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CATCH RATE STANDARDIZATION FOR BLUE MARLIN CAUGHT BY THE BRAZILIAN PELAGIC LONGLINE FLEET (1978-2016)

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SUMMARY

In the present paper, catch and effort data from 99,376 sets done by the Brazilian tuna longline fleet, including both national and chartered vessels, in the equatorial and southwestern Atlantic Ocean, from 1978 to 2016, were analyzed. The CPUE of the blue marlin was standardized by a Generalized Linear Mixed Model (GLMM) using a Delta Lognormal approach. The factors used in the model were: year, quarter and area. The standardized CPUE series shows a gradual decreasing trend, particularly after the year 2004, reaching a low level from 2007-2010, and decreasing to an even lower level from 2011 to 2016. These drops in CPUE, however, were much more a consequence of a new regulation, in 2005, prohibiting the taking of marlins if they were alive by the time of gear retrieval, as well as their commercialization, if they were dead, than to an actual change in abundance. This means the signal of blue marlin abundance from this fishery is lost and the CPUE series after 2005 is not suitable for stock assessment purposes.

RÉSUMÉ

En este documento se analizan los datos de captura y esfuerzo de 99.376 lances realizados por la flota atunera brasileña de palangre, tanto de buques nacionales como fletados, en el Atlántico sudoccidental y ecuatorial entre 1978 y 2016. Se estandarizó la CPUE de la aguja azul mediante modelos mixtos lineales generalizados (GLMM) utilizando un enfoque delta lognormal. Los factores utilizados en el modelo fueron: año, trimestre y área. La serie de CPUE estandarizada muestra una tendencia decreciente gradual, especialmente después del año 2004, alcanzando un nivel bajo entre 2007 y 2010 y descendiendo a un nivel aún más bajo entre 2011 y 2016. Sin embargo, estos descensos en la CPUE, más que un cambio real en la abundancia, eran una consecuencia de una nueva reglamentación, de 2005, que prohibía la captura de marlines si estaban vivos en el momento de izar el arte, así como su comercialización, si estaban muertos. Esto significa que la señal de abundancia de aguja azul de esta pesquería se ha perdido y que la serie de CPUE posterior a 2005 no es adecuada para la evaluación del stock.

RESUMEN

Le présent document analysait les données de prise et d'effort provenant de 99.376 opérations de la flottille palangrière brésilienne (nationale et affrétée) ciblant les thonidés dans l'océan Atlantique équatorial et du Sud-Ouest entre 1978 et 2016. La CPUE du makaire bleu a été standardisée en utilisant un modèle mixte linéaire généralisé (GLMM) au moyen d'une approche delta log-normale. Les facteurs utilisés dans le modèle étaient les suivants : année, trimestre et zone. La série de CPUE standardisée montre une tendance à la baisse graduelle, en particulier après 2004, atteignant un niveau bas de 2007 à 2010 et diminuant à un niveau encore plus bas de 2011 à 2016. Toutefois, ces baisses de CPUE, plutôt qu'un changement réel de l'abondance, résultaient bien plus d'une nouvelle réglementation, promulguée en 2005, qui interdisait la capture de makaires si les spécimens étaient vivants au moment de la récupération des engins, ainsi que leur commercialisation, s'ils étaient morts. Cela signifie que le signal d'abondance du makaire bleu de cette pêcherie est perdu et que les séries de CPUE après 2005 ne conviennent pas à l'évaluation des stocks.

KEYWORDS

Blue marlin, Catch and effort, CPUE, Pelagic longline fishing, South Atlantic

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1. Introduction

In recent decades, there has been a growing concern with the status of several billfish populations worldwide, mainly because of an increased mortality resulting from fishing, both commercial, including industrial and artisanal, as well recreational. Among the istiophorid, blue marlin (*Makaira nigricans*) is a highly valued species for the recreational fisheries, as well as for small-scale and artisanal fisheries, particularly in developing countries, where it represents an important source of food and income. It is also often caught, as by-catch, by the pelagic longline fishery, directed to tunas and swordfish, which accounts, by far, for the main impact on its stock in the Atlantic Ocean.

Stock assessments for large pelagic fish species are commonly based on catch per unit of effort (CPUE) due to the greater availability of such data. Although CPUE has been classically used as an index of relative abundance, the relationship between the CPUE and the actual abundance is not linear, being affected by several factors, which may, therefore, lead to interpretation errors and make its utilization rather complex. As a result of market changes over the years, for instance, a number of fleets have frequently altered their fishing strategies in order to increase their catching efficiency of a given species. Since 1956, when longline fishing operations began in the South Atlantic Ocean, a number of changes in fishing operations and strategies have been observed which directly affect catch composition (Amorim and Arfelli, 1984; Hazin *et al.*, 2007; Carvalho *et al.*, 2010; Mourato *et al.*, 2011). Such variations lead to oscillations in catchability which may introduce serious errors in the estimation of abundance indices. A common way to compensate for these interferences is to standardize the CPUE series by different methods that try to neutralize the effects of factors other than the actual abundance of the stock on the CPUE. In this study, therefore, in order to contribute information for the assessment of the blue marlin in the Atlantic Ocean, a standardized series of CPUE for the species, caught by the Brazilian fleet, including both national and chartered vessels, was updated, spanning for 39 years, from 1978 to 2016.

2. Material and Methods

In the present study, catch and effort data from 99,376 tuna longline sets obtained from logbooks reported by the Brazilian tuna longline fleet, including both national and foreign chartered vessels, from 1978 to 2016, were analyzed (**Table 1**). The longline sets were distributed along a wide area of the equatorial and South Atlantic Ocean, ranging from 3ºW to 52ºW of longitude, and from 011ºN to 40ºS of latitude **(Figure 1)**. The resolution of 1º x 1º, per fishing set, was used for the analysis of the geographical distribution of fishing effort and catches.

Due to the high proportion of sets with zero catches of blue marlin (~85%; **Table 1**), a Generalized Linear Mixed Model (GLMM) using a Delta Lognormal approach was used for the standardization of CPUE. In the Delta Lognormal model, the catch rates are assumed to be the result of two dependent processes: a) the probability of catching at least one fish; and b) the conditional expected mean catch rate given that there is a positive probability of capture. In this case, the probability of capture was assumed to follow a binomial distribution, while the mean catch rate was assumed to follow a normal error distribution of the log-transformed CPUE. A GLMM model was applied with the logit function being used as the link between the linear predictor and the binomial error response variable.

The following factors were considered as explanatory variables in both models: “Year” (39), “Quarter” (4) and “Area” (A1>-10ºS; A2≤-10°S & ≥-25°S; and A3≤-25°S) (**Figure 1**). For the final model, the selection of factors and interactions was carried out by analysis of deviance tables (Ortiz and Arocha, 2004). Briefly, main factors and interactions were included in the model if: a) the percent of total deviance explained by a given factor/interaction was 5% or greater; and b) the Chi-square probability was 0.05 or less for the test of deviance explained versus the number of additional parameters estimated for a given factor or interaction. In the case of a statistically significant interaction between the year factor and any other factor, they were considered as random interactions in the final model.

Once the fixed factors and interactions were selected, all interactions involving the factor year and area were evaluated as random variables to obtain the estimated index per year, transforming the GLMs in a GLMMs. Selection of the final mixed model was based on the Akaike’s Information Criterion (AIC), Schwarz’s Bayesian Information Criterion (BIC), and a chi-square test of the difference between the [-2 log likelihood statistic] successive model formulations. Besides, the pseudo-R^2 was also calculated, following the approach described in Nakagawa and Schielzeth (2013), with the extension proposed by Johnson (2014).

Relative indices for the delta model formulation were calculated as the product of the year effect least square means (LSmeans) from the binomial and the lognormal model components. The LSmeans estimates use a weighted factor of the proportional observed margins in the input data to account for the un-balanced characteristics of the data. All statistical and data analyses developed in this study were performed using the software R-3.4.3 (R Core Team, 2017) with the aid of packages *dplyr* (Wickham and Francois, 2015), *ggplot2* (Wickham and Chang, 2016), *lme4* (Bates, 2016), *lsmeans* (Lenth, 2016), *lmerTest* (Kuznetsova *et al.*., 2016) and *MuMIn* (Barton, 2018).

3. Results and Discussion

The proportion of null catches of blue marlin for the Brazilian fleet during the period of the present study was ~86%. However, the proportion of positive catches varied during the period of study, averaging about 16%, between 1978 and 2010, and only 3%, from 2011 to 2016 (**Table 1; Figures 2** and **3**). The number of sets with positive and null catches by factors indicates that the proportion of positive sets was relatively uniform for quarter and area (**Figure 3**).

Table 2 presents a summary of the deviance analysis for the two stages of the Delta model, with a description for Lognormal and Binomial models. In both cases, the interaction “Year:Area” explained more than 20% of the total deviance. Thus, all interactions were tested in the GLMM as random variables. Comparisons of models considering different combinations of interactions were conducted and the selected models for the Lognormal and Binomial components are presented in **Table 3**.

Diagnostic plot for the Lognormal model showed that the assumption of the lognormal distribution for the positive dataset seems to be adequate as indicated in the QQ-plots (**Figure 4**). Residuals were homoscedastic at least in the case of the positive dataset. There were no temporal trends in the residuals on a yearly basis, so the assumption of independence of the samples was acceptable (**Figure 4**). The pseudo-R^2 values of the Lognormal and Binomial models were 0.21 and 0.41. For both models, the main factors were, in order of importance, “Year” (47-67%), “Area” (9-13%), “Year:Area” (22-40%) and “Quarter” (1-2%). The higher importance of the interaction “Year:Area” suggests an important and variable fluctuation in the spatiotemporal trends of the relative abundance of blue marlin in the studied area.

Model coefficients and respective effects (**Figure 5**) indicate that lower catch rates of blue marlin are expected during the 4th quarter, while higher catch rates are expected during the other quarters, with the highest catches happening during the 3th quarter. With regard to the area, higher catch rates are expected in area 2. For the Binomial model, the expected proportion of positives seems to be higher during 2th and 4th quarters, as well as for the area 2 (**Figure 5)**.

The standardized CPUE series shows a gradual decreasing trend, particularly after the year 2004 (**Table 4** and **Figure 6**), reaching a low level from 2007-2010, and decreasing to an even lower level from 2011 to 2016. In July 2005, the Brazilian Government made it mandatory the release of all blue marlins that are alive by the time of gear retrieval (Normative Instruction 12). It also prohibited the discard and commercialization of the dead fish, meaning that all blue marlins that are dead by the time of gear retrieval shall be taken to port to be donated to charity institutions. The first abrupt drop in nominal CPUE from 2005 to 2007 reflects the entering into force of that measure. The second drop, from 2010 to 2011, reflects a strengthening of enforcement. Although the skippers are obliged to take all the dead fish back to port and to record all catches in the logbooks, after some of the fishing companies were fined, accused of holding blue marlin for illegal selling in their premises, to avoid such risk, they started to just release both dead and live fish back to sea and no longer record the catches. This means the signal of blue marlin abundance form this fishery is lost and the CPUE series should not be used for stock assessment purposes after 2005. The only way to get reliable data for blue marlin CPUE from Brazilian longliners from now on is by having observers on board. Presently, such data are not available, but a new research program that will include the presence of observers on board Brazilian longliners is scheduled to start soon.

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Table 1. Number of sets and proportion of positive sets (with blue marlin catch) of the Brazilian longline fleet from 1978 to 2016.

Year	Number of sets	Proportion of positive sets	Year	Number of sets	Proportion of positive sets
1978	497	17.5%	1998	2605	17.2%
1979	474	24.3%	1999	5175	15.6%
1980	567	22.0%	2000	7713	17.7%
1981	460	20.7%	2001	9543	19.3%
1982	891	18.2%	2002	6561	8.1%
1983	614	28.5%	2003	3314	7.6%
1984	707	13.9%	2004	5290	19.5%
1985	464	11.4%	2005	5498	24.4%
1986	965	17.1%	2006	3851	22.8%
1987	927	18.8%	2007	5144	12.3%
1988	1217	16.3%	2008	1938	13.3%
1989	1025	21.4%	2009	1800	11.1%
1990	290	11.0%	2010	1243	12.0%
1991	926	19.0%	2011	1906	6.2%
1992	1086	12.8%	2012	3240	4.4%
1993	265	20.8%	2013	3400	0.5%
1994	1067	13.0%	2014	7832	1.0%
1995	1955	15.3%	2015	2403	0.5%
1996	993	12.3%	2016	3725	0.2%
1997	1805	19.4%			

Table 2. Deviance analysis table of positive catch rates (Lognormal) and proportion of positive sets (Binomial) models.

	Df	Deviance	Resid.Df	Resid. Dev.	Pr(>Chi)	Expl. Dev.
Positive catch rates						
NULL	.	.	13101	9305.0	.	.
Y	38	727.107	13062	8577.9	1.45E-207	47%
Y + A	2	194.325	13060	8383.6	1.84E-66	13%
Y + A + Q	3	13.3943	13057	8370.2	1.11E-04	1%
Y + A + Q+ Y:A	56	617.02	13001	7753.2	3.85E-180	40%
Proportion of positive						
NULL	.	.	392	11686.9	.	.
Y	38	6446.87	354	5240.1	0.00E+00	67%
Y + A	2	870.298	352	4369.8	1.04E-189	9%
Y + A + Q	3	168.553	349	4201.2	2.61E-36	2%
Y + A + Q+ Y:A	68	2108.5	281	2092.7	0.00E+00	22%

Table 3. Summary table of analyses of Delta Lognormal Mixed Model formulations for blue marlin catch rates from Brazilian pelagic longline fisheries from 1978 to 2016.

Model	AIC	BIC	logLik	Deviance	LRT	R-squared
Log-normal (positive catch rates)						
Y+A+Q+(1|Y:Q)	31121	31466	-15515	31029	NA	0.139
Y+A+Q+(1|Y:A)	30685	31029	-15296	30593	0.00E+00	0.213
Y+A+Q+(1|A:Q)	31266	31610	-15587	31174	1.00E+00	0.112
Y+A+Q+(1|Y:A)+(1|Y:Q)	30439	30790	-15172	30345	2.84E-18	0.254
Y+A+Q+(1|Y:A)+(1|A:Q)	30642	30993	-15274	30548	1.00E+00	0.209
Y+A+Q+(1|Y:A)+(1|Y:Q)+(1|A:Q)	30392	30751	-15148	30296	1.47E-56	0.250
Binomial (proportion of positive)						
Y+A+Q+(1|Y:Q)	4682	4860	-2296	4592	NA	0.349
Y+A+Q+(1|Y:A)	4000	4178	-1955	3910	0.00E+00	0.410
Y+A+Q+(1|A:Q)	5591	5770	-2750	5501	1.00E+00	0.349
Y+A+Q+(1|Y:A)+(1|Y:Q)	3276	3459	-1592	3184	0.00E+00	0.422
Y+A+Q+(1|Y:A)+(1|A:Q)	3924	4106	-1916	3832	1.00E+00	0.410
Y+A+Q+(1|Y:A)+(1|Y:Q)+(1|A:Q)	3208	3395	-1557	3114	4.19E-158	0.423

Table 4. Nominal and standardized index of relative abundance of blue marlin caught by Brazilian pelagic longline fishery fleet between the years of 1978 to 2016.

Year	Index	LCI_index	UCI_index	CV_index	Nominal CPUE	Scaled Nominal CPUE	Scaled index
1978	0.102	0.031	0.292	0.208	0.131	0.656	0.787
1979	0.203	0.045	0.676	0.267	0.222	1.114	1.567
1980	0.158	0.031	0.633	0.289	0.212	1.067	1.217
1981	0.270	0.043	1.000	0.298	0.206	1.036	2.082
1982	0.261	0.054	0.848	0.270	0.238	1.194	2.013
1983	0.392	0.071	1.329	0.293	0.464	2.330	3.020
1984	0.139	0.039	0.447	0.224	0.244	1.223	1.068
1985	0.074	0.015	0.323	0.291	0.114	0.572	0.569
1986	0.132	0.035	0.431	0.223	0.191	0.962	1.017
1987	0.289	0.092	0.790	0.193	0.353	1.775	2.224
1988	0.129	0.032	0.443	0.227	0.159	0.796	0.991
1989	0.193	0.053	0.601	0.220	0.264	1.324	1.487
1990	0.077	0.009	0.537	0.343	0.131	0.656	0.597
1991	0.112	0.034	0.327	0.199	0.167	0.837	0.863
1992	0.119	0.036	0.356	0.198	0.195	0.978	0.917
1993	0.138	0.021	0.743	0.326	0.226	1.133	1.060
1994	0.087	0.026	0.265	0.203	0.166	0.833	0.669
1995	0.111	0.034	0.329	0.200	0.182	0.912	0.858
1996	0.143	0.044	0.409	0.197	0.172	0.864	1.100
1997	0.206	0.068	0.550	0.181	0.349	1.752	1.588
1998	0.149	0.048	0.414	0.181	0.466	2.343	1.145
1999	0.164	0.054	0.451	0.177	0.202	1.014	1.265
2000	0.225	0.074	0.604	0.175	0.328	1.646	1.730
2001	0.244	0.079	0.687	0.179	0.402	2.019	1.880
2002	0.104	0.032	0.318	0.188	0.156	0.783	0.799
2003	0.045	0.012	0.168	0.242	0.142	0.714	0.347
2004	0.199	0.062	0.583	0.188	0.312	1.568	1.536
2005	0.170	0.052	0.504	0.196	0.384	1.929	1.310
2006	0.128	0.039	0.378	0.196	0.256	1.287	0.988
2007	0.059	0.018	0.189	0.202	0.145	0.728	0.456
2008	0.052	0.014	0.185	0.233	0.169	0.850	0.402
2009	0.047	0.012	0.172	0.240	0.147	0.737	0.363
2010	0.051	0.013	0.186	0.244	0.126	0.635	0.391
2011	0.023	0.006	0.088	0.248	0.039	0.196	0.180
2012	0.041	0.011	0.148	0.236	0.065	0.326	0.318
2013	0.006	0.001	0.036	0.377	0.014	0.070	0.046
2014	0.011	0.003	0.041	0.235	0.017	0.084	0.087
2015	0.006	0.001	0.029	0.357	0.007	0.037	0.043
2016	0.003	0.000	0.020	0.406	0.004	0.020	0.022

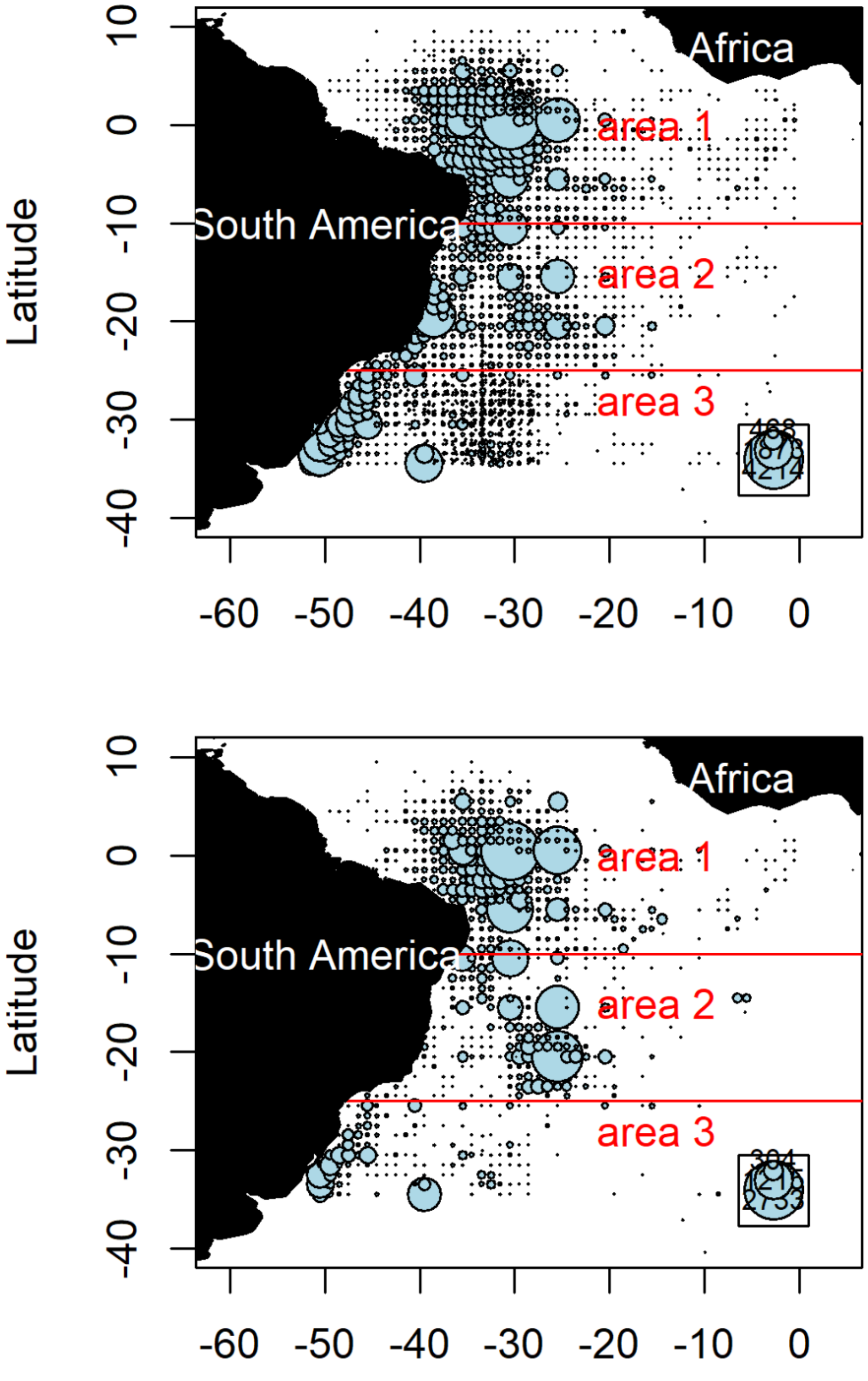

Figure 1. Distribution of the fishing sets (upper panel) and blue marlin catches (bottom panel), in numbers of fish, done by the Brazilian tuna longline fishery in the Atlantic Ocean from 1978 to 2016. Red lines depict the delimitation of the factor "Area" used in the models.

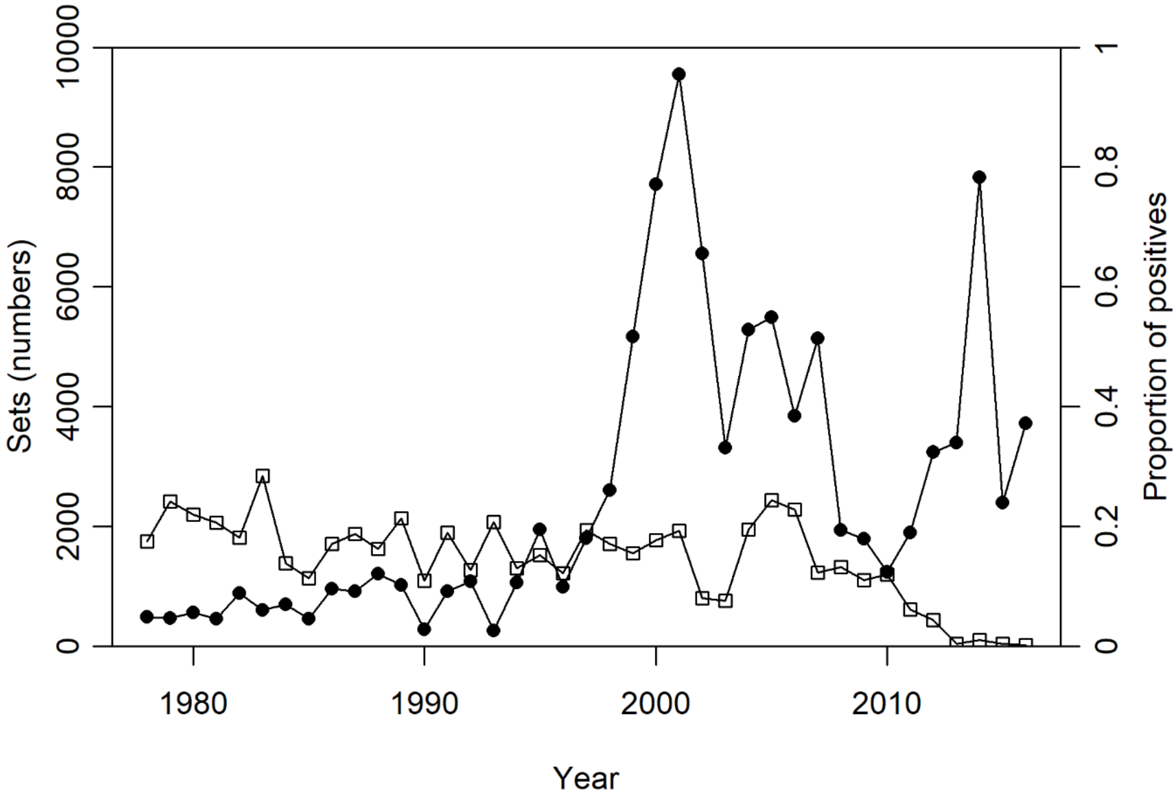

Figure 2. Number of sets (black circles) and proportion of positive catches (open squares) for blue marlin caught by the Brazilian tuna longline fleet 1978 to 2016.

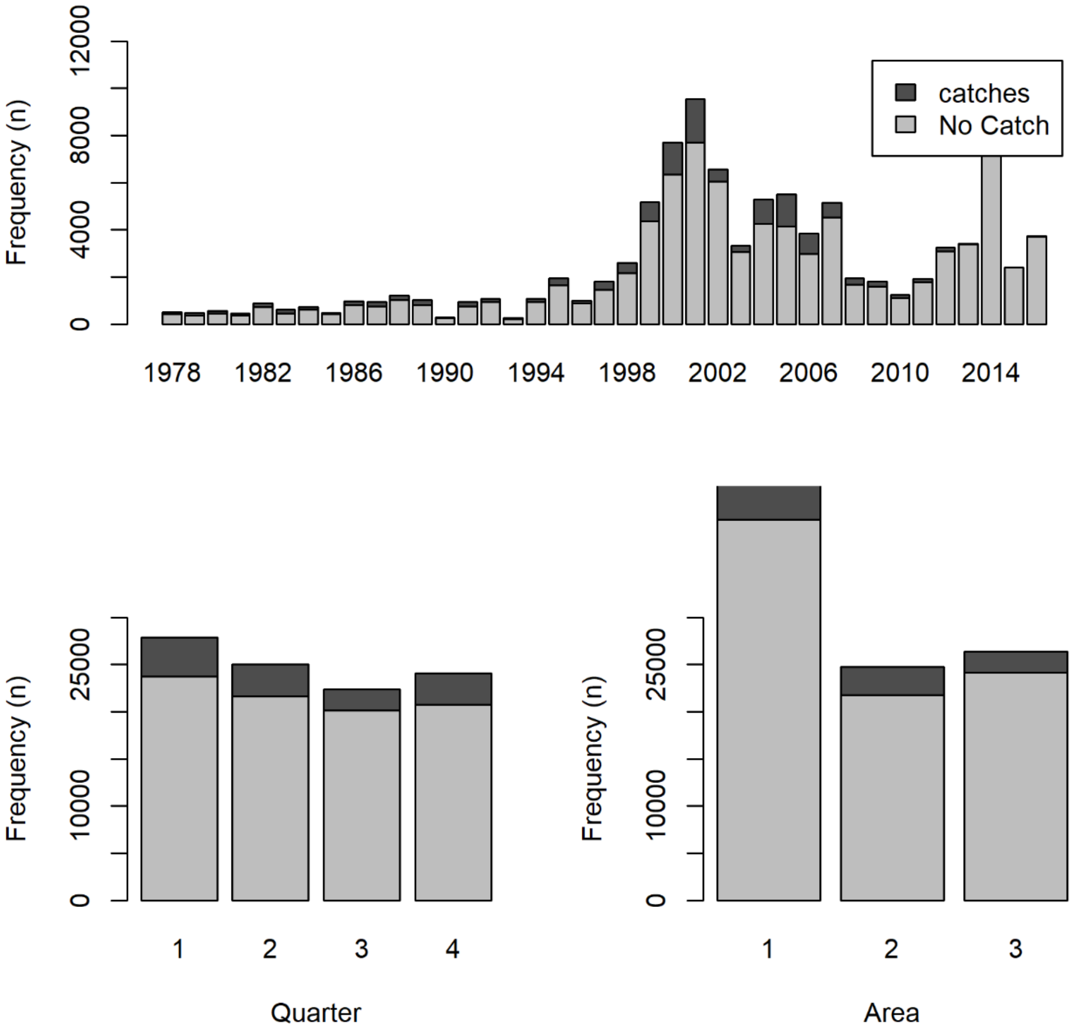

Figure 3. Proportion of positive catches and negative sets by year, quarter, area for blue marlin caught by the Brazilian tuna longline fleet 1978 to 2016.

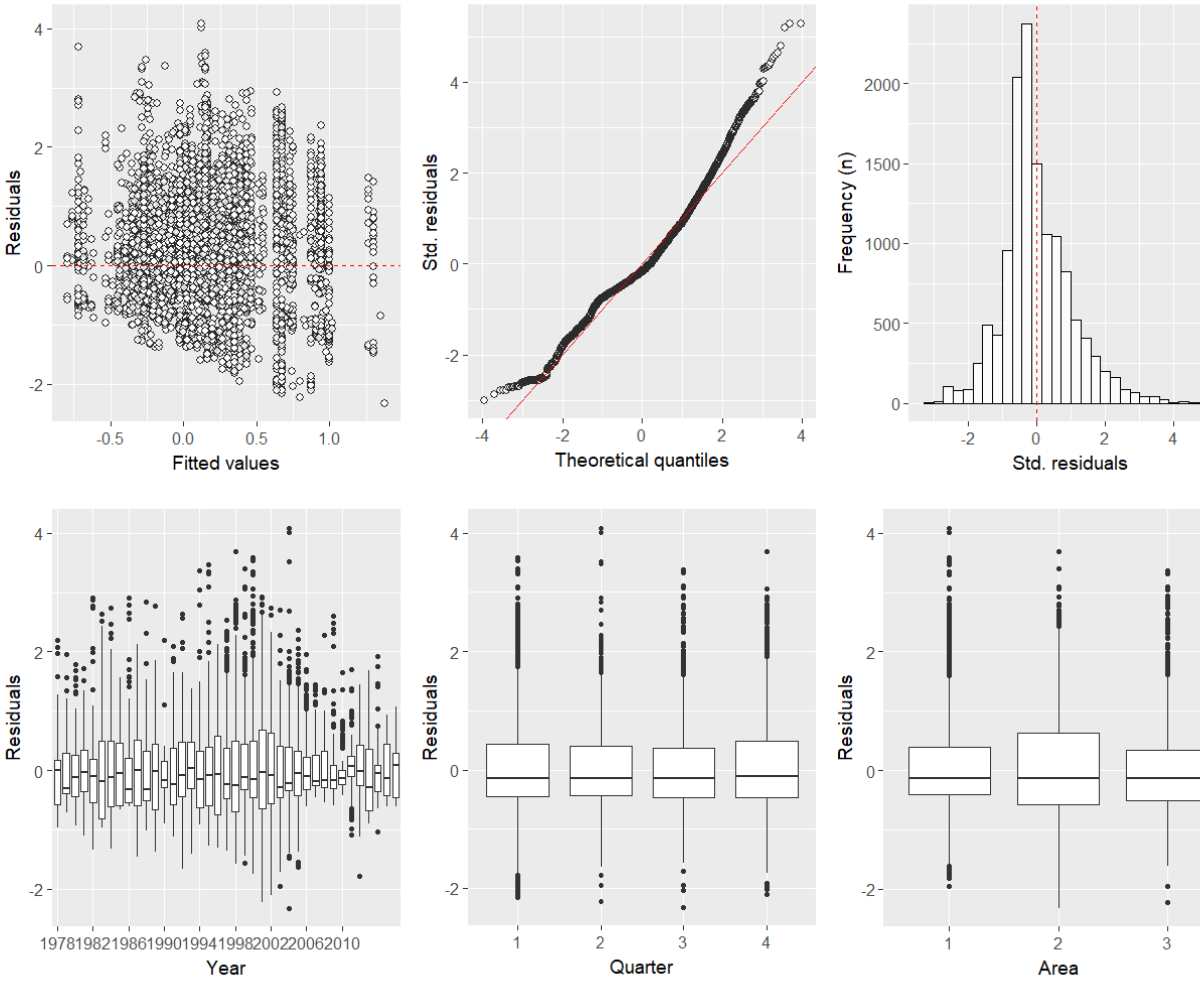

Figure 4. Residual analysis of the Lognormal model fitting of blue marlin caught by the Brazilian tuna longline fleet 1978 to 2016.

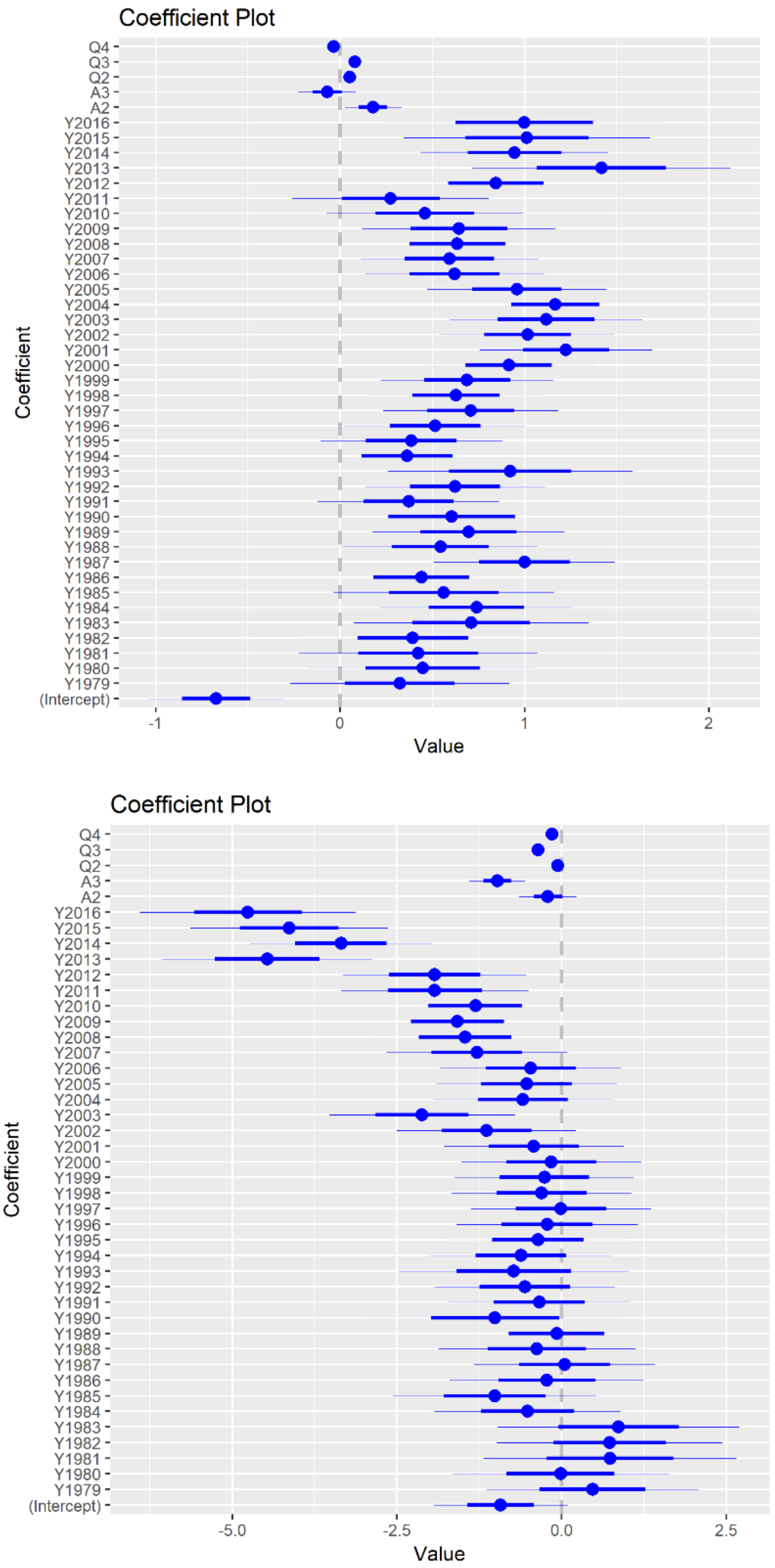

Figure 5. Coefficient estimates from Log-normal model (upper panel) and Binomial model (bottom panel) for predicting blue marlin catch rates in the Atlantic Ocean. For each parameter it is indicated the point estimate, the 50% (thick lines) and the 95% (thin lines) confidence intervals.

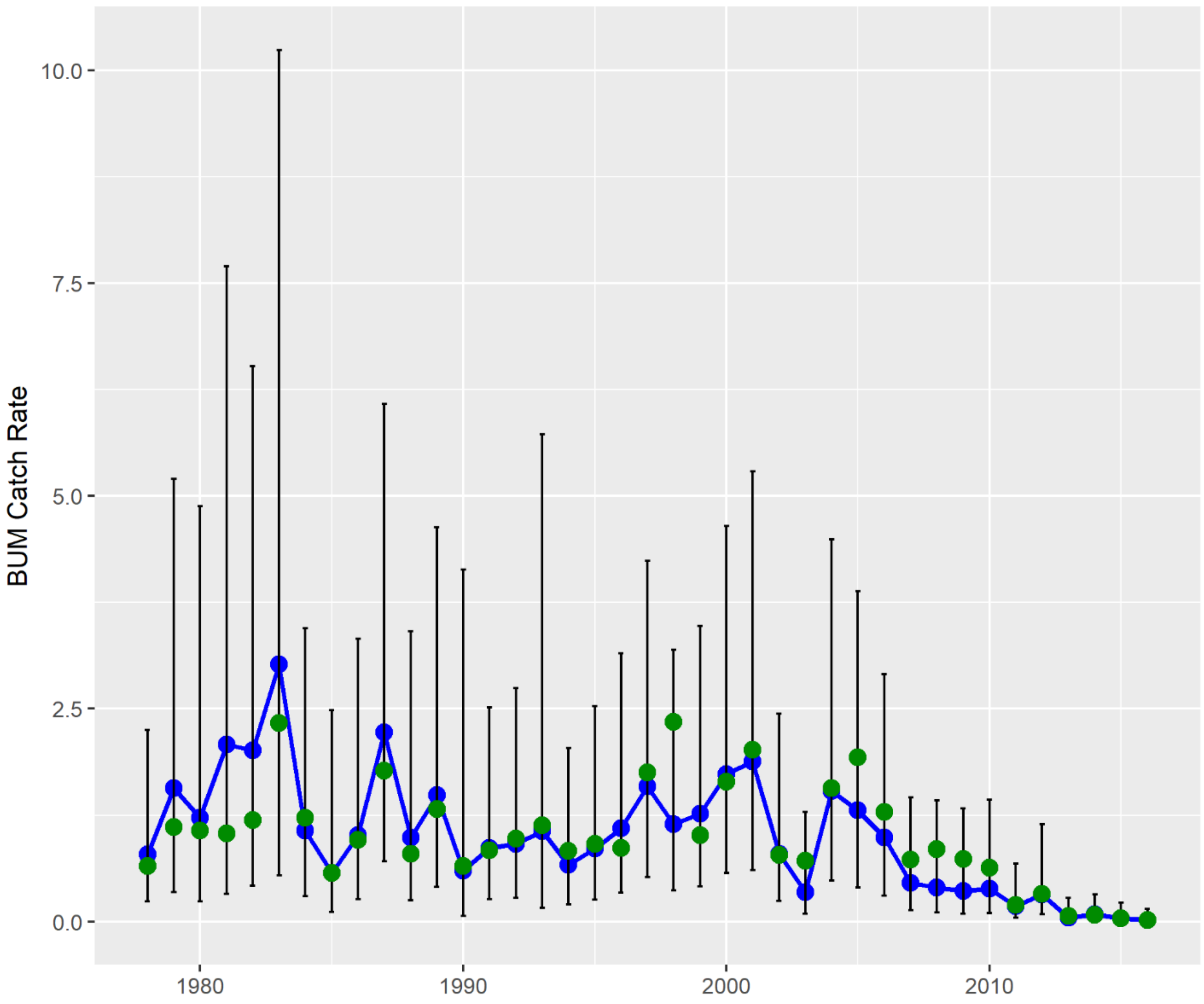

Figure 6. Catch rates of blue marlin for Brazilian tuna longliners from 1978 to 2016. Blue line represents the standardized catch rate and error bars depicts the associated confidence intervals estimates (95%). Green circles are the nominal catch rates.