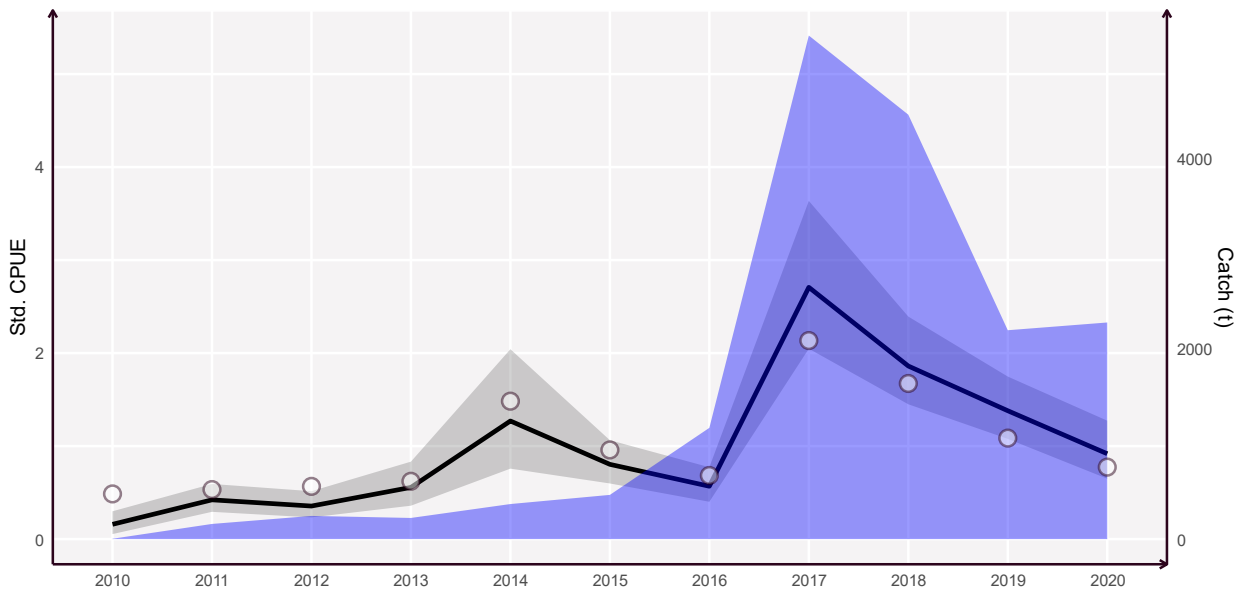

Figure 4. Yearly standardized catch rates (black line) with shaded grey area representing the 2.5th and 97.5th percentiles of the marginal posterior distributions of each year. Secondary axis expresses skipjack landings (t) caught by Brazilian handline fishery in associated schools in the western equatorial Atlantic (2010-2020)