Collect. Vol. Sci. Pap. ICCAT, 80(8): 236-243 (2023)

ESTIMATED ATLANTIC SAILFISH CATCH RATE FOR THE BRAZILIAN BILLFISH SPORT FISHING TOURNAMENTS (2001-2020)

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SUMMARY

In the present study, a generalized linear model (GLM), assuming a Tweedie distribution, was used to generate a standardized CPUE series for sailfish caught by sport fishing boats based in São Paulo, Rio de Janeiro, Espirito Santo and Bahia States, from 2001 to 2020. The response variable was the number of sailfish caught per number of boats registered in the tournament per day. The following factors were tested in the analyses: "year", "target", and "local", representing the main effects of the explanatory variables. The target species was estimated by a cluster analysis, based on the proportion of each species or group of species in relation to the total catch, using the "K Means" method. The standardized catch rate's general pattern shows a trend of reduction from 2000 to 2012, followed by a trend of relative stability in more recent years up to 2020. Our estimates could be taken to accurately reflect the stock's local relative abundance and might be applied to assessment models.

RÉSUMÉ

Dans la présente étude, un modèle linéaire généralisé (GLM), supposant une distribution de Tweedie, a été utilisé pour générer une série standardisée de CPUE pour les voiliers capturés par les bateaux de pêche sportive basés dans les États de São Paulo, Rio de Janeiro, Espirito Santo et Bahia, de 2001 à 2020. La variable de réponse était le nombre de voiliers capturés par nombre de bateaux inscrits au tournoi par jour. Les facteurs suivants ont été testés dans les analyses : "année", "cible" et "local", représentant les effets principaux des variables explicatives. L'espèce cible a été estimée par une analyse par grappes, basée sur la proportion de chaque espèce ou groupe d'espèces par rapport à la capture totale, en utilisant la méthode «K Means». Le schéma général du taux de capture standardisé montre une tendance à la réduction entre 2000 et 2012, suivie d'une tendance à la stabilité relative au cours des années les plus récentes jusqu'en 2020. Nos estimations pourraient être considérées comme reflétant avec précision l'abondance relative locale du stock et pourraient être appliquées aux modèles d'évaluation.

RESUMEN

En el presente estudio, se utilizó un modelo lineal generalizado (GLM), asumiendo una distribución de Tweedie, para generar una serie estandarizada de CPUE de pez vela capturado por embarcaciones de pesca deportiva con base en los Estados de São Paulo, Río de Janeiro, Espírito Santo y Bahía, desde 2001 hasta 2020. La variable de respuesta fue el número de peces vela capturados por número de embarcaciones inscritas en el torneo por día. En los análisis se probaron los siguientes factores: "año", "objetivo" y "local", que representan los efectos principales de las variables explicativas. La especie objetivo se estimó mediante un análisis de conglomerados, basado en la proporción de cada especie o grupo de especies en relación con la captura total, utilizando el método de "Kmeans". El patrón general de la tasa de captura estandarizada muestra una tendencia a la reducción de 2000 a 2012, seguida de una tendencia de relativa estabilidad en los años más recientes hasta 2020. Podría considerarse que nuestras estimaciones reflejan con exactitud la abundancia relativa local del stock y podrían aplicarse a los modelos de evaluación.

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Introduction

Billfish sport fishing tournaments were first held in Brazil in 1963/64 at the yacht club do Rio de Janeiro (Arfelli *et al*., 1994). This activity has been pushed mostly in the Brazilian states of São Paulo, Rio de Janeiro, Espirito Santo, Bahia, Rio Grande do Norte, and Fernando de Noronha since then. The fishing season on the southeast Brazilian coast runs from October to February (spring/summer), with blue marlin (*Makaira nigricans*), sailfish (*Istiophorus platypterus*), and white marlin (*Kaijika albida*) being the most popular species (Arfelli *et al*., 1994).

Changes in fishing grounds and target species have been well-documented in the Brazilian sport fishing tournaments and have a direct impact on the catch composition (Arfelli *et al.,* 1994; Amorim and Arfelli, 2001; Amorim and Silva, 2005; Mourato *et al*., 2009; Mourato *et al.,* 2016; Mourato *et al*., 2018, Mourato *et al*., 2019). As a result, it is difficult to utilize the nominal catch rates from this fishery as a measure of relative abundance without risking misinterpretation. In order to update the CPUE series of Mourato *et al.* (2016), a standardized catch rate series of Atlantic sailfish obtained by sport fishing tournaments in southern Brazil (2001-2020) is presented to contribute to the assessment of the western Atlantic stock.

Material and methods

Radio logbook records from recreational tournaments of Yacht Clubs from São Paulo, Rio de Janeiro, Espírito Santo and Bahia States have been collected since 1996 by voluntary submission of the tournament organizers and by onboard observers. However, after an exploratory analysis, the final data set included a total of 326 tournament days, from 2001 to 2020. Records for each tournament day included boat names, total number of operating boats per tournament day, total number of fish hooked, and their fate (i.e. lost, released, tagged and released, or boarded), by species, as well as the size and weight of all boarded fish.

Due to the high percentage of zeros in the catch data (~50% of the tournament days with no sailfish catches; **Table 1**), the empirical distribution of sailfish catch data was still too zero-inflated and overdispersed to fit a traditional generalized linear model (GLM) with Poisson distribution. Also, in the exploratory analysis, we tested the negative binomial distribution (not shown here), however, this model was still over dispersed and seemed to not accommodate the data well. For this reason, we opted to fit a GLM using the Tweedie distribution. The family Tweedie is derived from a broader class of probabilistic models, called models of dispersion. Because the Tweedie model is expressed as the Poisson distribution, if the power-parameter (*p*) of the probability density function is between 1 and 2, then it seems to be appropriate for the analysis (Shono, 2008). Hence, the expected values of the response variable Y_i is assumed to follow a probability distribution of Tweedie, with mean $\mu_i = E(Y_i)$, which is linked to the linear predictor η_i by a link function $g(\mu_i) = \eta_i$ for each tournament day monitored *i*, according to the general formulation:

$$\boldsymbol{\eta_i = \beta_0 + \sum_{m=1}^{M} \beta m X m_i + offset}[\boldsymbol{log(fishing\ effort_i)}];\ i = 1, ..., n$$

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 $E(Y_i)$, while the term *offset* is utilized to account for variations in the fishing effort (defined as the total number of operating boats per tournament day), which is appropriate when the response variable is a discrete variable (i.e. sailfish counts) (e.g. Mourato *et al*., 2014). In the present study, the power parameter was calculated by maximum likelihood estimation, using functions available in library Tweedie (Dunn, 2011) in R (R Development Core Team, 2021). The best value of *p* was 1.57, assuming a Gamma-Poisson distribution.

Three main parametric covariates (i.e. factors) were considered. The factor "year" included data from 2001 to 2020, while "local" accounted for the tournaments carried out off São Paulo, Rio de Janeiro, Espírito Santo and Bahia; and in order to account for different targeting strategies and species, we also calculated the factor "target" by using a cluster analysis. Clusters were calculated based on proportion of each species or group of species in relation to the total catch, using the *"K Means"* method. Each cluster (or tournament day) can be considered a target strategy (Mourato *et al.,* 2011; Mourato *et al*., 2018; Mourato *et al.,* 2019). The selection of predictors or interactions and the decision on their entry or exclusion was based on Akaike Information Criterion (AIC) and on the proportion of the total deviance explained. Chi-square tests were also computed to determine whether terms yielded significant ($p < 0.05$) reductions in the residual deviance upon entry into the GLM. Finally, the residual distribution was checked to evaluate the goodness of fit model following the methodology of Dunn and

Smyth (1996). The final standardized CPUEs were estimated by least square means (LSMeans) for the effects of year averaged over the effects of the other variables.

Results and discussion

The cluster analysis resulted in the 326 tournament days being divided into three distinct groups (**Table 2**). Clusters 1 and 2 strongly separated tournament days aimed at white marlin and blue marlin (84% and 86%, respectively). Cluster 3 was distinguished by the grouping of tournament days targeting sailfish (60%), but also by a significant proportion of "other fishes" (32%), which is defined by a multi-species targeting approach and includes tunas, wahoos, and primarily dolphin fish (**Table 2**).

Table 3 shows the deviance analysis of the selected model. All factors were significant; however, no interactions were included in the final model. The proportion of the deviance explained by the model is about 46 %. The factor “target” explained the largest amount of variation, followed by “year” and “local”. Estimations of the coefficients are depicted in **Figure 1**. In terms of area, the fishery seems to have higher catch rates for sailfish in front of Bahia and São Paulo states, while lower catch rates are expected in Rio de Janeiro and Espirito Santo. Fishing target strategy clearly is an oversimplification of the many factors that certainly cannot be incorporated in the model; however, the high importance of the factor “target” suggests that might exist an important and variable fluctuation in the temporal distribution of the fishing strategy, from one year to the other. Coefficients of target 3 clearly show higher catch rates in comparison to the target 1 and 2 (**Figure 1)**. The diagnostic plots revealed that the model residuals are homoscedastic and approximately normally distributed (**Figure 2**). The differences between the residual and standard normal distributions are minor and mainly visible in the tails. As a result, both the Tweedie error distribution and the link function appear to fit the data well.

Table 4 shows the standardized catch rates and the estimation's coefficient of variation. The standardized catch rate's general pattern shows a trend of reduction from 2000 to 2012, followed by a trend of relative stability in more recent years up through 2020 (**Figure 3**). The model appears to fit the observed data effectively, according to the model diagnostics (**Figure 2**), 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. Proportion of zeros (no sailfish catch) by year of the Brazilian sport fishing tournaments (12001-2020).

Year	*Proportion of zeros*
2001	77%
2002	63%
2003	39%
2004	50%
2005	60%
2006	25%
2007	0%
2008	50%
2009	50%
2010	42%
2011	77%
2012	57%
2013	32%
2014	54%
2015	50%
2016	57%
2017	50%
2018	40%
2019	69%
2020	64%

Table 2. Number of tournament days (n), proportion of total catch for each species/group by target species from Brazilian sport fishing tournaments (2001-2020). Values in bold represent the species or group predominant in each cluster.

Target	*n*	*sailfish*	*white marlin*	*blue marlin*	*others*
1	52	2%	**84%**	5%	9%
2	130	6%	7%	**86%**	1%
3	144	**60%**	6%	3%	32%

Table 3. Deviance analysis of the fitted model for the standardization of sailfish catch rate caught by the Brazilian sport fishery in the Atlantic Ocean from 2001 to 2020.

Model	*Df*	*Deviance*	*Resid. Df*	*Resid. Dev*	*Pr(>Chi)*	*Explained Deviance*
NULL			325	2887.1		
year	19	440.8	306	2446.3	0.000164433	15%
year + target	2	800.5	304	1645.8	3.52E-20	43%
year + target + local	3	96.0	301	1549.8	0.013180431	46%

Table 4. Standardized CPUE of sailfish of sailfish catch rate caught by the Brazilian sport fishery in the Atlantic Ocean from 2001 to 2023.

Year	*Standardized index*	*C.V.*
2001	1.35	50%
2002	1.48	21%
2003	2.14	13%
2004	1.29	22%
2005	1.42	23%
2006	1.86	16%
2007	1.16	26%
2008	1.61	22%
2009	0.56	68%
2010	0.35	22%
2011	0.24	38%
2012	0.21	54%
2013	1.12	16%
2014	0.45	27%
2015	0.83	26%
2016	1.09	17%
2017	0.74	25%
2018	1.53	12%
2019	0.20	48%
2020	0.38	28%

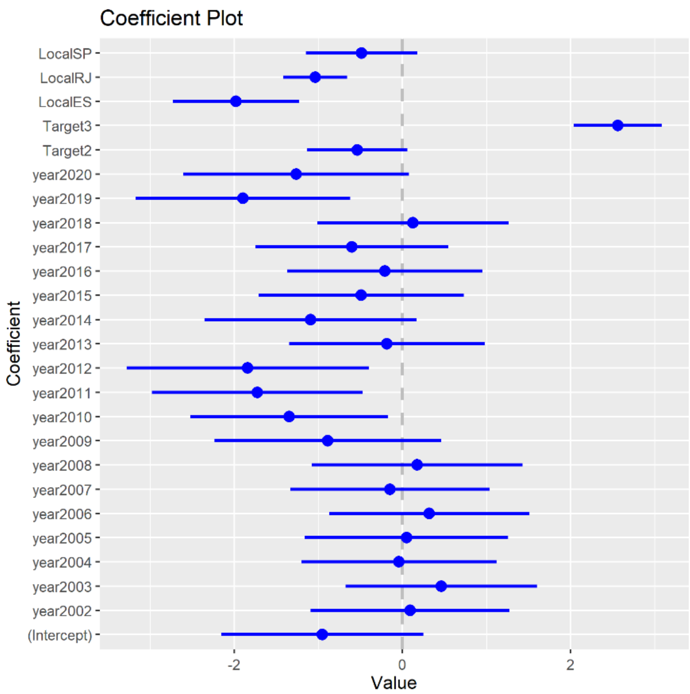

Figure 1. Estimations of coefficients and standard errors of the fitted model for the standardization of sailfish catch rate caught by the Brazilian sport fishery.

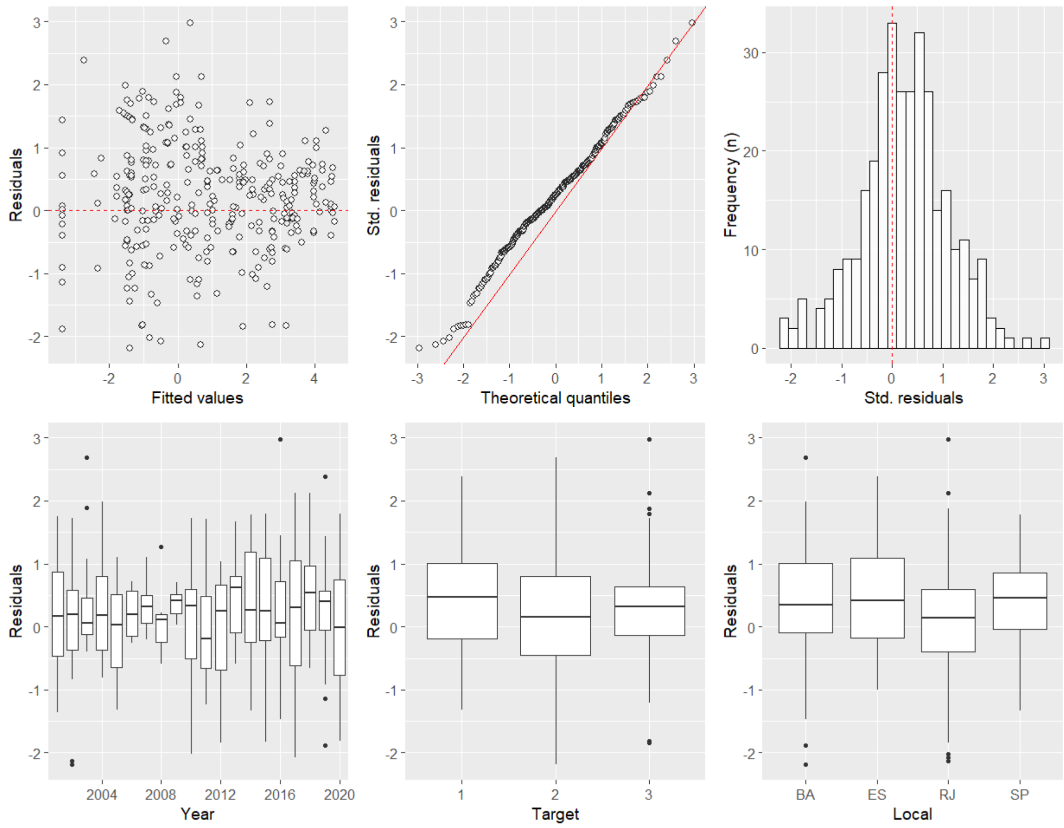

Figure 2. Diagnostics plots of the fitted model for the standardization of sailfish caught by the Brazilian sport fishery in Atlantic Ocean (2001-2020).

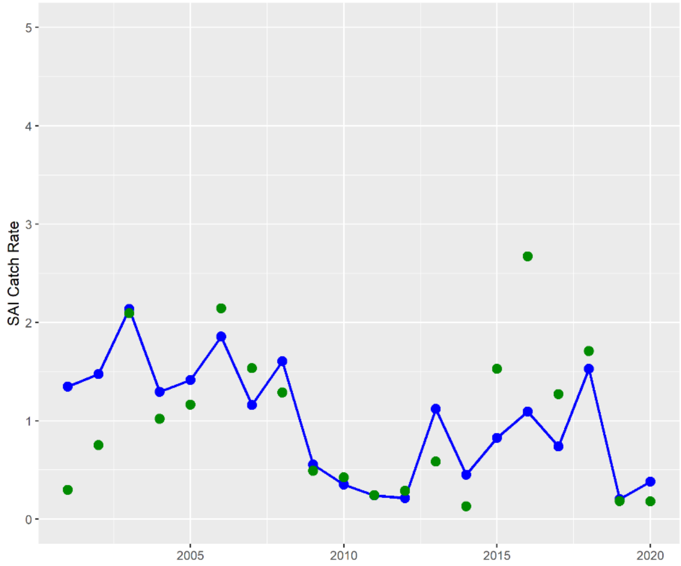

Figure 3. Standardized CPUE of sailfish caught by the Brazilian sport fishery in Atlantic Ocean, from 2001 to 2020. Green points represent the nominal CPUE.