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UPDATED STANDARDIZED CATCH RATES FOR SKIPJACK TUNA (*KATSUWONUS PELAMIS*) CAUGHT IN THE SOUTHWEST OF SOUTH ATLANTIC OCEAN

Vívian Carneiro[1], Erika Fialho[2], Humber A. Andrade[3]

SUMMARY

In this study standardized catch rates for skipjack Brazilian pole-and-line fleet were calculated using generalized linear models and lognormal distributions. Year, quarter and fishing area were the explanatory variables while the response variable was catch-per-unit-effort. Standardized catch rates did not show clear time trends over the years. If we rely in the standardized catch rates as useful indices of relative abundance, the conclusion would be that the biomass of the population did not change much over the past decades.

RÉSUMÉ

Dans la présente étude, les taux de capture standardisés de la flottille de canneurs brésiliens ciblant le listao ont été calculés à l'aide de modèles linéaires généralisés et de distributions lognormales. L'année, le trimestre et la zone de pêche étaient les variables explicatives tandis que la variable réponse était la prise par unité d'effort. Les taux de capture standardisés n'ont dégagé aucune tendance temporelle claire au cours des années. À en croire les taux de capture standardisés comme indices utiles de l'abondance relative, on pourrait conclure que la biomasse de la population n'a guère changé au cours de ces dernières décennies.

RESUMEN

En este estudio se calculan las tasas de captura estandarizadas para la flota de cañeros brasileña dirigida al listado utilizando modelos lineales generalizados y distribuciones lognormales. Las variables explicativas eran año, trimestre y zona de pesca, mientras que la variable de respuesta era la captura por unidad de esfuerzo. Las tasas de captura estandarizadas no mostraron tendencias temporales claras a lo largo de los años. Si confiamos en las tasas de captura estandarizadas como índices de abundancia relativa útiles, la conclusión sería que la biomasa de la población no ha cambiado mucho en las últimas décadas.

KEYWORDS

Catch/effort, Fishery statistics, Abundance

[1] UFRPE – DEPAq – Av. Dom Manuel de Medeiros, s/n – 52171-030 – Recife-PE – Brazil. carneirovivian0@gmail.com

1. Introduction

Standardized catch rates are often used as relative abundance indices in stock assessment models. In most of the papers the relationship between catch rates (weight/fishing effort) (I) and biomass (B) is assumed to be linear across time (t) $[I_t = qB_t]$ (Hilborn and Walters, 1992).. Above equation is useful if the coefficient of catchability (q) is constant. However, q is affected by several factors (*e.g.* fishing area) across the time, hence calculations are necessary to estimate a modified catch rate index (I_t^*) that reflect B_t only.

In order to obtain I_t^* many approaches have been used. One alternative is to model I_t as response of "year" and other explanatory variables (*e.g.* fishing area) using a generalized linear model (GLM) (Maunder and Punt, 2004). Ideally estimations of the parameters concerning "year" reflect the variations of B_t, hence those estimations are the relative abundance indices (I_t^*), which are usually denominated "standardized catch rates". On the other hand, the estimations of parameters for the other explanatory variables concerns the variations of q. This approach works out if all factors changing q across the years are included in the model.

In this paper a GLM is used to standardize catch rates for skipjack tuna caught by Brazilian bait-boat fleet in the southwest of South Atlantic Ocean. In Brazil there are not regulations imposing restrictions on skipjack bait-boat fisheries. Fishing operational pattern is the same since the beginning of the commercial fishery. Fisherman search for the fish and released live bait together with a shower of spray when the school is found. Almost all the crew participates of the fishery. Very few and punctual attempts to use fishing attractive devices have been used in Brazil. Hence most of the fisheries occur on free schools.

2. Database

Information about fishing effort and skipjack tuna caught in the Southwest South Atlantic is available in the "Task II – catch and effort" (ICCAT, 2014). I have analyzed the subset of the Brazilian fishing fleet. Bait boats have been fishing offshore of Brazil since 1981. Brazilian boats operate based on different harbors and each of them has a different code in the task II database. Most of the reports are for the fleets coded 003BR00, 003BR02, 003BR05, 003BR08, which are the fleets considered in the analysis. The analyzed dataset contains information from 1981 to 2011, but there are no data for 2000.

Most of the catches were reported in kilos, however there are reports in which the unit of the catch is not available. Those reports where discarded. Effort unit in most of the reports are "fishing day", which was the effort measurement considered in the analysis. In 11% of the reports the effort is equal to zero, hence they were discarded. Database entries with geographical locations unreliable (fishing in land and isolated fishing activity far away from Brazilian coast) were also discarded. After this preliminary exploratory 3708 reports were selected for analysis.

In spite the fishermen eventually catches other tuna species in mixed schools, most of fish caught in weight are skipjack (90.6%). Data are aggregated in the sense the effort is higher than one fishing day in most of the reports (87.9%). Because the skipjack is the fishermen target and because the data are aggregated, catches equal to zero are very scarce (1.6%). Bait-boat fishermen pursue skipjack schools which move in a seasonal manner along the Brazilian coast. Andrade (2003) showed that the south coast (southward of 28^o S) is explored mainly in austral summer when the influence of tropical Brazil Current increase over the continental shelf. In opposition the north of Southeastern Brazilian Coast is explored mainly in austral winter thought the number of fishing activities there are small all across the year. Based on the study about the relationship between skipjack tuna availability and oceanographic dynamic patterns, wee have considered three fishing grounds (North, Central and South) as showed in **Figure 1**. The number of reports per fishing ground, year and quarter is summarized in **Table 1**.

3. Analysis

3.1 Models

Generalized linear models can be written in matrix notation as

(1) $$g[E(y)] = X\beta$$

where y is a vector of the response variable, $E(\cdot)$ is the expectation, $g[\cdot]$ is the link function and β is the vector of parameters. Further details about GLM can be found in Dobson (2002). Because the analysis carried in the last stock assessment the results were similar when considering zero catches or positive catches only (Andrade, 2009), in this work only positive catches were analyzed. The models are not sensitive to zero catches because they are very rare, hence the proportions of positive catches are equal to one or close to one in most of the crossing levels of the factors year, quarter and area.

The response variable (y) is the catch per unit effort (CPUE) calculated in tons per fishing day. We have assumed that it follows a lognormal, or a normal or a gamma distribution. The link functions evaluated for the gamma distribution were inverse, identity and logarithm. Identity and logarithm were the link functions for the normal model, while identity was the link for the lognormal model.

3.2 Selection of models and diagnostic of the fitting

In all the models the categorical explanatory variables were "year", "quarter" and "area" (fishing ground). In order to choose the order they enter in model, we fitted three models one for each them separated. Deviance and Akaike Information Criterion (AIC) (Akaike, 1974) were used to rank the variable. We have considered main factors as well the first order interactions as fixed effects. In order to select the relevant factors and interactions we relied again on the AIC using a backward selection function.

Akaike Information Criterion and Bayesian Information Criterion (BIC) (Schwarz, 1978) were used to compare models calculated using different density distributions (gamma and gaussian) and link functions (e.g. logarithm and identity). Those criteria can not be used to compare models when the response variables are not the same. Hence information criteria can not be used to compare a model fitted to CPUE with a model fitted to the logarithm of the CPUE. In such case we have relied in the R^2. Whenever the models have different number of parameters the comparison was based on the adjusted R^2. Standard diagnostic plots (e.g. residual x fitted, qqplot) and calculations based on the diagonal of the hat matrix (e.g. Cook's distances, leverage) (e.g. Venables and Ripley, 2002) were used to assess the fitting of the selected model and the influence of the individual reports on the calculations. All the analyses were carried out using R software functions. Investigations about the normality of the residuals distributions were based on attempts do calculate the confidence "envelope" (Cook and Weisberg, 1982) or in the Shapiro-Wilk hypothesis tests.

3.3 Estimation of Standard Catch Rate

In the first step the estimations of coefficients (β) and their covariance matrix were used to calculate the predictions and standard errors for a design matrix (X') containing one positive indicator variable (dummy) for crossing levels of all factors. Hereafter $\hat{y}_{ijk}$ and $\mathrm{var}(\hat{y}_{ijk})$ are the prediction and the variance (square of standard error) for the CPUE prediction for year i , quarter j and area k .

In order to obtain an estimation of standardized CPUE for the factors of interest (*e.g.* year) predictions were then averaged over the effects of the nuisance factors (*e.g.* area) as follow:

(2) $$\hat{y}_{ij} = \frac{\sum w_k \cdot \hat{y}_{ijk}}{W}$$

where w_k is the weight of the prediction for fishing ground k and $W = \sum w_k$. This approach is an appropriate way to develop indices of abundances when the model includes interactions between year and other factors (Maunder and Punt, 2004). Finally, the variance of the prediction is

(3) $$\mathrm{var}(\hat{y}_{ij}) = \sum\left(\frac{w_k}{W}\right)^2 \cdot \mathrm{var}(\hat{y}_{ijk})$$

We have found no motivation to consider that one particular level of factor area or quarter is more important than others. Hence we have used $w_k = 1$ for all quarters and areas. Standardized CPUE predictions for the positive data can be obtained straightforward from the above solutions. The approach used in this paper is a "continuous case" in the sense it is the same approach used in the last skipjack stock assessment meeting.

4. Results

4.1 Exploratory analysis

Bait-boat fleet has been fishing along Brazilian coast from 19^o S to 36^o S (**Figure 1**). High efforts were concentrated in the central coast exceeding 4500 fishing day, while in south coast the efforts were low. In the north area effort was high in just one particular geographical location but most effort values ranged from 9 to 260 fishing day. High catches appear in the central area, in which the effort is also high. Catches are small in the north and south areas. Overall CPUEs are high in the south coast, reaching 35 t/fishing day. However, notice that the highest CPUE (56 t/fishing day) has occurred in the central region. In the north area most of the CPUEs were low.

Boxplots of logarithm of positive CPUE are in **Figure 2**. All boxes for years overlap, hence the differences among the distributions of CPUEs are not large. Overall the CPUE values show a slight increasing time trend, though the values in 2011 were low if compared to the CPUEs of the previous years. There is a clear seasonal pattern. Catch-per-unit-effort is large in austral summer (1st quarter) and small in the winter (3rd quarter). The CPUEs are quite different in the three fishing grounds. Values of the north area are low and the dispersion is high, while the CPUEs are high and the dispersion is low in the south area.

4.2 Model fitting and coefficient estimation

All three explanatory variables main effects were considered relevant and were kept in the selected models (**Table 2**). However the interactions between year and quarter and, between year and area were discarded when CPUE was assumed to follows Gaussian distribution. When CPUE in the original scale is the response variable the models with gamma distribution performed better, especially when using the logarithm link function. However, if we rely on adjusted R^2 to compare the gamma models to the lognormal model, the later shows the better performance. Hence the lognormal model was selected to calculate the standardized CPUE. Nevertheless, notice that the R^2 of the better model is not much higher than 0.3.

Standard diagnostic plots are in **Figure 3**. The left pane shows that the model is not strongly biased and the homocedasticity of the residuals. The graph in the second panel indicates that residual distribution is close to normal distribution, but the tails of the distribution adherence to the theoretical normal distribution seem not satisfactory. In order to investigate the validity of the normal distribution assumption we tried to calculate the encapsulated confidence envelope (Cook and Weisberg, 1982). Nevertheless, the hat matrix is impossible to calculate because of the singularities. Then we tried out Shapiro-Wilk normality hypothesis test, which did not reject the normality hypothesis if the sample size is not very large. Hence we have assumed the normality assumption is reasonable.

Analysis of deviance for selected lognormal model is showed in **Table 3**. Year is the more important factor to explain CPUE variations. Area is more important than quarter. Deviance after the inclusion of the factor year is 14% smaller than the deviance of the null model. Deviance after the inclusion of all the factors and interactions is 30% smaller than the deviance of the null model. Most of the deviance reduction occurred after the inclusion of the year factor. The interaction between year and quarter showed to be the more important, while the interaction between quarter and area did not strongly affect the CPUE.

Estimations of parameters of the lognormal model are in **Table 4**. Notice that the estimations of main effects for most of the years are not significant. Most of the significant estimations are negative, but 2007 is an exception. However, several estimations of interactions including year were positive and significant, particularly those interactions between year and area. Hence, in order to understand year effect the interactions might be taken into account. Similar conclusions are valid for are quarter and area. The main effects of the later factor were not significant but a couple of interactions including it showed to be important to explain the variability of the CPUE.

4.3 Estimations of the standardized catch rates

Standardized CPUE per year and quarter as calculated using the lognormal model is showed in **Figure 4**. Confidence intervals are large for estimations in 1990, 1993, 2001, and especially in 2007. Estimation of CPUE oscillated around 5-6 tons/fishing days until 2000, peaked in 2007 then decreased until 2011. Estimations of standardized CPUE per year (**Figure 5 and Table 5**) where similar to the estimations calculated per year and quarter. Nominal standard and skipjack catch per unit effort beyond the scaled coefficient of variation and not scaled are shown in **Table 5**.

5. Discussion

There are at least two explanations for the very low quantity of zero catch reports: a) The skipjack schools are the target of the pole-and-line fishermen hence the bait is released and the fishing operation starts only after the school has been found and the boat is close to it. The probability that no fish try to eat is small; b) Fishermen can fail to catch fish when they find one school, but they can find more than one school per fishing day; and c) Task II data are aggregated, hence catches of several fishing days are summed up.

Catch rates of south and north fishing grounds were very different. Catch rates are varies between. In fact, the spatial distribution of catches, CPUEs and fishing efforts have been related to factors like sea surface temperature and continental shelf fronts, which show seasonal variability (Andrade and Garcia, 1999; Andrade, 2003). The effects of the seasonal components on the CPUE values were depicted by “area” and “quarter” explanatory variables and the interaction among then. However, interannual effects were also important as indicated buy the calculations for “year”, which was the more important factor explaining the variability of the CPUEs.

Lognormal model for skipjack outperformed the other approaches evaluated in this paper. Similar results have been found for positive CPUE of other tuna like species (e.g. Ortiz and Arocha, 2004). However, it is important to highlight that because of singularities the complete hat matrix was not calculated, hence some of the diagnostics (e.g. confidence envelope) concerning the assumption on the CPUE distribution were not carried out. Difficulties have arisen mainly because the matrix of explanatory variables is not balanced, which make impossible to build an orthogonal design matrix. In spite of the failure to calculate the complete hat matrix and the confidence envelope we have assumed the lognormal distribution is acceptable based on the Shapiro-Wilk test with sample size between 50 and 100.

Overall, uncertain concerning standardized CPUEs per year and quarter, or per year only. However the later showed less variability because it averaged over the quarter effect. The main differences between the nominal and the standardized CPUEs are: a) Standardized calculations are slightly higher than nominal in most of 1980’s years, but smaller than nominal in the very end of the time series; b) Nominal CPUEs were high in two quarters of 2005, but the standardized CPUEs were not; and c) Standardized CPUEs show a peak in 2007, which does not appears in the nominal time series. Overall there are not clear time trends in the standardized CPUEs.

The main objective when standardizing CPUE is to obtain relative abundance indices. However, no data concerning changes in technologies, in characteristics of fishing boats (*e.g.* capacity, installation of freezing chambers), in fishing strategies (*e.g.* number of fishermen, amount of bait released) or in fishing operations (*e.g*. time spent searching for schools) were included in the model. Hence results gathered using such limited model might be carefully considered in the light of the information available in task II dataset only.

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Table 1. Number of reports in the "Task II" ICCAT database concerning Brazilian bait-boat fleet used in the analysis. Reports are showed per year, quarter and area (North, Central and South). Numbers between brackets stand for catches of skipjack (*Katsuwonus pelamis*) equal zero.

	North				*Central*				*South*				
	1st	*2nd*	*3rd*	*4th*	*1st*	*2nd*	*3rd*	*4th*	*1st*	*2nd*	*3rd*	*4th*	*Total*
1981	6	7(1)	5	9	8	7	11	10	0	0	0	0	63(1)
1982	7	8	6	7	11	13	18	19	0	0	0	0	89(1)
1983	8	10(1)	8	7	24	25	16(1)	19	0	0	0	2	119(2)
1984	8	7	7(1)	5	20	25	19(1)	30	6	5	2	1	135(3)
1985	10	8	7(1)	13	35(1)	34(1)	18	34(1)	8	6	0	0	173(5)
1986	6	5	8(1)	5	28(1)	22	15	11	3	0	0	0	103(2)
1987	6	8	8	5	8	18(1)	16	6	1	0	0	2	78(1)
1988	6(1)	4(1)	4	4	8	17	5	19	6	0	0	0	73(3)
1989	4	6	2(1)	2	2	7	2	5	0	0	0	0	30(2)
1990	0	3	0	0	6	13	7(1)	7	13	0	0	0	49(1)
1991	5	7(1)	7	7	19	29	11	11	22	1	0	0	119(1)
1992	3	5	5	4	18	39	11	15	33	14	0	12	159
1993	0	0	2	0	37	50(3)	28(4)	28(1)	41	6	0	6(2)	198(10)
1994	0	0	1	2	39	61(2)	29	26(1)	43	17	0	16(1)	234(4)
1995	0	1	1	0	32	35(3)	7	10	25	1(1)	0	10	122(4)
1996	0	0	0	0	27	16(1)	6	24	25(1)	0	0	0	98(2)
1997	0	2	0	0	51	63	26	23	27	7	0	12	211
1998	3	4	3	3	5	10	6(1)	5	6	2	0	3	50(1)
1999	0	0	0	0	2	15(2)	0	0	25(1)	6(1)	0	0	48(4)
2001	0	2(1)	3	1	17	23(3)	22(1)	17	11	3	0	11	110(5)
2002	2	2	0	1	23	29	27	14	10	3	1	5	117(1)
2003	0	1	0	0	10	23	17	12	19(1)	0	0	4	86(1)
2004	0	1	0	0	13	23	16	16	23	3	0	3	98
2005	0	0	0	0	13	47	28	5	25	1	1	17	137
2006	0	1	0	2	6	21	20	29	19	0	0	7	105
2007	0	0	4	0	13	24	14	11	21	3	0	10	100
2008	0	7	3(1)	0	13	23	19	13	14	2	0	13	107(1)
2009	0	7(2)	0	0	26	41(1)	10	15	32	6	0	13	150(3)
2010	0	3	0	0	17	30	15	29	26	0	0	7	127
2011	14	50	9	14	62	114	27	69	38	0	0	23	420
Total	88(1)	159(7)	93(5)	91(6)	593(2)	897(17)	466(9)	532(3)	522(3)	86(2)	4	177(3)	3708(58)

Table 2. Generalized linear models fitted to positive catch-per-unit-effort of skipjack tuna (*Katsuwonus pelamis*) and to proportion of positive catches. Residual degrees of freedom are 3528 and 231 in the models for positive catches and proportion of positive catches, respectively. Factors: A – area; Y – year; Q – quarter. Main effects and first order interaction were considered as indicated by the term "^2". AIC – Akaike Information Criteria (Akaike, 1973); BIC – Bayesian Information Criteria (Schwartz, 1998).

Response Variables	*Explanatory Variables*	*Density Distribution*	*Link Function*	*AIC*	*BIC*	R^2	R^2 *adjusted*	*Residual Deviance*
log(CPUE)	(Y+A+Q)^2	gaussian	identity	10619.22	11729.47	0.302	0.264	3554.2
CPUE	Y+A+Q+A:Q	gaussian	identity	24688.69	24949.19	0.115	0.106	180884.8
CPUE	Y+A+Q+A:Q	gaussian	log	24663.19	24923.69	0.122	0.112	179625.4
CPUE	(A+Y+Q)^2	gamma	inverse	20605.32	21715.56	0.220	0.178	3033.3
CPUE	(A+Y+Q)^2	gamma	log	20569.46	21679.70	0.227	0.186	3006.8

Table 3. Analysis of deviance table for the lognormal model fitted to positive catch rates and binomial model fitted to proportion of positive catch rates. Df – Degrees of freedom; Resid. – Residual; Dev. – Deviance; Dec. Dev. – Decrease of deviance when the explanatory variable was included in the model; Prop. Dev. – Proportion of the total reduction of the deviance due to the inclusion of the explanatory variable.

	Df	*Deviance*	*Resid. Df*	*Resid. Dev*	*F*	*Pr(>F)*	*Dec. Dev.*	*Prop. Dev.*
NULL			3649	5090,57				
Year	29	713,12	3620	4377,45	24,02	1,2E-115	14,01	46,42
Area	2	256,07	3618	4121,38	125,07	3,5E-53	5,03	16,67
Quarter	3	112,79	3615	4008,59	36,73	2,3E-23	2,22	7,34
Year:Area	52	157,69	3563	3850,91	2,96	1,1E-11	3,10	10,26
Year:Quarter	85	256,61	3478	3594,30	2,95	2,1E-17	5,04	16,70
Area:Quarter	6	40,05	3472	3554,25	6,52	7,4E-07	0,79	2,61

Table 4. Estimations of the parameters significantly ($\alpha < 0.05$) different of zero.

	Estimate	*Std. Error*	*t value*	*Pr(>|t|)*
(Intercept)	*1,318548*	*0,316137*	*4,170812*	*3,11E-05*
Year1982	-1,08723	0,416514	-2,61031	0,009085
Year1983	-1,32656	0,391258	-3,39051	0,000705
Year1984	-1,49994	0,395909	-3,78859	0,000154
Year1991	-0,89394	0,417481	-2,14126	0,032323
Year2007	2,457146	0,707259	3,474183	0,000519
Quarter4	-1,24463	0,370564	-3,35875	0,000791
AreaC:Year1982	1,203482	0,353696	3,402591	0,000675
AreaC:Year1983	0,691577	0,337413	2,049641	0,040474
AreaC:Year1984	0,700738	0,350235	2,000763	0,045496
AreaS:Year1984	1,641628	0,401601	4,087713	4,46E-05
AreaS:Year1988	1,366287	0,568756	2,402238	0,016347
AreaS:Year1991	1,255943	0,396034	3,171301	0,001531
AreaS:Year1992	0,916001	0,353113	2,594074	0,009524
AreaC:Year1993	-1,57973	0,798526	-1,97831	0,047973
AreaC:Year2005	-1,0408	0,421304	-2,47042	0,013543
AreaC:Year2007	-2,41294	0,642019	-3,75836	0,000174
AreaS:Year2007	-2,05043	0,669255	-3,06376	0,002203
AreaC:Quarter3	0,716213	0,188414	3,801265	0,000146
AreaS:Quarter4	0,610926	0,211989	2,881871	0,003977
Year1984:Quarter2	-1,12386	0,460358	-2,44127	0,014685
Year2001:Quarter2	-1,17221	0,491746	-2,38377	0,01719
Year1984:Quarter3	-2,06455	0,460066	-4,48751	7,44E-06
Year1994:Quarter3	-1,22797	0,443493	-2,76886	0,005655
Year1996:Quarter3	-1,2274	0,592837	-2,07038	0,03849
Year2001:Quarter3	-1,26958	0,484373	-2,62108	0,008803
Year2006:Quarter3	-1,22597	0,543397	-2,25613	0,024125
Year2010:Quarter3	-1,01509	0,508942	-1,99451	0,046174
Year1983:Quarter4	1,084276	0,446901	2,426208	0,015308
Year1984:Quarter4	1,252013	0,438782	2,853381	0,004351
Year1988:Quarter4	1,022559	0,505586	2,022522	0,043199
Year1991:Quarter4	0,98147	0,477431	2,055734	0,039883
Year1992:Quarter4	0,900993	0,433495	2,078438	0,037742
Year1993:Quarter4	1,394199	0,43139	3,231878	0,001241
Year1996:Quarter4	1,072887	0,46312	2,316651	0,020581
Year2005:Quarter4	1,118723	0,464113	2,410453	0,015984

Table 5. Nominal, standardized catch rates and the coefficients of variation (CV) as calculated for skipjack tuna caught in the southwestern Atlantic.

Year	*Nominal CPUE*	*Standardized CPUE*	*CV*	*Standardized CPUE (Scaled)*	*CV (Scaled)*
1981	5.86	4.56	0.14	5.86	0.22
1982	4.85	2.53	0.10	3.83	0.30
1983	3.37	2.62	0.26	3.92	0.34
1984	2.73	2.31	0.15	3.60	0.33
1985	4.15	3.55	0.12	4.84	0.25
1986	5.57	4.28	0.19	5.58	0.25
1987	4.34	3.47	0.25	4.76	0.30
1988	4.54	5.22	0.25	6.51	0.26
1989	3.79	2.89	0.19	4.19	0.30
1990	9.11	6.89	0.27	8.19	0.26
1991	4.66	3.65	0.16	4.95	0.26
1992	7.52	5.25	0.14	6.55	0.21
1993	6.28	7.62	0.27	8.91	0.26
1994	7.60	4.19	0.12	5.48	0.22
1995	6.36	5.44	0.27	6.74	0.27
1996	8.41	5.37	0.12	6.66	0.19
1997	9.91	6.6	0.15	7.90	0.19
1998	5.01	4.13	0.13	5.42	0.23
1999	6.17	3.78	0.19	5.07	0.26
2001	6.69	4.84	0.13	6.13	0.21
2002	6.00	3.90	0.13	5.19	0.24
2003	6.5	6.98	0.32	8.27	0.31
2004	7.01	4.97	0.18	6.26	0.23
2005	9.88	8.18	0.10	9.47	0.15
2006	10.1	6.95	0.14	8.25	0.18
2007	9.10	17.1	0.30	18.4	0.29
2008	8.89	6.40	0.13	7.69	0.18
2009	10.00	7.11	0.13	8.41	0.17
2010	8.88	6.31	0.17	7.60	0.21
2011	5.61	2.96	0.13	4.26	0.28

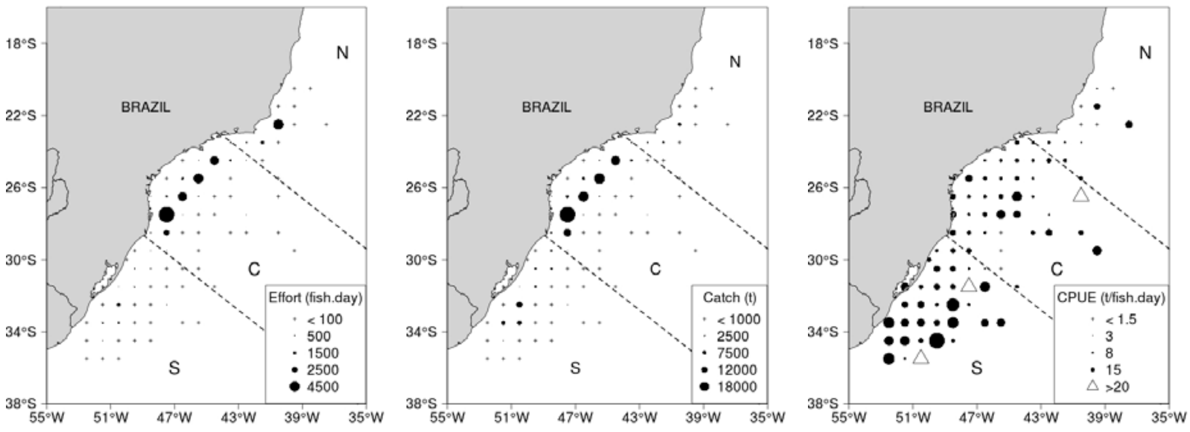

Figure 1. Effort (fishing days) of Brazilian bait-boat fleet from 1981 to 2011, skipjack tuna catch (tons) and catch-per-unit-effort (tons/fishing days). Fishing areas are: N – north; C – central and S – south. Source: Task II – ICCAT database (ICCAT, 2014).

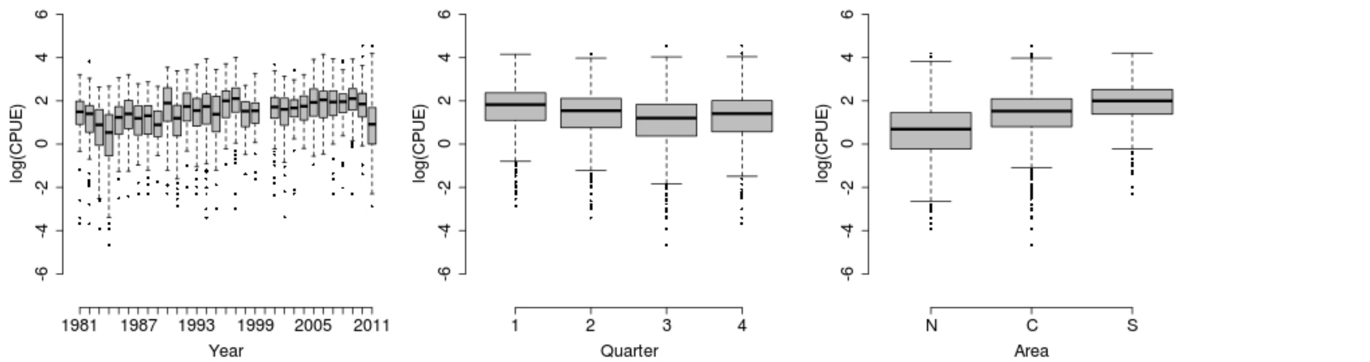

Figure 2. Logarithm of the catch-per-unit-effort (t/fishing days) in each year, area (N-north; C-central; S-south) and quarter.

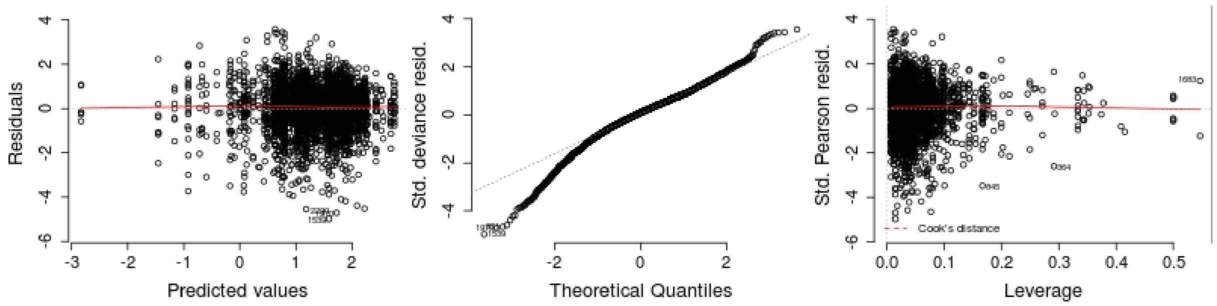

Figure 3. Standard diagnostic plots for the fitting of the lognormal generalized linear model.

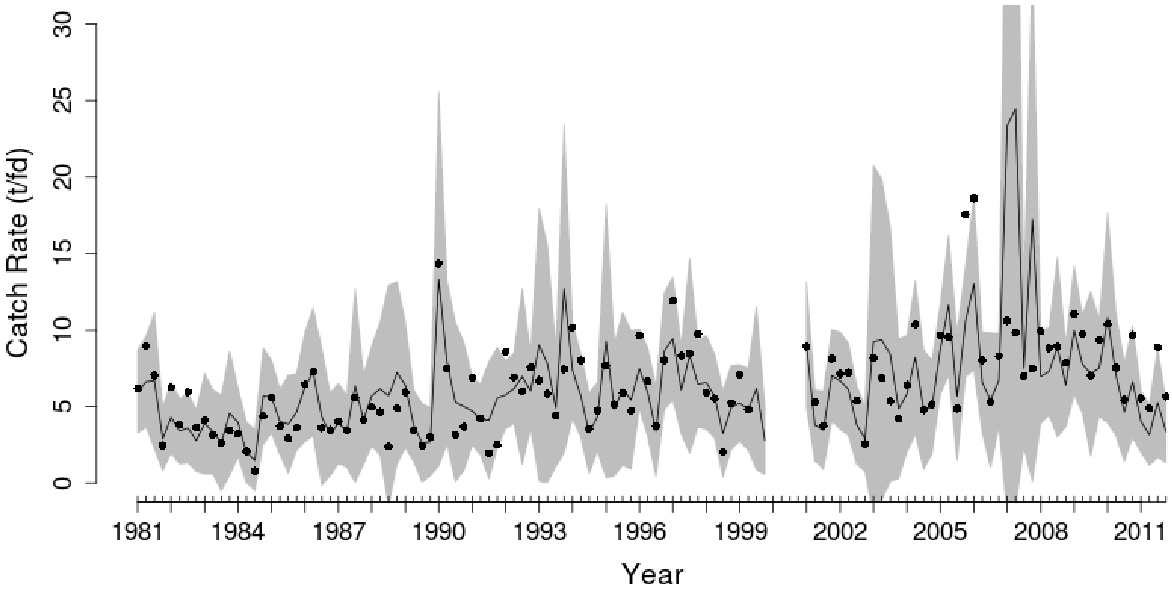

Figure 4. Standardized catch rate (tons/fishing day) per year and quarter as calculated using a lognormal model (solid lines). Gray polygons stand for the 95% confidence interval. Dots stand for the average nominal CPUE.

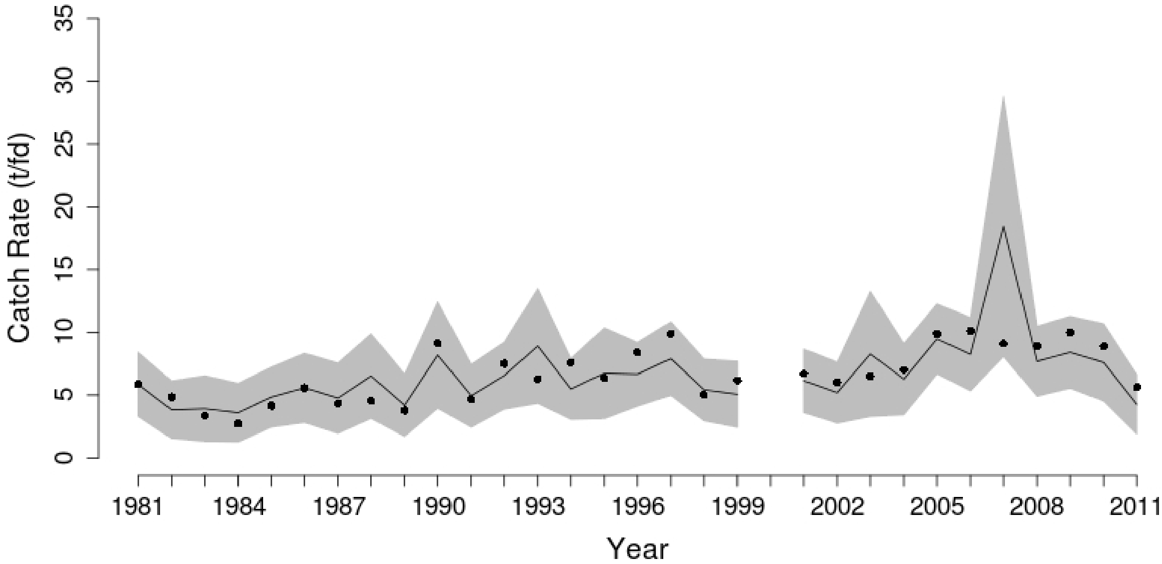

Figure 5. Standardized catch rate (tons/fishing day) per year as calculated using a lognormal model (solid lines). Gray polygons stand for the 95% confidence interval. Dots stand for the average nominal CPUE.