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STANDARDIZED CATCH RATES OF SHORTFIN MAKO CAUGHT BY THE BRAZILIAN FLEET (1978-2012) USING A GENERALIZED LINEAR MIXED MODEL (GLMM), WITH A DELTA LOG APPROACH

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SUMMARY

*In the present paper, catch and effort data from 91,831 sets done by the Brazilian tuna longline fleet, including both national and chartered vessels, in the equatorial and southwestern Atlantic Ocean, from 1978 to 2012, were analyzed. The fished area was 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. The CPUE of the shortfin mako shark was standardized by a Generalized Linear Mixed Model (GLMM) using a Delta Lognormal approach. The factors used in the model were: year, fishing strategy, quarter, area, sea surface temperature, and the interactions year:area and year:quarter. The standardized CPUE series of the shortfin mako showed a gradual increasing trend, particularly after the year 2000 (**Table 4** and **Figure 7**). The reason for such a trend is not clear and could result from a number of factors, including: an actual increase in abundance, an increase in catchability, a change in the fishing strategy or an improvement in data reporting.*

RÉSUMÉ

*Le présent document analysait les données de prise et d'effort provenant de 91.831 opérations de la flottille palangrière brésilienne (nationale et affrétée) ciblant les thonidés dans l'océan Atlantique équatorial et du Sud-Ouest entre 1978 et 2012. La zone de pêche a été distribuée sur une vaste zone de l'océan Atlantique équatorial et du Sud, s'étendant de 3ºW à 52ºW de longitude et de 11ºN à 40ºS de latitude. La CPUE du requin-taupe 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 : année, stratégie de pêche, trimestre, zone, température de surface de la mer et les interactions année-zone et année-trimestre. La série de CPUE standardisée du requin-taupe bleu a montré une tendance ascendante progressive, surtout après l'an 2000 (**tableau 4 et figure 7**). La raison de cette tendance n'est pas claire et pourrait résulter d'un certain nombre de facteurs, notamment une augmentation réelle de l'abondance, une augmentation de la capturabilité, un changement de stratégie de pêche ou une amélioration de la déclaration des données.*

RESUMEN

*En este documento se analizan los datos de captura y esfuerzo de 91.831 lances realizados por la flota atunera brasileña de palangre (de buques nacionales y fletados) en el Atlántico suroccidental y ecuatorial entre 1978 y 2012. La zona de pesca se distribuía a lo largo de una amplia zona del Atlántico meridional y ecuatorial, entre 3ºW y 52ºW de longitud y 011ºN y 40ºS de latitud. Se estandarizó la CPUE del marrajo dientuso mediante un modelo lineal mixto generalizado (GLMM) utilizando un enfoque delta lognormal. Los factores usados en el modelo fueron: año, estrategia de pesca, trimestre, área, temperatura de la superficie del mar, y las interacciones año:área y año:trimestre. La serie de CPUE estandarizada del marrajo dientuso presentaba una tendencia creciente gradual, especialmente después del año 2000 (**Tabla 4 y Figura 7**). La razón de dicha tendencia no está clara y podría ser el resultado de varios factores, lo que incluye un aumento real en la abundancia, un aumento de la capturabilidad, un cambio en la estrategia de pesca o una mejora en la comunicación de datos.*

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KEYWORDS

Shortfin mako; CPUE; GLMM

1. Introduction

In recent decades, there has been a growing concern with the status of several shark populations worldwide, mainly because of an increased mortality resulting from fishing. Among the pelagic sharks, the blue shark and the mako shark are two of the most common and widely distributed species, being mainly caught by the tuna longline fishery targeting tunas and swordfish. Although they were initially caught exclusively as bycatch, their status in the fishery has gradually changed over time, with an increased number of boats and fleets starting to target them, together with tunas and swordfish. The increased fishing pressure on these species has prompted Regional Fisheries Management Organizations, such as the International Commission for the Conservation of Atlantic Tunas- ICCAT, to assess the condition of their stocks and the impact of the tuna fishery on them, aiming at designing and implementing management and conservation measures required to ensure their conservation.

The first attempt to assess the status of the mako stocks in the Atlantic Ocean was led by the Standing Committee on Research and Statistics of ICCAT (SCRS), in 2004. At that time, the main hindrance for the evaluation exercise was the lack of adequate data. Subsequent attempts to assess the condition of the mako stocks in the Atlantic Ocean were undertaken by ICCAT/SCRS in 2008 and 2012, but the results were again rather inconclusive, particularly in the case of the South Atlantic Population. As noted in the SCRS report of the 2008 assessment, it resulted in an estimate of unfished biomass that was biologically implausible, and thus the Committee could not draw any conclusion about the status of the southern stock. During the 2012 shortfin mako stock assessment, different standardized CPUE series were presented, both for the South and North stocks, but conflicting trends of CPUE and catch tendencies again casted doubt on the accuracy of the results. According to the report, the Committee noted that the increase in the CPUE series could be due to several reasons, including an increase in abundance, an increase in catchability, in the fishing strategy or in data reporting for this species. Finally, in 2015, a new stock assessment was required by the Commission, to be done in 2017, preceded by a data preparatory meeting in 2016.

With a view, therefore, to contribute information for the assessment of the South Atlantic stock of the mako shark, scheduled for 2017, in the present paper a standardized series of CPUE for the species, caught by the Brazilian fleet, including both national and chartered vessels, was updated, spanning for 35 years, from 1978 to 2012.

2. Material and Methods

In the present study, catch and effort data from 91,831 tuna longline sets obtained from logbooks reported by the Brazilian tuna longline fleet, including both national and foreign chartered vessels, from 1978 to 2012, were analyzed. 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 shortfin mako (85.6%), a 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.

GLMM models are generally non-orthogonal and the order of entry of explanatory variables affects the contribution of each variable in the final model (McCullagh & Nelder, 1989). 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 (Generalized Linear Mixed Models) (Cooke 1997). 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 (Littell et al. 1996). 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. The factors considered as explanatory variables were "Year" (35), "Quarter" (4), "Area" (A1>20ºS; A2<20ºS), "Fleet strategy" (3). The fleet strategy was estimated in two steps. In the first step, a multivariate cluster analysis was conducted to identify the different Targeting Strategies (TS) by combining clusters of predominant species that were internally coherent and externally isolated (MathSoft, 1995). A total of 91,831 fishing sets with approximately 25 species reported in the observer logbooks were analyzed. The Target Strategy typology was then built using the "K Means" method (Kaufman and Rousseeuw, 2005). This approach is widely applied among non-hierarchical clustering techniques and is well adapted to very large datasets. Each cluster (of fishing sets) can be considered a Target Strategy (He *et al*., 1997; Pelletier and Ferraris, 2000; Hazin *et al*., 2007; Mourato *et al*., 2011). For a given number of clusters, the final value of the criterion is given. Analyses were conducted with different numbers of clusters, among which the most realistic solution was chosen when considering the evolution of the criterion value. The Target Strategy can be described by the mean values obtained (centroids) (Fall *et al*., 2006). In the second step, a matrix was constructed considering the frequency of sets conducted by each fishing vessel within each cluster (Target Strategy). Then, a Fuzzy Clustering method with ordination-based Canonical Correspondence Analysis (CCA) was applied to find coherent patterns that may discriminate clusters of vessels (Fishing Fleets) with similar fishing strategies.

Because multiple explanatory variables were used in these models, which may potentially cause multicollinearity problems, Generalized Variance Inflation Factors (GVIF) were calculated for the models main effects (Fox and Monette, 1992). The definition of threshold values for these GVIF seems to be somewhat arbitrary, but as a general rule most authors recommend that values higher than 5 may be cause for concern, while values higher than 10 can indicate serious collinearity problems (Hair *et al.*, 1995; O'Brien, 2007).

All statistical and data analyses developed on this study were performed using the software R-3.2.4 (R Core Team, 2016) with the aid of packages *dplyr* (Wickham and Francois, 2015), *ggplot2* (Wickham, 2016), *lme4* (Bates, 2016), *lsmeans* (Lenth, 2016), *lmerTest* (Kuznetsova et al., 2016).

3. Results and Discussion

In terms of preliminary analysis of the explanatory variables, the shortfin mako CPUE had a significant and positive correlation with year, area, quarter and fishing strategy, and a significant negative correlation with SST (**Figure 2**). Some of the possible explanatory variables were also correlated between themselves, such as for example SST that was negatively correlated with both area (-0.78) and quarter (-0.27) (Figure 2). In this multivariate simple effect model, the Generalized Variance Inflation Factors (GVIFs) were calculated and in all cases the values were < 10, meaning that severe collinearity problems between these explanatory variables were not likely to be occurring. The calculated GVIF factors were: Year=3.66, Quarter=1.72, Area=3.26, Strategy=2.75 and SST=3.89.

The proportion of null catches of shortfin mako for the Brazilian fleet during the period of the present study was 85.6%. Positive catches proportion varied during the period of study between 1.9% and 36.6% of the sets (**Table 1**). The number of sets with positive and null catches by factors (**Figures 3**) indicates that the proportion of positive sets was relatively uniform for quarter and area, but different for fishing strategy, as it should be expected, and for different years, since the distribution of the different fishing strategies changed from year to year.

Table 2 presents a summary of the deviance analysis for the two stages of the Delta model, a description for Lognormal and Binomial models. In both cases, the interactions year:quarter and year:area explained more than 5% 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 their summaries are presented in **table 3**. The selected models for the Lognormal and Binomial components were:

- Lognormal Model: log(CPUE)= Year+Strategy+Quarter+Area+SST+Year:Area+Year:Quarter
- Binomial Model: PROP= Year+Strategy+Quarter+Area+SST+Year:Area+Year:Quarter

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 final models explained 40% of the total variance. The value of parameter dispersion was 0.58, indicating that the final model does not show an overdispersion. The main factors were, in order of importance, year (52.3%), year:area (17.4%), year:quarter (14.6%), quarter (4.9%), area (4.9%), fishing strategy (4.3%) and SST (1.5%). According to Maunder & Punt (2004), the relatively low values of the pseudo-R^2 found in the present work are common in catch and effort data, due to the several factors that influence relative abundance but can't be considered in the model, including environmental, technological and operational factors. Besides, despite the "fishing strategy" was included as a factor in the present case, it is clearly an oversimplification of the many factors that certainly can't be accounted for, including the targeting behavior of the skipper, which might be reflected in slight operational changes in the fishing operation, which may have a significant impact on the catch composition. The higher importance of the factor year:quarter and year:area in shortfin mako CPUE suggests an important and variable fluctuation in the spatiotemporal distribution of the species, from one year to the other.

In terms of model interpretation, models coefficients and respective effects presented in **Figure 5 and 6**, some interpretations can be taken with regards to the effects of the explanatory variables in the expected shortfin mako catch rates. In terms of seasonality it is expected for the fishery to have lower catch rates of shortfin mako during the quarter 1 (baseline), while higher catch rates are expected during the other quarters, specifically with highest catches during quarter 3 and 4. With regards to the environmental variables, higher catch rates are expected with decreasing SST. In terms of spatial variables, the expected catch rates increase towards area 2.

The standardized CPUE series shows a gradual increasing trend, particularly after the year 2000 (**Table 4 and Figure 7**). The reason for such a trend is not clear and could result from a number of factors, including those already noted in the 2008 assessment report, i.e.: an actual increase in abundance, an increase in catchability, a change in the fishing strategy or an improvement in data reporting for this species. Based exclusively on the present data, it is not possible to infer any of these potential reasons. The increasing trend noted in 2012, based on data spanning up to 2010, seems to be confirmed by the present results. A comparison with the trends shown in recent years by other fleets in this same ocean basin, e.g. Japanese, Chinese Taipei, Spanish, might confirm if this is a general trend or a behavior peculiar to the Brazilian fleet. Unfortunately, due to several problems faced by the country with regard to its fisheries statistics, it was not possible to update the Brazilian CPUE series up to more recent years, i.e. 2015 or, at least, 2014. Efforts, however, are on the way and hopefully more recent data will be made available, before the 2017 assessment.

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Table 1. Catch and effort information of the Brazilian longline fleet from 1978 to 2012.

Year	*Positive*	*Zero*	*% of zero*
1978	41	408	90.9
1979	21	389	94.9
1980	73	458	86.3
1981	29	436	93.8
1982	66	811	92.5
1983	31	576	94.9
1984	59	649	91.7
1985	63	394	86.2
1986	120	843	87.5
1987	58	820	93.4
1988	177	1030	85.3
1989	100	911	90.1
1990	16	274	94.5
1991	109	786	87.8
1992	70	1030	93.6
1993	5	258	98.1
1994	114	960	89.4
1995	192	1760	90.2
1996	69	911	93.0
1997	87	1658	95.0
1998	601	2013	77.0
1999	412	4832	92.1
2000	412	7566	94.8
2001	781	8929	92.0
2002	1137	5401	82.6
2003	543	2733	83.4
2004	1074	4133	79.4
2005	882	3064	77.6
2006	770	2107	73.2
2007	622	1883	75.2
2008	251	1272	83.5
2009	311	1643	84.1
2010	115	646	84.9
2011	286	764	72.8
2012	1107	1920	63.4

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

Model	*Deviance*	*Change in deviance*	*% of total deviance*
Positive catch rates			
Null	8952.03	NA	NA
Y	7518.00	1434.03	52.3
Y +S	7400.48	117.52	4.3
Y +S + Q	7265.40	135.08	4.9
Y + S + Q + A	7130.34	135.06	4.9
Y + S + Q + A + SST	7089.03	41.32	1.5
Y + S + Q + A + SST + Y:A	6571.46	517.57	18.9
Y + S + Q + A + SST + Y:Q	6688.40	-116.94	-4.3
Y + S + Q + A + SST + Y:A + Y:Q	6209.59	478.81	17.5
Proportion of positive			
Null	35773.29	NA	NA
Y	31760.50	4012.79	32.0
Y +S	30022.15	1738.36	13.9
Y +S + Q	29124.13	898.01	7.2
Y + S + Q + A	25639.71	3484.43	27.8
Y + S + Q + A + SST	25395.07	244.64	1.9
Y + S + Q + A + SST + Y:A	23934.62	1460.45	11.6
Y + S + Q + A + SST + Y:Q	24428.23	-493.61	-3.9
Y + S + Q + A + SST + Y:A + Y:Q	23224.81	1203.43	9.6

Table 3. Summary table of analyses of Delta Lognormal Mixed Model formulations for shortfin mako catch rates from Brazilian pelagic longline fisheries from 1978 to 2012.

Model	**AIC**	**BIC**	**logLink**	**LHT**
Positive catch rates				
Y + S + Q + A + SST + (1 | Y:A)	25588.3	25909.0	-12750.2	0.00
Y + S + Q + A + SST + (1 | Y:Q)	25888.0	26208.7	-12900.0	1
Y + S + Q + A + SST + (1 | Y:A) + (1 | Y:Q)	25251.6	25579.6	-12580.8	0.01
Proportion of positive				
Y + S + Q + A + SST + (1 | Y:A)	30305.9	30633.0	-15110.0	0.00
Y + S + Q + A + SST + (1 | Y:Q)	30968.2	31295.3	-15441.1	1
Y + S + Q + A + SST + (1 | Y:A) + (1 | Y:Q)	29922.6	30257.3	-14917.3	0.00

Table 4. Nominal and standardized index of relative abundance of shortfin mako caught by Brazilian pelagic longline fishery fleet between the years of 1978 to 2012.

Year	*CPUE nominal*	*index*	*LCI index*	*UCI index*	*CV*	*Scaled index*	*LCI index scaled*	*UCI index scaled*	*Scaled CPUE*
1978	0.051	0.013	0.082	0.002	0.506	0.111	0.718	0.016	0.178
1979	0.031	0.007	0.064	0.001	0.548	0.061	0.556	0.006	0.109
1980	0.118	0.033	0.244	0.004	0.542	0.290	2.130	0.036	0.411
1981	0.056	0.010	0.086	0.001	0.538	0.087	0.752	0.010	0.194
1982	0.060	0.010	0.081	0.001	0.529	0.088	0.712	0.011	0.209
1983	0.032	0.006	0.054	0.001	0.538	0.054	0.471	0.006	0.113
1984	0.132	0.040	0.188	0.008	0.429	0.353	1.640	0.073	0.461
1985	0.157	0.058	0.264	0.012	0.439	0.510	2.305	0.105	0.549
1986	0.122	0.044	0.191	0.010	0.425	0.384	1.670	0.083	0.427
1987	0.061	0.021	0.103	0.004	0.432	0.186	0.896	0.037	0.212
1988	0.194	0.075	0.312	0.017	0.429	0.654	2.730	0.145	0.677
1989	0.133	0.059	0.259	0.012	0.428	0.512	2.264	0.109	0.464
1990	0.319	0.131	1.145	0.013	0.587	1.141	10.008	0.115	1.113
1991	0.126	0.043	0.232	0.008	0.477	0.376	2.028	0.066	0.439
1992	0.048	0.052	0.237	0.011	0.438	0.459	2.067	0.095	0.167
1993	0.025	0.015	0.187	0.001	0.633	0.133	1.635	0.010	0.087
1994	0.127	0.077	0.328	0.017	0.430	0.674	2.862	0.148	0.442
1995	0.186	0.138	0.581	0.030	0.426	1.205	5.079	0.266	0.651
1996	0.175	0.147	0.654	0.030	0.446	1.282	5.716	0.265	0.611
1997	0.121	0.078	0.355	0.016	0.422	0.679	3.101	0.143	0.424
1998	0.244	0.160	0.563	0.039	0.450	1.396	4.916	0.343	0.850
1999	0.162	0.081	0.345	0.018	0.420	0.707	3.013	0.157	0.566
2000	0.088	0.052	0.227	0.012	0.414	0.457	1.981	0.101	0.306
2001	0.195	0.179	0.734	0.041	0.422	1.568	6.418	0.356	0.679
2002	0.318	0.210	0.826	0.048	0.430	1.833	7.215	0.424	1.111
2003	0.483	0.246	0.947	0.057	0.436	2.150	8.277	0.502	1.686
2004	0.364	0.271	0.940	0.067	0.451	2.367	8.210	0.588	1.272
2005	0.488	0.163	0.612	0.039	0.438	1.423	5.343	0.337	1.702
2006	0.872	0.158	0.610	0.037	0.435	1.380	5.327	0.322	3.043
2007	0.989	0.200	0.757	0.047	0.438	1.744	6.619	0.410	3.452
2008	1.632	0.227	0.915	0.051	0.433	1.983	7.995	0.448	5.697
2009	0.504	0.191	0.744	0.044	0.435	1.669	6.505	0.386	1.760
2010	0.342	0.194	0.793	0.042	0.451	1.694	6.927	0.368	1.193
2011	0.321	0.394	1.235	0.102	0.484	3.446	10.792	0.891	1.122
2012	0.751	0.223	0.790	0.054	0.449	1.945	6.905	0.475	2.621

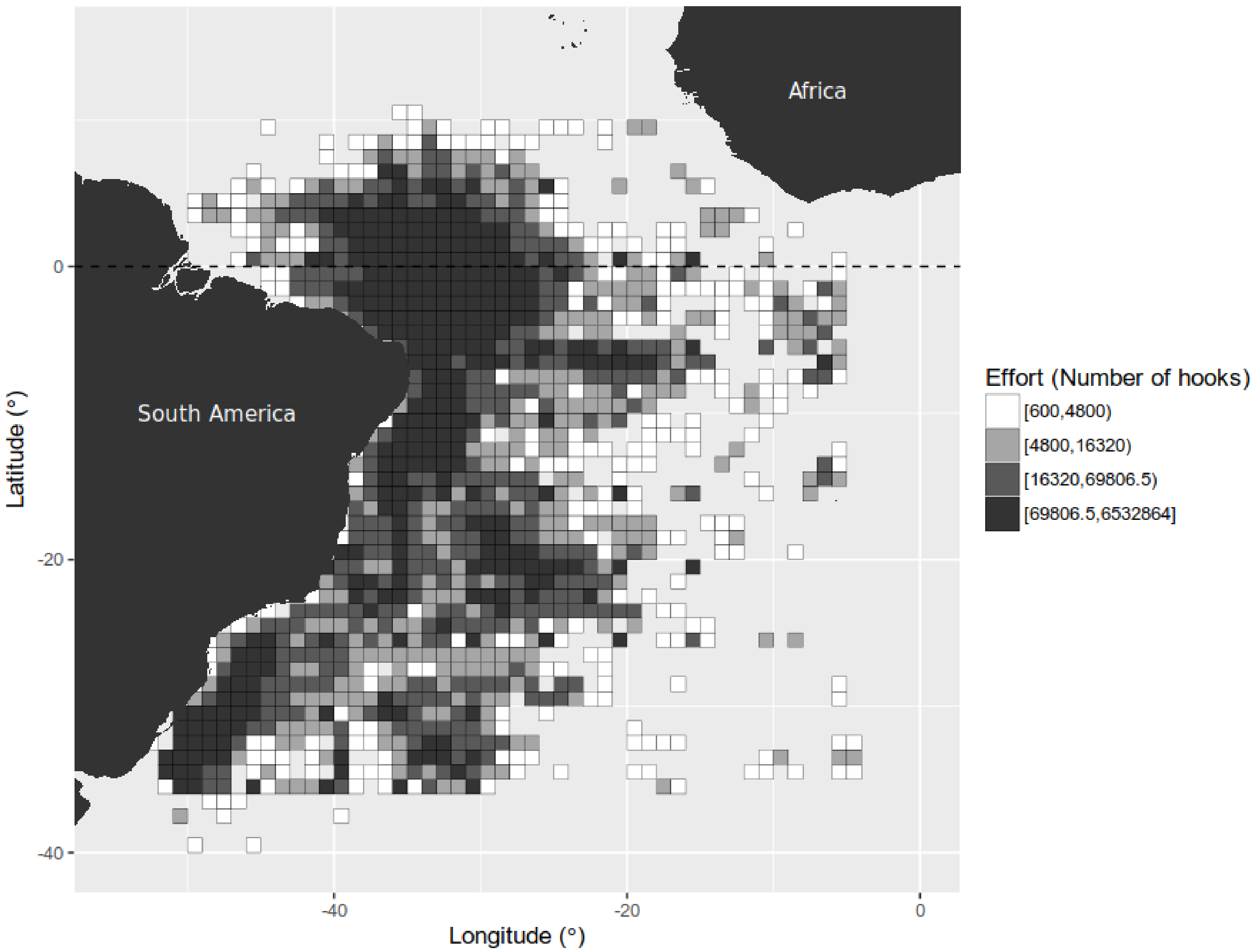

Figure 1. Distribution of the effort done by the Brazilian tuna longline fishery in the Atlantic Ocean from 1978 to 2012 (35 years).

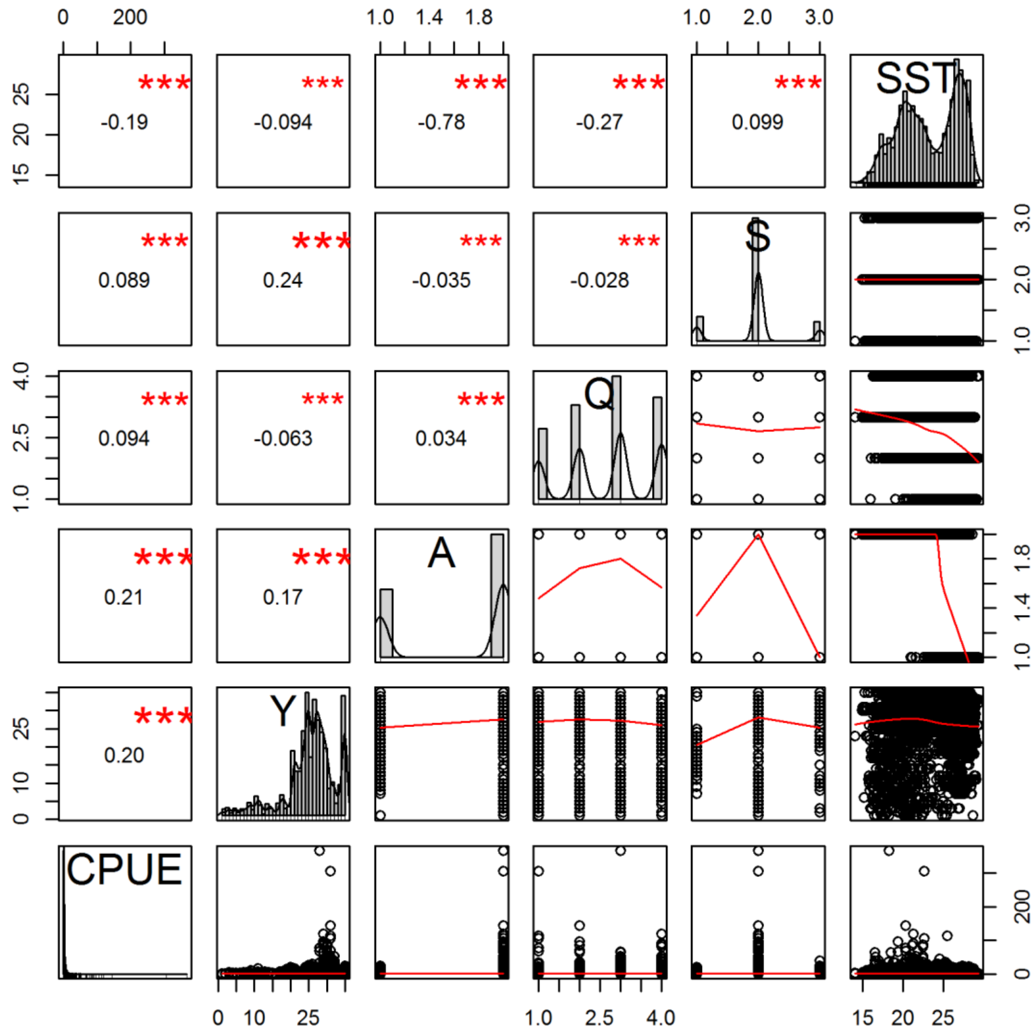

Figure 2. Scatterplots matrices with the relationships between shortfin mako CPUE and the candidate continuous explanatory variables used diagonal panels show the scatterplots with smooth lowess regression lines.

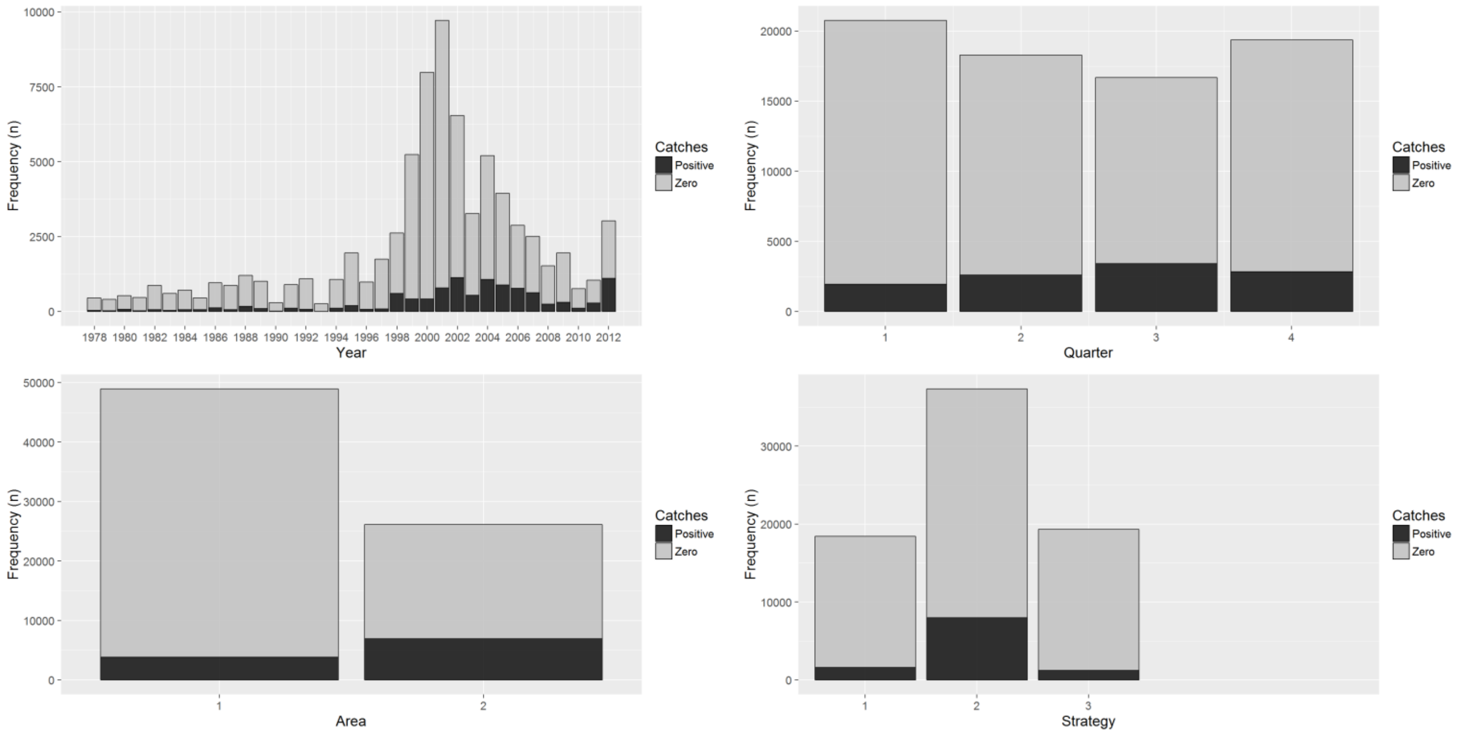

Figure 3. Proportion of positive captures and negative sets by year, quarter, area and strategy.

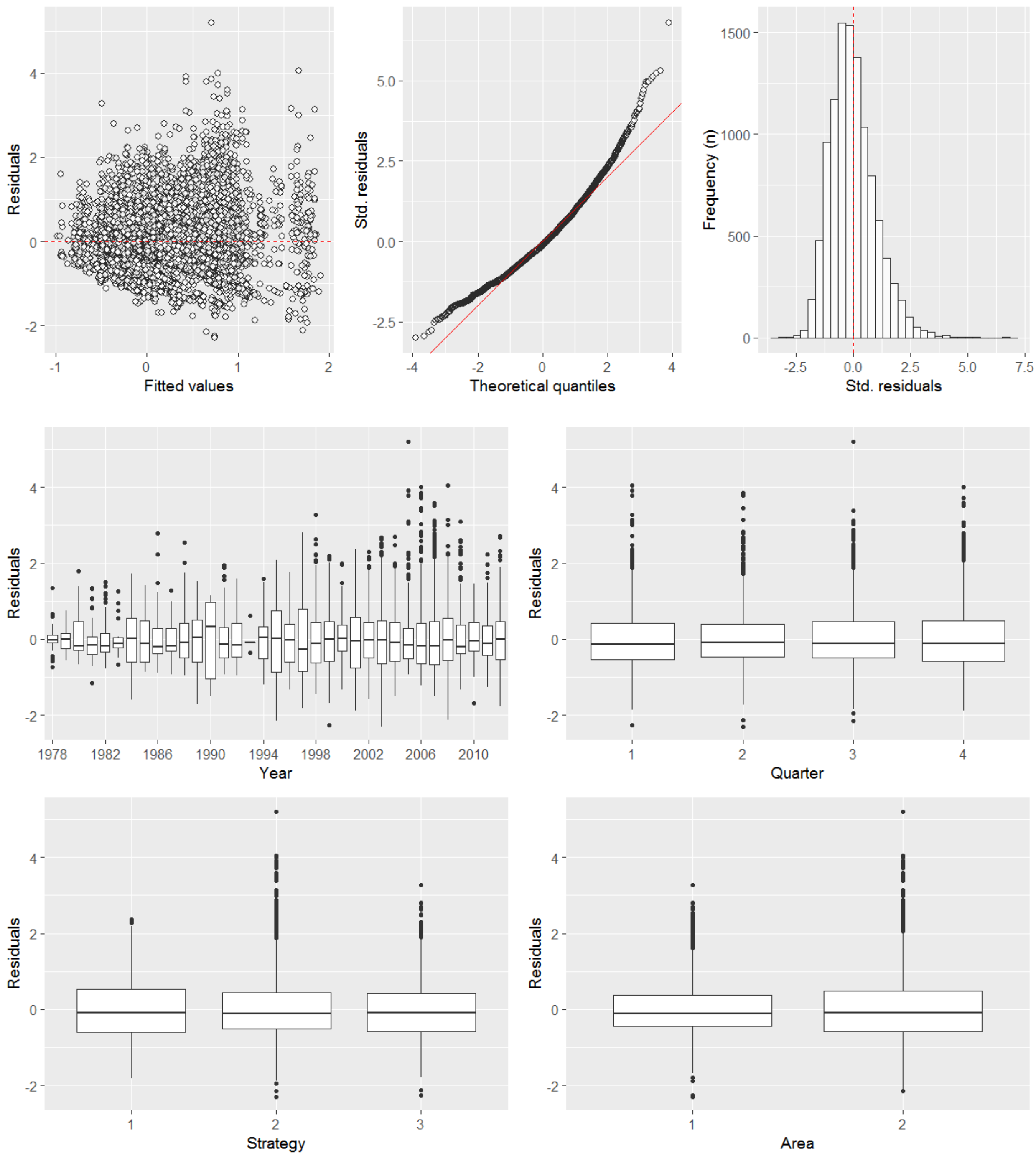

Figure 4. Residual analysis of the Lognormal model fitting of shortfin mako caught by the Brazilian tuna longline fleet 1978 to 2012.

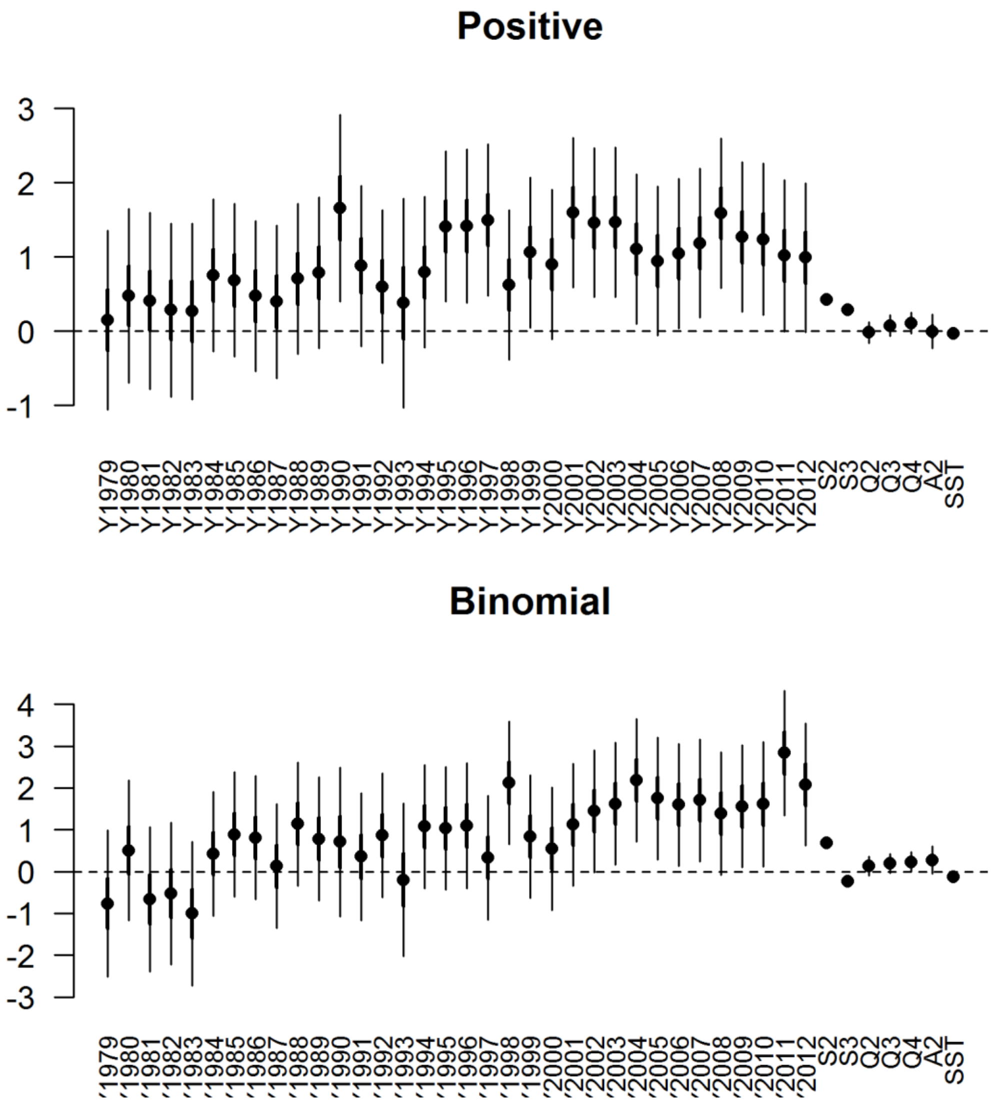

Figure 5. Parameter estimates for predicting shortfin mako catch rates in the Southern Atlantic Ocean. For each parameter it is indicated the point estimate, the 50% (thick lines) and the 95% (thin lines) confidence intervals.

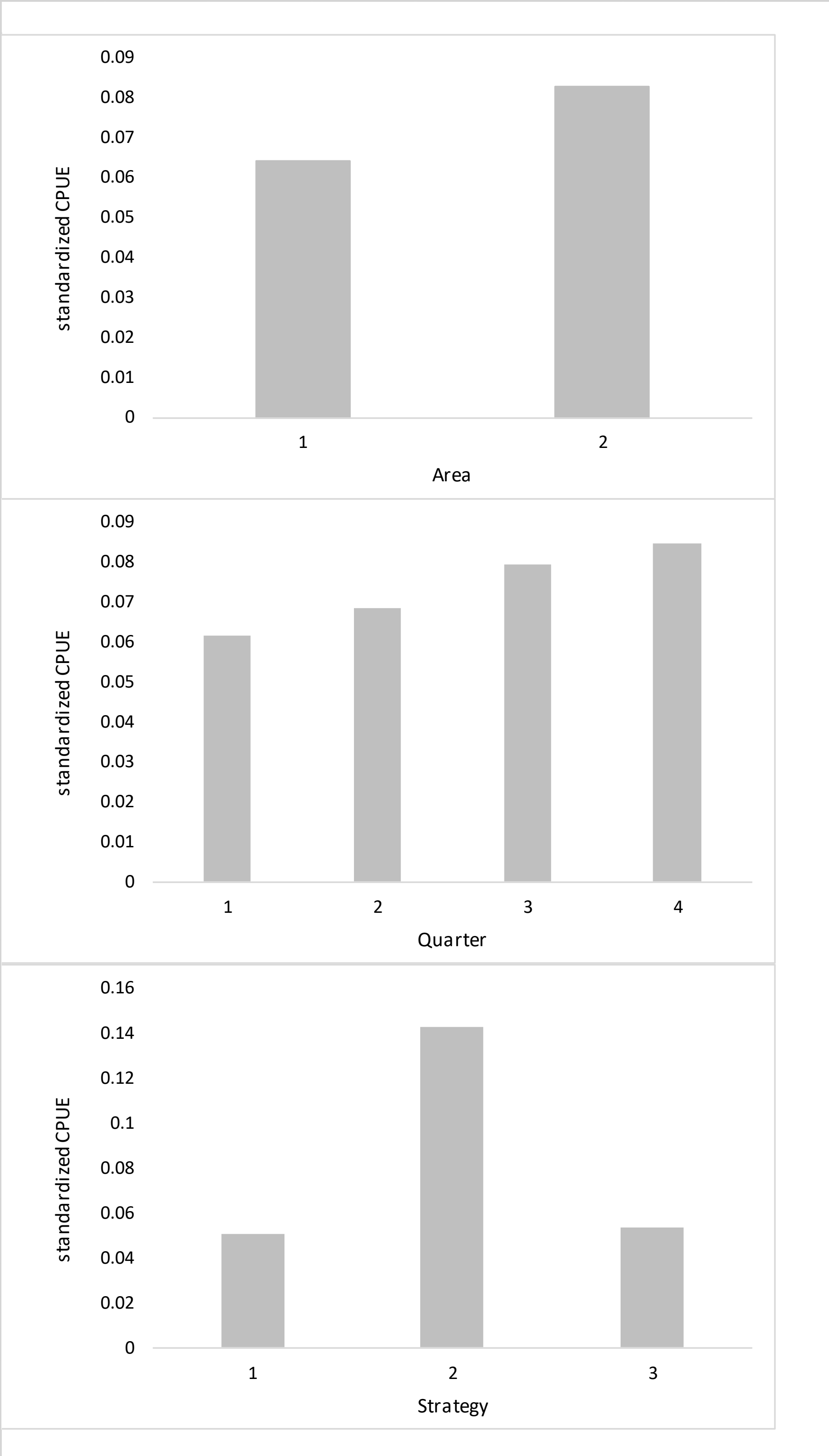

Figure 6. CPUE standardized by factors to shortfin mako.

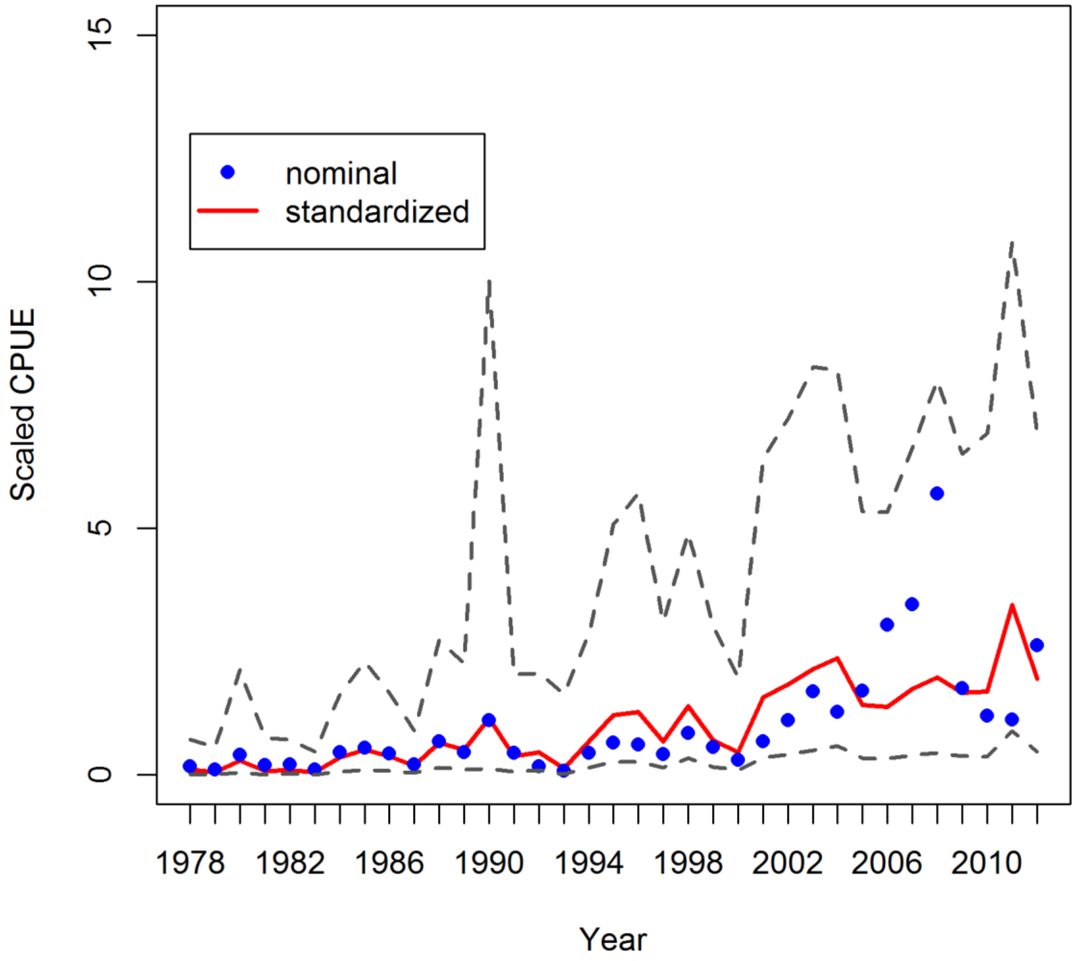

Figure 7. Nominal and standardized scaled CPUE of shortfin mako for Brazilian tuna longliners from 1978 to 2012.