ASSESSING ATLANTIC SAILFISH CATCH RATES BASED ON BRAZILIAN SPORT FISHING TOURNAMENTS (1996-2014)

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ABSTRACT

In the present study, a generalized linear model (GLM), assuming a Tweedie distribution and log as link function, was used to generate a standardized catch per unit effort (CPUE) series for the sailfish caught by sport fishing boats based in São Paulo, Rio de Janeiro, Espírito Santo and Bahia States, from 1996 to 2014. 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", "month", and "local", representing the main effects of the explanatory variables. The overall pattern of the standardized catch rate indicates a relatively stable trend with a slight decline in the recent years, from 2009 to 2014.

Key-words: catch per unit effort (CPUE); billfishes; generalized linear model; tweedie distribution

AVALIAÇÃO DAS TAXAS DE CAPTURA DO AGULHÃO-VELA BASEADO NOS TORNEIOS DE PESCA ESPORTIVA BRASILEIRA (1996-2014)

RESUMO

No presente trabalho, um modelo linear generalizado (GLM) assumindo a distribuição de tweedie e função link log, foi utilizado para gerar uma série de captura por unidade de esforço (CPUE) para o agulhão-vela capturado pela pesca esportiva baseada nos estados de São Paulo, Rio de Janeiro, Espirito Santo e Bahia de 1996 a 2014. A variável resposta foi o número de agulhões-vela capturados pelo número de embarcações registradas por dia de torneio. Os seguintes fatores foram testados: "ano", "mês", e "local", representando as principais variáveis explicativas do modelo. O padrão geral da série de CPUE padronizada indica uma tendência relativamente estável com um leve declínio nos anos recentes entre 2009 e 2014.

Palavras-chave: captura por unidade de esforço (CPUE); peixes de bico; modelo linear generalizado; e distribuição de tweedie.

Artigo Científico: Recebido em 20/12/2015 – Aprovado em 17/08/2016

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Doi 10.20950/1678-2305.2016v42n3p625

INTRODUCTION

In Brazil, billfish sport fishing tournaments began in 1963/64 at the *Iate Clube do Rio de Janeiro* (ARFELLI *et al.*, 1994). Since then, this activity has been promoted mainly in the Brazilian States of São Paulo, Rio de Janeiro, Espírito Santo, Bahia, Rio Grande do Norte and Fernando de Noronha. In the southeast Brazilian coast fishing season happens mainly from October to February (spring/summer), with blue marlin, *Makaira nigricans* Lacepède, 1802, sailfish, *Istiophorus platypterus* (Shaw, 1792) and white marlin, *Kajikia albida* (Poey, 1860) being the main targeted species (ARFELLI *et al.,* 1994).

Catch and effort data from sport fisheries are an important source of information on trends of fish stocks. Time series of catch rate have been frequently used in stock assessments for large pelagic fishes, as an index of relative abundance. Such application, however, has been widely debated (MAUNDER and PUNT, 2004), since trends in catch rate can be influenced by many factors in addition to stock abundance, including the fishing season, spatial variability of the fish stock, target species as response to changes in fishing gear, environmental conditions and fishermen's experience. Such variations may lead to significant changes in catchability, introducing serious errors in the estimation of abundance indices (FRÉON and MISUND, 1999). To overcome this problem, the most common approach has been to standardize the catch rate, in order to remove the effects of other factors unrelated to stock abundance (MAUNDER and PUNT, 2004). This approach has been used widely in fisheries science, having become a crucial step for accurate stock assessments (GULLAND, 1983; MAUNDER and PUNT, 2004).

In the Brazilian sport fishery, a number of changes in fishing grounds and target species, among others, which directly affect the catch composition, have been well documented (ARFELLI *et al.,* 1994; AMORIM and ARFELLI, 2001; AMORIM and SILVA, 2005; MOURATO *et al.,* 2009a). Thus, the use of nominal catch rates derived from this fishery as an index of relative abundance can lead to interpretation errors, making its utilization rather complex. Hence, in the present document a nominal catch rate series of sailfish caught by the sport fishing in the southern Brazil (1996-2014) is presented with the corresponding standardized values (1996-2014), and represents an update of the CPUE series of MOURATO *et al.* (2009a).

MATERIAL AND METHODS

Catch and effort data

Radio logbook records from recreational tournaments of Yacht Clubs from São Paulo, Rio de Janeiro, Espírito Santo and Bahia have been collected since 1996 by voluntary submission of the tournament organizers and by onboard observers. The data set included a total of 281 tournament days, from 1996 to 2014 (Table 1). 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.

Modeling

The number of sailfish caught per number of boats recorded in the tournament per day (C) was considered as a relative index of abundance. The logarithm was used as a link function, in the following GLM model:

$y \equiv \log(C)$

$\mu \sim$ year + local+ month + interactions + ε

where the terms "year", "local" and "month" represent the main effects of the explanatory variables, while "interactions" stands for the first order interaction between all main effects and ε is an independent identically distributed (i.i.d) random variable with a tweedie distribution. Despite the relatively low zero-count (~35%, Figure 1), the empirical distribution of C data was still too zero-inflated and overdispersed to fit a traditional

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 the model using 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). 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, 2014). The best value of p was 1.54 (Figure 2), assuming a Gamma-Poisson distribution.

The factor "year" included data from 1996 to 2014, while "month" included only data from October to April, since there is no tournament out of this period. The factor "local" accounted for the tournaments carried out off São Paulo, Rio de Janeiro, Espírito Santo and Bahia coasts. The selection of predictors or interactions and the decision on their entry or exclusion was based on Akaike Information Criterion (AIC) (AKAIKE, 1978) and 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 in order to evaluate the goodness of fitted 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.

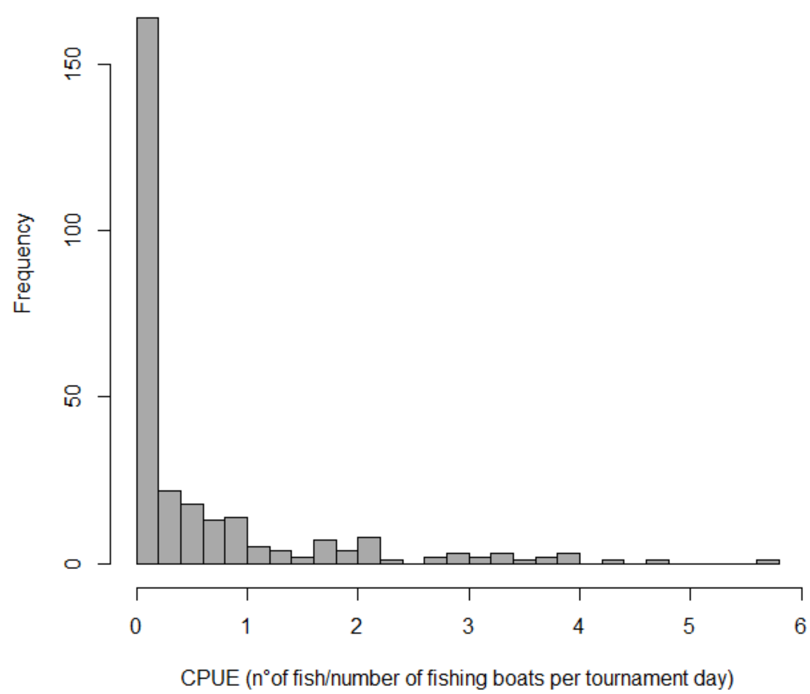

Figure 1. Sailfish catch per number of boats registered per tournament day for the Brazilian sport fishery in the Atlantic Ocean from 1996 to 2004.

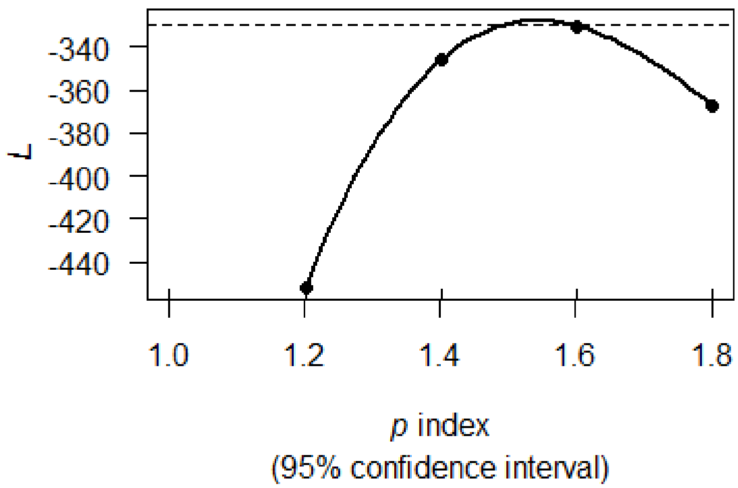

Figure 2. Value of log-likelihood function (L) changing the power-parameter (p) in the tweedie model for CPUE standardization of sailfish caught by the Brazilian sport fishery in the Atlantic Ocean from 1996 to 2014

Table 1. Number of sailfish caught (SC) and monitored tournament days (MTD) by year and location based on Brazilian sport fishery in the Atlantic Ocean from 1996 to 2014.

	Bahia		*Espírito Santo*		*Rio de Janeiro*		*São Paulo*	
Year	SC	MTD	SC	MTD	SC	MTD	SC	MTD
1996							54	7
1997	29	3					38	9
1998	11	5					16	6
1999	3	2					24	7
2000	42	11					98	10
2001	4	11			0	2	54	11
2002	5	8			278	7	51	8
2003	37	7			441	13	37	5
2004	5	6			341	14	11	4
2005					256	7		
2006					463	8		
2007					384	10		
2008					251	6		
2009			3	6	3	6		
2010					200	17	7	3
2011					78	12	0	1
2012					15	4	16	3
2013	10	6	0	5	200	14	32	6
2014					1	4	13	7
Total,n	146	59	3	11	2911	124	451	87

RESULTS

Table 2 shows the deviance analysis of the selected model. All factors were significant, however, no interactions were included in the final model. The factor "year" explained the largest amount of variation, followed by "month" and "local". The proportion of the deviance explained by the model is about 34 %. Estimations of the coefficients are in Table 3. Most of coefficients for the factor "year" were positive, however, the great majority of these coefficients were not significant though most of standard errors were bigger than the estimated coefficients. All estimations for "month" were negative (except December) and most of them were significant. December and January were the most productive period for fishing sailfish. In addition, higher catch rates were observed when the tournaments were carried out in São Paulo and Rio de Janeiro. The diagnostic plots revealed that the model residuals are homoscedastic and approximately normally distributed (Figure 3). Discrepancies between residual and standard normal distributions are small and appear only in the tails. Therefore, both the tweedie error distribution and link functions seem to conform well to the data.

The standardized catch rates and standard error of estimations are depicted in Figure 4 and Table 4. The overall pattern of the standardized catch rate indicates a relatively stable trend with a slightly decline in recent years, from 2009 to 2014. The nominal catch rate, in turn, showed a different trend, with an apparent increase in values after 2002, with pronounced peaks from 2005 to 2008 (Figure 4).

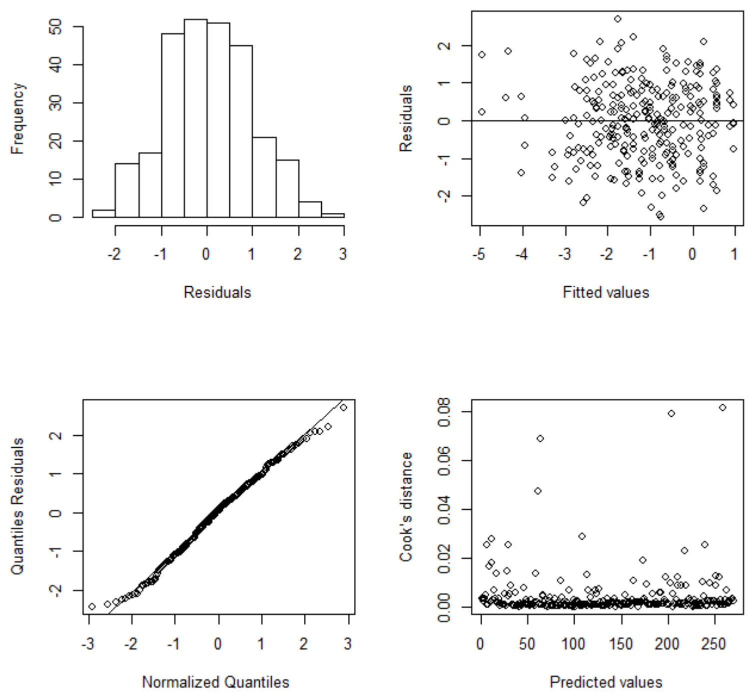

Figure 3. Diagnostics plots of the fitted model for the standardization of sailfish CPUE caught by the Brazilian sport fishery in Atlantic Ocean (1996-2014).

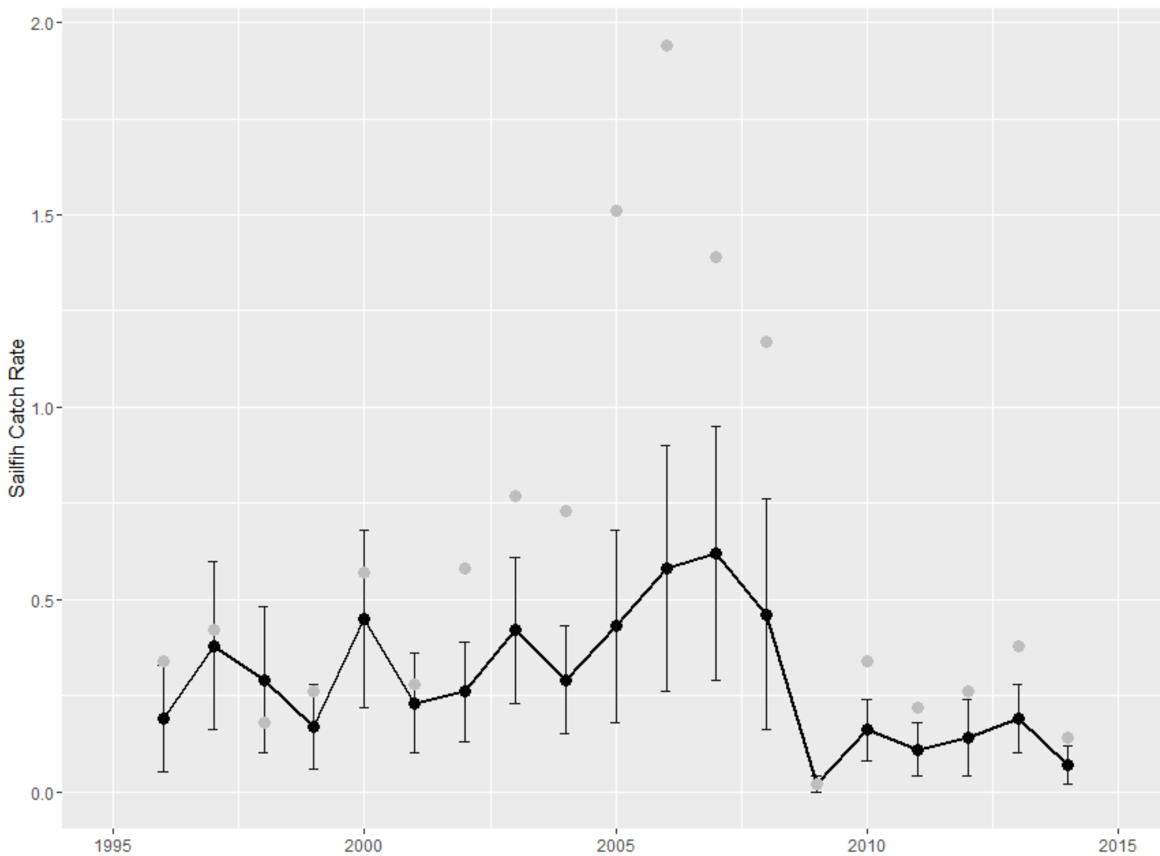

Figure 4. Catch rates of sailfish caught by the Brazilian sport fishery in Atlantic Ocean, from 1996 to 2014. Black line with black circles represents the standardized catch rate and associated standard error estimates (error bars). Grey circles are the nominal catch rates

Table 2. Deviance analysis of the fitted model for the standardization of sailfish catch rate caught by the Brazilian sport fishery in the Atlantic Ocean from 1996 to 2014. ED: explained deviance; and EM: explained model.

	Df	Deviance	Resid. Df	Resid. Dev	Pr(>Chi)	ED (%)	EM (%)
NULL			269	590.48			
year	18	106.241	251	484.24	3.39E-10	53%	18%
year+ local	3	23.04	248	461.2	4.73E-04	12%	22%
year+ local +month	6	69.927	242	391.27	6.84E-10	35%	34%

Table 3. Estimations of coefficients, standard errors, t-statistic and P-value of the t test of the fitted model for the standardization of sailfish catch rate caught by the Brazilian sport fishery

	Estimate	Std. Error	t value	Pr(>|t|)
(Intercept)	-1.259	0.689	-1.827	0.069
year1997	0.696	0.713	0.976	0.330
year1998	0.426	0.775	0.549	0.583
year1999	-0.099	0.785	-0.126	0.900
year2000	0.869	0.669	1.300	0.195
year2001	0.224	0.690	0.324	0.746
year2002	0.330	0.670	0.492	0.623
year2003	0.804	0.665	1.209	0.228
year2004	0.423	0.684	0.619	0.536
year2005	0.825	0.763	1.080	0.281
year2006	1.124	0.741	1.517	0.131
year2007	1.194	0.726	1.644	0.101
year2008	0.905	0.814	1.112	0.267
year2009	-2.028	1.002	-2.025	0.044
year2010	-0.138	0.707	-0.195	0.845
year2011	-0.504	0.764	-0.659	0.510
year2012	-0.301	0.860	-0.350	0.726
year2013	0.022	0.672	0.033	0.974
year2014	-0.948	0.802	-1.182	0.238
Espírito Santo	-1.050	0.904	-1.161	0.247
Rio de Janeiro	0.620	0.335	1.851	0.065
São Paulo	0.359	0.308	1.167	0.245
month2	-1.651	0.476	-3.469	0.001
month3	-0.800	0.729	-1.098	0.273
month4	-1.959	0.913	-2.146	0.033
month10	-1.728	0.364	-4.744	0.000
month11	-0.624	0.264	-2.360	0.019
month12	0.400	0.222	1.798	0.073

Table 4. Standardized catch rate, standard error (SE) and coefficient of variation (CV) of sailfish caught by the Brazilian sport fishery in the Atlantic Ocean from 1996 to 2014.

Year	Index	SE	CV
1996	0.188	0.137	73%
1997	0.376	0.222	59%
1998	0.287	0.189	66%
1999	0.170	0.114	67%
2000	0.447	0.230	51%
2001	0.235	0.127	54%
2002	0.261	0.129	49%
2003	0.419	0.194	46%
2004	0.287	0.137	48%
2005	0.428	0.250	59%
2006	0.577	0.315	55%
2007	0.619	0.331	54%
2008	0.464	0.297	64%
2009	0.025	0.022	87%
2010	0.163	0.085	52%
2011	0.113	0.067	60%
2012	0.139	0.103	74%
2013	0.192	0.091	47%
2014	0.073	0.049	68%

DISCUSSION

Assuming that catch rates are proportional to the actual stock abundance implies the acceptance of several assumptions related to the variation of the catchability coefficient. However, there are several limitations in this approach. Such constraints are particularly complex in the case of non-target species, such as billfishes in the pelagic longline fishery, which is characterized for high percentage of zero observations (MOURATO *et al.,* 2014) combined with few large catch values due to school aggregation, since some Istiophorid billfishes, like sailfish, often form schools in specific locations (NAKAMURA, 1985). Catch and effort data from sport fishery tournaments, therefore, may be a better alternative to estimate billfish catch rates.

Comparatively, the present data set had an amount of zero-valued observations much lower (~35%) than the commercial longline fishing (~75%, see MOURATO *et al.*, 2014), although, it was still zero-inflated and left-skewed distribution to account with problems of overdispersion, when the ratio of the residual deviance and the degrees of freedom is much higher than 1 (ZUUR *et al.*, 2009). In the previous exploratory analysis, different statistical probability distributions that are able to accommodate a high percentage of zero observations (*i.e.* Poisson and negative binomial) were tested. However, the tweedie distribution appeared to be the best option to analyze the sailfish catch rate, with no evidence of overdispersion and the most satisfactory residuals distribution.

For the season effect (*i.e.* month), December and January were the most productive fishing period. In fact, sailfish catch rates are highly seasonal (MOURATO *et al.*, 2014), since it is very likely that mature sailfish migrate from the western central tropical Atlantic towards the southeast Brazilian coast to spawn and remain in the area from about February to March (MOURATO *et al*., 2009b). After spawning, sailfish probably depart in a north-east direction to return to the tropical western central tropical Atlantic (MOURATO *et al*., 2014). Regarding the fishing grounds effect (*i.e.* local), São Paulo and Rio de Janeiro coasts seems to be the most productive fishing areas for sailfish. On the other hand, the fishing grounds in front of Espírito Santo e Bahia states are more productive for blue marlin and white marlin (AMORIM *et al.*, 2006).

The final estimations of year effect showed that most of the estimated standard errors are not larger than the coefficient estimations; hence we assumed the results are useful to evaluate the sailfish recreational fisheries status off the Brazilian coast. Also, the model residuals are satisfactory with no evidences of heterogeneity. Hence the fitted model seems to be not biased and the estimates of standardize catch rates might be considered to reflect well the local relative abundance index. The results suggest that the biomass of sailfish caught in southwestern Atlantic have suffered a very slight decline along the studied years. AMORIM *et al.* (2006) also reported catch rate indices calculated for sailfish caught by tournaments of recreational fishery carried out in São Paulo State and found a similar trend of standardized CPUE, which seemed to oscillate around a rather stable level, from 1996 to 2004. WOR *et al.* (2010) analyzed catch and effort data from Brazilian longline fleet and demonstrated a similar trend with a moderate decline between 1978 and 2008.

CONCLUSIONS

Despite the present results agree relatively well with previous findings, there were some discrepancies between the available times series of sailfish catch rate in southwestern Atlantic. This could be explained primarily by the different data sets used, but also by the diverse standardization procedures. Furthermore, it should also take in account that Brazilian sport fishery has a low fishing effort which covers a small area in the southwestern Atlantic. Hence, this interpretation must be carefully analyzed and interpreted, but they might be taken into account in the next western Atlantic sailfish stock assessments.

REFERENCES

AKAIKE, H. 1974 A new look at the statistical identification model. IEEE transactions on Automatic Control, *19:* 716-723.

AMORIM, A.F. and ARFELLI, C.A. 2001 Analysis of the Santos fleet from São Paulo, Southern Brazil (1971-1999). Collective Volume of Scientific Papers, *53:* 263-71.

AMORIM, A.F. and SILVA, B.O. 2005 Game fisheries off São Paulo State coast, in Brazil (1996- 2004). Collective Volume of Scientific Papers *58(5):* 1574-1588.

AMORIM, A.F.; ANDRADE, H.A.; LINS, J.E. 2006 Assessment of billfish abundance based on Brazilian sport fishing catches. Bulletin of Marine Science, *79:* 659-666.

AMORIM, A.F. and ARFELLI, C.A. 1984 Estudo biológico pesqueiro do espadarte, Xiphias gladius Linnaeus, 1758, no sudeste e sul do Brasil (1971 a 1981). Boletim do Instituto de Pesca, 11(único): *35-62*.

ARFELLI, C.A., AMORIM, A.F., GRAÇA-LOPES, R., 1994 Billfish sport fishery off Brazilian coast. Collective Volume of Scientific Papers, 41: 214-217.

DUNN, P.K. 2011 Tweedie exponential family models. R package version 2.1.1.

DUNN, P.K. and SMYTH, G.K. 1996 Randomized quantile residuals. Journal of Computational and Graphical Statistics, *5:* 236–244.

FRÉON, P. and MISUND, O.A. Dynamics of pelagic fish distribution and behaviour: effects on fisheries and stock assessment. First Edition, Science, B.S. Fishing News Books, Oxford, 1999. 348p.

GULLAND, J.A. Fish stock assessment: a manual of basic methods. FAO/Wiley Ser. on Food and Agriculture, vol. 1, 1993. 233p.

MAUNDER, M.N. and PUNT, A.E. 2004 Standardizing catch and effort data: a review of recent approaches. Fisheries Research, *70:* 141-159.

MOURATO, B.L.; AMORIM, A.F.; ARFELLI, C.A; HAZIN, H.G.; HAZIN, F.H.V.; LIMA, C.W. 2009a Standardized CPUE of atlantic sailfish (Istiophorus platypterus) caught by recreational fishery in southern Brazil. Collective Volume of Scientific Papers, *64:* 1941-1950.

MOURATO, B.L.; PINHEIRO, P.; HAZIN, F.H.V.; MELO, V.B.; AMORIM, A.F.; PIMENTA, E.; GUIMARÃES, C. 2009b Preliminary analysis of gonadal development, spawning period, sex ratio and length at first sexual maturity of sailfish, Istiophorus platypterus in Brazilian coast. Collective Volume of Scientific Papers, *64:* 1927-1940.

MOURATO, B.L.; HAZIN, F.H.V..; BIGELOW, K.; MUSYL, M.; CARVALHO, F.; HAZIN, H. 2014 Spatio-temporal trends of sailfish, Istiophorus platypterus catch rates in relation to spawning ground and environmental factors in the equatorial and southwestern Atlantic Ocean. Fisheries Oceanography, *23 (1):* 32-44.

NAKAMURA, I. FAO species catalogue. Vol. 5: Billfishes of the world. An annotated and illustrated catalogue of marlins, sailfishes, spearfishes and swordfishes known to date. FAO Fish. Synop., Rome, n. 125, 1985. 65p.

R CORE TEAM. 2014 R: A language and environment for statistical computing. R Foundation for Statistical Computing, Vienna, Austria. URL http://www.R-project.org/.

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

WOR, C.; Mourato, B.L.; Hazin, H.G.; Hazin, F.H.V.; Travassos, P.; Andrade, H.A. 2010 Standardized catch rate of sailfish (Istiophorus platypterus) caught by Brazilian longliners in the Atlantic Ocean (1978-2008). Collective Volume of Scientific Papers, *65* -1762 - 1771.

ZUUR, A.F.; IENO, E.N.; SAVELIEV, A.A.; SMITH, G.M. Mixed effects models and extensions in ecology with R. 1st Edition, Springer, 2009. 574p.