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STANDARDIZED CATCH RATES OF WHITE MARLIN AND BLUE MARLIN CAUGHT BY THE BRAZILIAN TUNA LONGLINE FLEET (1978-2012) USING GENERALIZED LINEAR MIXED MODELS (GLMM) WITH A DELTA LOG APPROACH

José C. Pacheco[1], Ítala Alves[1,2], Humberto G. Hazin[1,2], Fábio H.V. Hazin[1], Felipe C. Carvalho[1], Bruno L. Mourato[3]

SUMMARY

Catch and effort data collected from the Brazilian tuna longline fleet (national and chartered) in the equatorial and southwestern Atlantic Ocean, from 1978 to 2012, including 92,766 sets, were analyzed. The CPUE of white marlin and blue marlin was standardized by a Generalized Linear Mixed Model (GLMM), using a Delta Lognormal approach. The factors used in the model were: quarter, year, area, and fishing strategy. The standardized CPUE series showed a significant oscillation over time, with a consistent declining trend from 2004 to 2012. The possible influence of regulatory measures on these trends is briefly discussed.

RÉSUMÉ

Les données de prise et d'effort provenant de la flottille palangrière brésilienne (nationale et affrétée) ciblant les thonidés dans l'océan Atlantique équatorial et du Sud-Ouest entre 1978 et 2012, incluant 92.766 opérations, ont été analysées. La CPUE du makaire blanc et bleu a été standardisée en utilisant un modèle linéaire mixte généralisé (GLMM) au moyen d'une approche delta log-normale. Les facteurs utilisés dans le modèle étaient les suivants : trimestre, année, zone et stratégie de pêche. Les séries standardisées de CPUE présentaient une importante variation dans le temps, avec une tendance à la baisse constante de 2004 à 2012. L'influence possible des mesures réglementaires sur ces tendances est abordée brièvement.

RESUMEN

Se analizan los datos de captura y esfuerzo de la flota atunera de palangre brasileña (nacional y fletada) en el Atlántico suroccidental y ecuatorial entre 1978 y 2012, incluidos 92.766 lances. Se estandarizó la CPUE de aguja blanca y aguja azul mediante modelos mixtos lineales generalizados (GLMM) utilizando un enfoque delta lognormal. Los factores utilizados en el modelo fueron trimestre, año, área y estrategia de pesca. La serie de CPUE estandarizada mostraba una oscilación importante en el tiempo, con una tendencia decreciente constante desde 2004 a 2012. Se discute brevemente la posible influencia de las medidas reglamentarias en estas tendencias.

KEYWORDS

Blue marlin, White marlin, Standardized catch rate, Longliners

[1] Universidade Federal Rural de Pernambuco, Brazil.
[2] Universidade Federal Rural do Semiárido, Brazil.
[3] Universidade Federal de São Paulo, Brazil.

Introduction

The tuna longline fishery in the Atlantic Ocean started in 1950 and it has been, since then, one of the main gears used to catch these species, together with the purse seine and the baitboat fisheries. Despite the main target species of the tuna longline fishery has always been the swordfish and tunas of the genus *Thunnus* (*i.e.* albacore, *T. alalunga*; yellowfin, *T. albacares*; bigeye, *T. obesus*; and Bluefin, *T. thynnus*), several other species are caught together with them, including the various billfish species of the Istiophoridae family present in the Atlantic Ocean. Of them, the sailfish (*Istiophorus platypterus*), the white marlin, *Kajikia albida* (formerly *Tetrapturus albidus*), and the blue marlin (*Makaira nigricans*), are the ones most frequently caught. With regard to the white and blue marlin, the tuna longline fishery, together with the gillnet fishery in some African countries, such as Ghana, is the main source of fishing mortality, being, therefore, the main driver of the sharp reduction of their stocks observed in recent decades (Anon., 2002, 2013).

The significant impact of the tuna longline fishery on the sustainability of blue and white marlin stocks make the historical series of their relative abundance in this fishery a crucial component for the assessment of their status. For this purpose, the Catch per Unit of Effort (CPUE) from commercial fisheries has been traditionally used as the main index of relative abundance, despite its limitations (Shelton *et al*., 2001), since it is commonly the only one available. The intrinsic limitations of the use of CPUE as an index of relative abundance are related to their non-liner relationship, since several factors influence the "catchability" of a given species, such as fishing area, season, time of the day, moon phase, fishing gear configuration, among others, which are constantly altered in the fishing strategy, in order to maximize the catches of the target species (Amorim e Arfelli, 1984; Hazin *et al*., 2007; Carvalho *et al*., 2010; Mourato *et al*., 2011). The incorporation of these factors in the estimation of CPUE is, therefore, crucial for accurate stock assessments.

The main objective of the present paper was, therefore, to generate a standardized CPUE series for the white and blue marlins caught by Brazilian longliners in the Atlantic Ocean, which may be then utilized as an index of relative abundance in future stock assessments of the species. The Brazilian data on the historical changes of relative abundance of these marlin species are particularly relevant, not only because of the great geographic range of the fishing operations of Brazilian fishing boats, but also because the Brazilian catches have been historically among the largest in the Atlantic Ocean (Anon., 2013).

Material and Methods

In the present study, catch and effort data from 92,766 tuna longline sets reported by the Brazilian tuna longline fleet, including both national and foreign chartered vessels, from 1978 to 2012, were analyzed. Data were obtained from fishing logbooks filled in by the skippers of the boat. The longline sets were distributed along a wide area of the equatorial and southwestern Atlantic Ocean, ranging from 10ºE to 52ºW of longitude, and from 10ºN to 50ºS 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 white marlin (80%) and blue marlin (82%), a generalized linear mixed model (GLMM) using the Delta Lognormal approach was used for the standardization of the CPUE series. 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 observed 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). The relative importance of each explanatory variable was, therefore, calculated to set the order of entry for each variable (R^2 - contribution averaged over ordering of regressors: LMG) (**Figure 2**) (Groemping, 2006).

For the final model, the selection of factors and interactions was carried out by analysis of deviance tables (Ortiz & Arocha, 2004). Briefly, main factors and interactions were included in the model if: a) the percentage of total deviance explained by a given factor/interaction was 4% 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 were evaluated as random variables to obtain the estimated index per year, transforming the GLMs in a GLMMs (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 unbalanced characteristics of the data. LSmeans of lognormal positive trips were bias corrected using Lo *et al.* (1992) algorithms. Also, variance estimation of the standardized index was calculated following Walter & Ortiz (2012) for two-stage CPUE estimator.

The factors considered as explanatory variables were "Year" (35), "Quarter" (4), "Area" (A1=10ºN-15ºS; A2=15ºS -25ºS, A3=25ºS -50ºS), and "Fishing strategy" (3). The fishing strategy was estimated in two steps (Hazin, *et al.*, in press): in the first step, a cluster analysis was done to identify the different targeting strategies by combining groups that are internally coherent and externally isolated. Accordingly, based on the 92,766 fishing sets done, with about 25 species reported in the log-books, 6 clusters were identified, with the following species being predominant in the catches: 1) YFT; 2) BET; 3) BSH; 4) Others; 5) ALB; and 6) SWO. 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 discriminated clusters of vessels (Fishing Fleets) with similar fishing strategies. The choice of this method was based on the complexity of the Brazilian tuna longline fishery, which results from constant changes in fishing strategies and fleet composition, that cause many clusters to overlap, making interpretation of the results difficult. The other advantage of this method is that it is robust to the presence of outliers and overlapping which does not occur using only the K means methods (Mingoti & Lima, 2006).

Results and Discussion

The proportion of null catches of white and blue marlin was 80.0% and 82.0% for the entire period. In most cases, the proportion of positive catches of white marlin ranged between 4% and 37% of the sets and of the blue marlin from 3% to 35% (**Table 1**). The Strategy 1 was highly correlated with yellowfin tuna (39%), with important catches of albacore tuna (21%) and bigeye tuna (13%), blue marlin (6%) and white marlin (4%). Strategy 2 adopted a fishing strategy targeting mainly albacore tuna (61%), yellowfin tuna (15%) and bigeye tuna (11%). Strategy 3 was highly correlated with swordfish (29%), blue shark (19%), yellowfin tuna (17%), bigeye tuna (16%) and albacore tuna (14%).

The number of sets with positive and null catches by factors (**Figures 3 and 4**) 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 (**Figure 5**). The standardized CPUE was estimated as the product of the estimated proportion of positive sets per year and the mean catch rate per year for positive sets for each year. The selected models for the lognormal and binomial components for both species were:

Lognormal Model: $\log(CPUE_{BUM})$= Year+Strategy+Quarter+Area+random(Year:Quarter)

Lognormal Model: $\log(CPUE_{WHM})$= Strategy+ Year +Quarter+Area+random(Year:Quarter)

Binomial Model:
$Proportion_{BUM\ and\ WHM}$= Year+Strategy+Quarter+Area+random(Year:Quarter)+random (Year:Area)

A diagnostic plot for the lognormal model showed that the assumption of the lognormal distribution for the positive dataset seemed to be adequate, as indicated by the QQ-plots (**Figures 6 and 7**). Residuals were homoscedastic in the case of the positive dataset. There were no temporal trends in the residuals in a yearly basis, so the assumption of independence of the samples was considered to be acceptable (**Figures 6 and 7**).The pseudo-R^2 values of the final models explained 23% (white marlin) and 27% (blue marlin) of the total variance. For the white marlin, the main factors were, in order of importance: year (58%), fishing strategy (31%), quarter (11%), and area (0.3%). For the blue marlin, the contributions of each factor were: fishing strategy (39%), year (34%), area (25%), and quarter (2%).

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 quarter in the relative abundance of the white marlin (11.0%), in relation to area (0.3%), and the contrary trend for the blue marlin, with area (25%) having a much higher contribution than quarter (2%), may suggested a more restricted distribution of the later. This aspect had already been indicated by previous works, which have shown that the blue marlin seem to be much more concentrated in the equatorial area (Silva *et al.*, 1994) than the white marlin, which tends to migrate seasonally along the Brazilian coast, southwardly, from the third to the first quarter of the year (Amorim *et al*., 1994).

The estimates of the year factor for both species were significant, except for the white marlin in 1982, 1984 and 1985, suggesting the existence of clear interannual trends (**Table 2**). The standardized yearly CPUE for both species showed a strong oscillation throughout the whole period, but both of them exhibited a consistent declining trend from 2004 to 2012, dropping from 1.88 to 0.36 (5 times less), in the case of the white marlin, and from 2.36 to 0.23 (10 times less), in the case of the blue marlin (**Tables 3 and 4, Figures 8 and 9**). This declining trend, however, may reflect, in part, the entering into force of the normative instruction (N.I.) 11, of November 2004, of the Special Secretariat of Fisheries and Aquaculture, which prohibited the selling of blue and white marlin in the whole country. This normative instruction was reinforced by the N.I. 12, of July 2005, which prohibited the discard of marlins that were dead by the time of boarding. These regulatory instruments may have discouraged the catch of these species, with a direct influence in the fishing strategy, i.e. the skippers may have started to actively avoid areas with higher abundance of these species, particularly considering the nuisance to retrieve a big fish and store it on board, knowing that it will have to be donated. Furthermore, it is also possible that, due to the prohibition of selling, skippers have started to underreport the catches of both species, to avoid compliance issues. Unfortunately, based on the present data, it is not possible to estimate the possible influence of these behaviors on the blue and white marlin CPUE.

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

			WHM			*BUM*		
Year	*Number of observations*	*Effort*	*Proportion Positive*	*Catches (n)*	*CPUE (n)*	*Proportion Positive*	*Catches (n)*	*CPUE (n)*
1978	502	1,231,307.00	23%	534	0.4337	18%	160	0.130
1979	482	900,557.00	35%	707	0.7851	24%	201	0.223
1980	582	965,085.00	25%	444	0.4601	22%	204	0.211
1981	466	863,548.00	28%	345	0.3995	20%	176	0.204
1982	894	1,696,371.00	12%	219	0.1291	18%	402	0.237
1983	619	1,259,504.00	12%	219	0.1739	28%	580	0.460
1984	716	1,586,165.00	14%	169	0.1065	14%	381	0.240
1985	471	974,801.00	11%	119	0.1221	11%	109	0.112
1986	992	2,033,997.00	22%	666	0.3274	17%	391	0.192
1987	927	1,573,170.00	22%	493	0.3134	19%	556	0.353
1988	1221	2,393,556.00	17%	544	0.2273	16%	380	0.159
1989	1032	2,284,831.00	9%	351	0.1536	21%	600	0.263
1990	290	398,334.00	26%	253	0.6351	11%	52	0.131
1991	994	2,386,536.00	12%	511	0.2141	18%	394	0.165
1992	1215	3,362,712.00	12%	627	0.1865	12%	597	0.178
1993	265	447,782.00	29%	312	0.6968	21%	101	0.226
1994	875	2,051,283.00	8%	235	0.1146	13%	414	0.165
1995	1738	4,246,587.00	11%	595	0.1401	15%	871	0.182
1996	952	1,668,220.00	25%	1357	0.8134	12%	304	0.172
1997	1813	3,254,839.00	16%	1341	0.412	19%	1132	0.348
1998	2660	6,028,826.00	13%	1491	0.2473	17%	2728	0.452
1999	5253	10,798,082.00	17%	3846	0.3562	15%	2124	0.197
2000	8037	15,031,597.00	19%	6046	0.4022	17%	4626	0.308
2001	9500	18,678,703.00	10%	3753	0.2009	19%	7430	0.384
2002	6206	10,022,580.00	4%	837	0.0835	8%	1686	0.155
2003	3300	3,635,537.00	6%	487	0.134	8%	522	0.141
2004	7718	10,780,833.00	25%	7083	0.657	30%	6742	0.622
2005	8950	12,899,976.00	32%	8551	0.6629	37%	8198	0.630
2006	6120	7,890,150.00	28%	3834	0.4859	33%	4851	0.585
2007	5039	5,629,199.00	20%	3131	0.5562	19%	1840	0.326
2008	2699	3,036,739.00	19%	1274	0.4195	21%	1175	0.387
2009	2722	3,233,954.00	11%	523	0.1617	15%	793	0.245
2010	1452	1,797,697.00	20%	912	0.5073	14%	399	0.222
2011	2558	5,060,294.00	30%	1829	0.3614	15%	858	0.170
2012	3506	4,809,862.00	9%	607	0.1262	4%	291	0.061

Table 2. Estimated coefficients of the fixed factors of the GLMM models used for blue and white marlins.

WHM							BUM					
	Estimate	Std. Error	t value	Pr(>|t|)				Estimate	Std. Error	t value	Pr(>|t|)	
(Intercept)	-0.11826	0.0725	-1.631	0.102846			(Intercept)	-0.8102	0.08009	-10.116	< 2e-16	***
Y1979	0.52643	0.09028	5.831	5.61E-09	***		Y1979	0.48907	0.10101	4.842	1.30E-06	***
Y1980	0.4742	0.09293	5.103	3.38E-07	***		Y1980	0.54457	0.09942	5.477	4.38E-08	***
Y1981	0.26432	0.09494	2.784	0.005377	**		Y1981	0.45441	0.10593	4.29	1.80E-05	***
Y1982	0.06589	0.0995	0.662	0.507889			Y1982	0.41579	0.09528	4.364	1.29E-05	***
Y1983	0.39093	0.11056	3.536	0.000407	***		Y1983	0.67681	0.094	7.2	6.24E-13	***
Y1984	-0.04019	0.10179	-0.395	0.693003			Y1984	0.63458	0.10569	6.004	1.96E-09	***
Y1985	0.05005	0.12302	0.407	0.684106			Y1985	0.55336	0.1243	4.452	8.56E-06	***
Y1986	0.37234	0.08579	4.34	1.43E-05	***		Y1986	0.54646	0.09419	5.802	6.67E-09	***
Y1987	0.4096	0.08696	4.71	2.50E-06	***		Y1987	0.99953	0.09423	10.607	< 2e-16	***
Y1988	0.22716	0.08709	2.608	0.009105	**		Y1988	0.53821	0.09161	5.875	4.29E-09	***
Y1989	0.7443	0.10458	7.117	1.15E-12	***		Y1989	0.8899	0.09043	9.841	< 2e-16	***
Y1990	0.91169	0.11299	8.069	7.58E-16	***		Y1990	0.76098	0.1488	5.114	3.19E-07	***
Y1991	0.61943	0.09825	6.305	2.96E-10	***		Y1991	0.86808	0.09349	9.285	< 2e-16	***
Y1992	0.65435	0.09618	6.803	1.06E-11	***		Y1992	0.95029	0.09808	9.689	< 2e-16	***
Y1993	0.88021	0.11329	7.77	8.35E-15	***		Y1993	1.15454	0.12505	9.233	< 2e-16	***
Y1994	0.67704	0.11336	5.973	2.38E-09	***		Y1994	0.99902	0.10713	9.325	< 2e-16	***
Y1995	0.62783	0.09024	6.958	3.60E-12	***		Y1995	1.03161	0.09074	11.369	< 2e-16	***
Y1996	0.99921	0.08811	11.341	< 2e-16	***		Y1996	1.05155	0.10306	10.204	< 2e-16	***
Y1997	0.85758	0.08373	10.242	< 2e-16	***		Y1997	0.9521	0.08725	10.912	< 2e-16	***
Y1998	0.8263	0.08125	10.17	< 2e-16	***		Y1998	0.85792	0.08652	9.916	< 2e-16	***
Y1999	0.90702	0.07545	12.022	< 2e-16	***		Y1999	0.92552	0.08261	11.204	< 2e-16	***
Y2000	0.81418	0.07387	11.022	< 2e-16	***		Y2000	1.07288	0.08108	13.233	< 2e-16	***
Y2001	1.00592	0.07525	13.368	< 2e-16	***		Y2001	1.16095	0.08035	14.449	< 2e-16	***
Y2002	0.84638	0.08369	10.113	< 2e-16	***		Y2002	0.94994	0.0846	11.228	< 2e-16	***
Y2003	0.67565	0.08981	7.523	5.63E-14	***		Y2003	1.04326	0.09123	11.436	< 2e-16	***
Y2004	0.63056	0.07329	8.604	< 2e-16	***		Y2004	0.9854	0.08006	12.308	< 2e-16	***
Y2005	0.4751	0.07251	6.552	5.85E-11	***		Y2005	0.87107	0.07974	10.923	< 2e-16	***
Y2006	0.46016	0.07282	6.319	2.70E-10	***		Y2006	0.83927	0.08013	10.474	< 2e-16	***
Y2007	0.60487	0.07442	8.128	4.68E-16	***		Y2007	0.84297	0.08182	10.303	< 2e-16	***
Y2008	0.60107	0.07808	7.698	1.46E-14	***		Y2008	0.85638	0.0842	10.171	< 2e-16	***
Y2009	0.37473	0.08172	4.586	4.56E-06	***		Y2009	0.74668	0.08646	8.637	< 2e-16	***
Y2010	0.79493	0.08246	9.64	< 2e-16	***		Y2010	0.77727	0.0928	8.376	< 2e-16	***
Y2011	0.32063	0.07576	4.232	2.33E-05	***		Y2011	0.74741	0.08676	8.615	< 2e-16	***
Y2012	0.33873	0.08182	4.14	3.49E-05	***		Y2012	0.68949	0.09853	6.998	2.69E-12	***
S2	-0.70692	0.02664	-26.536	< 2e-16	***		S2	-0.50924	0.02454	-20.754	< 2e-16	***
S3	-0.23247	0.01604	-14.49	< 2e-16	***		S3	0.12689	0.01632	7.775	7.94E-15	***
A2	0.08497	0.01853	4.585	4.57E-06	***		A2	0.41734	0.01528	27.315	< 2e-16	***
A3	0.0082	0.02414	0.34	0.734162			A3	-0.01163	0.02712	-0.429	0.66805	
Q2	-0.06099	0.01758	-3.47	0.000522	***		Q2	-0.10175	0.0153	-6.65	3.02E-11	***
Q3	0.19197	0.01725	11.129	< 2e-16	***		Q3	-0.05192	0.01687	-3.078	0.00209	**
Q4	0.11325	0.0169	6.701	2.14E-11	***		Q4	0.01382	0.01465	0.943	0.34553	

Table 3. Standardized CPUE white marlin caught by the Brazilian tuna longline fleet, 1978-2012.

Year	*index*	*LCI_index*	*UCI_index*	*se_index*	*CV_index*	*scaled_index*	*scaled_CPUE*
1978	0.192	0.058	0.559	0.101	0.524	0.977	1.244
1979	0.344	0.087	1.119	0.198	0.576	1.748	2.251
1980	0.216	0.052	0.792	0.133	0.616	1.097	1.319
1981	0.271	0.047	1.178	0.185	0.683	1.378	1.146
1982	0.126	0.024	0.548	0.088	0.693	0.642	0.370
1983	0.168	0.028	0.815	0.124	0.737	0.853	0.499
1984	0.085	0.020	0.323	0.054	0.636	0.434	0.306
1985	0.061	0.012	0.280	0.043	0.697	0.312	0.350
1986	0.217	0.055	0.741	0.128	0.592	1.102	0.939
1987	0.201	0.055	0.646	0.114	0.568	1.019	0.899
1988	0.139	0.034	0.511	0.086	0.618	0.706	0.652
1989	0.095	0.021	0.415	0.065	0.679	0.485	0.440
1990	0.236	0.034	1.360	0.186	0.789	1.200	1.821
1991	0.161	0.042	0.560	0.096	0.596	0.817	0.614
1992	0.087	0.023	0.314	0.053	0.607	0.442	0.535
1993	0.189	0.028	1.070	0.146	0.771	0.959	1.998
1994	0.122	0.030	0.471	0.077	0.630	0.622	0.328
1995	0.178	0.043	0.668	0.111	0.624	0.904	0.402
1996	0.696	0.221	1.918	0.348	0.501	3.536	2.332
1997	0.287	0.086	0.871	0.155	0.540	1.457	1.181
1998	0.218	0.065	0.677	0.119	0.549	1.107	0.709
1999	0.377	0.116	1.115	0.199	0.528	1.918	1.021
2000	0.255	0.077	0.782	0.138	0.543	1.296	1.153
2001	0.085	0.023	0.303	0.051	0.599	0.434	0.576
2002	0.037	0.010	0.134	0.022	0.604	0.189	0.239
2003	0.078	0.021	0.282	0.047	0.609	0.395	0.384
2004	0.128	0.037	0.418	0.073	0.567	0.652	1.884
2005	0.193	0.059	0.581	0.103	0.534	0.983	1.901
2006	0.245	0.076	0.712	0.127	0.521	1.243	1.393
2007	0.207	0.062	0.642	0.113	0.547	1.053	1.595
2008	0.210	0.061	0.682	0.119	0.567	1.065	1.203
2009	0.111	0.032	0.363	0.063	0.568	0.565	0.464
2010	0.234	0.070	0.708	0.126	0.539	1.187	1.455
2011	0.384	0.130	0.991	0.181	0.470	1.952	1.036
2012	0.053	0.014	0.190	0.032	0.604	0.269	0.362

Table 4. Standardized CPUE blue marlin caught by the Brazilian tuna longline fleet, 1978-2012.

Year	*index*	*LCI_index*	*UCI_index*	*se_index*	*CV_index*	*scaled_index*	*scaled_CPUE*
1978	0.098	0.052	0.180	0.029	0.299	0.612	0.493
1979	0.272	0.137	0.536	0.096	0.353	1.708	0.847
1980	0.287	0.150	0.546	0.096	0.333	1.803	0.802
1981	0.309	0.145	0.648	0.117	0.379	1.940	0.774
1982	0.235	0.121	0.453	0.081	0.343	1.476	0.899
1983	0.509	0.245	1.050	0.197	0.386	3.194	1.748
1984	0.149	0.077	0.286	0.047	0.317	0.935	0.912
1985	0.129	0.057	0.286	0.049	0.378	0.807	0.424
1986	0.107	0.058	0.198	0.033	0.308	0.672	0.730
1987	0.165	0.090	0.301	0.050	0.301	1.037	1.341
1988	0.137	0.075	0.251	0.042	0.307	0.860	0.603
1989	0.212	0.117	0.382	0.064	0.302	1.332	0.997
1990	0.052	0.019	0.145	0.024	0.458	0.329	0.495
1991	0.151	0.086	0.265	0.043	0.283	0.949	0.627
1992	0.078	0.042	0.144	0.024	0.303	0.490	0.674
1993	0.132	0.053	0.329	0.056	0.424	0.830	0.856
1994	0.103	0.057	0.186	0.030	0.292	0.646	0.635
1995	0.108	0.060	0.193	0.032	0.300	0.677	0.725
1996	0.075	0.041	0.138	0.022	0.294	0.472	0.664
1997	0.132	0.080	0.219	0.034	0.260	0.830	1.320
1998	0.172	0.105	0.282	0.045	0.259	1.080	1.717
1999	0.083	0.051	0.133	0.021	0.258	0.518	0.747
2000	0.136	0.086	0.215	0.034	0.252	0.851	1.168
2001	0.226	0.144	0.355	0.056	0.250	1.416	1.510
2002	0.087	0.053	0.142	0.022	0.260	0.543	0.558
2003	0.051	0.028	0.092	0.015	0.301	0.319	0.519
2004	0.272	0.173	0.427	0.069	0.252	1.707	2.362
2005	0.276	0.177	0.431	0.070	0.252	1.734	2.403
2006	0.241	0.152	0.383	0.063	0.260	1.512	2.102
2007	0.143	0.089	0.230	0.037	0.257	0.899	1.235
2008	0.150	0.088	0.257	0.043	0.287	0.942	1.468
2009	0.083	0.047	0.147	0.025	0.297	0.523	0.931
2010	0.093	0.051	0.169	0.028	0.299	0.585	0.842
2011	0.084	0.048	0.149	0.025	0.297	0.529	0.643
2012	0.039	0.021	0.072	0.012	0.310	0.243	0.230

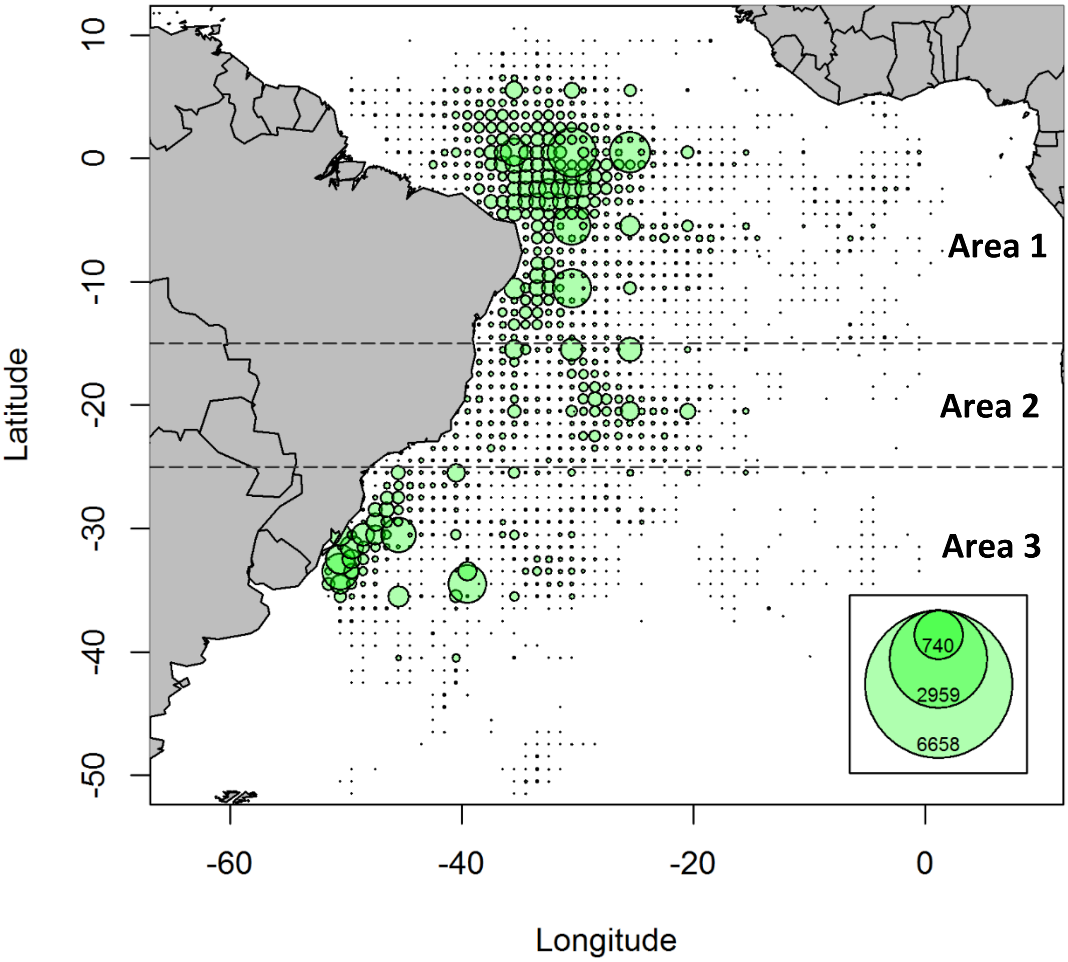

Figure 1. Distribution of the effort done by the Brazilian tuna longline fishery in the Atlantic Ocean, from 1978 to 2012 (35 years).

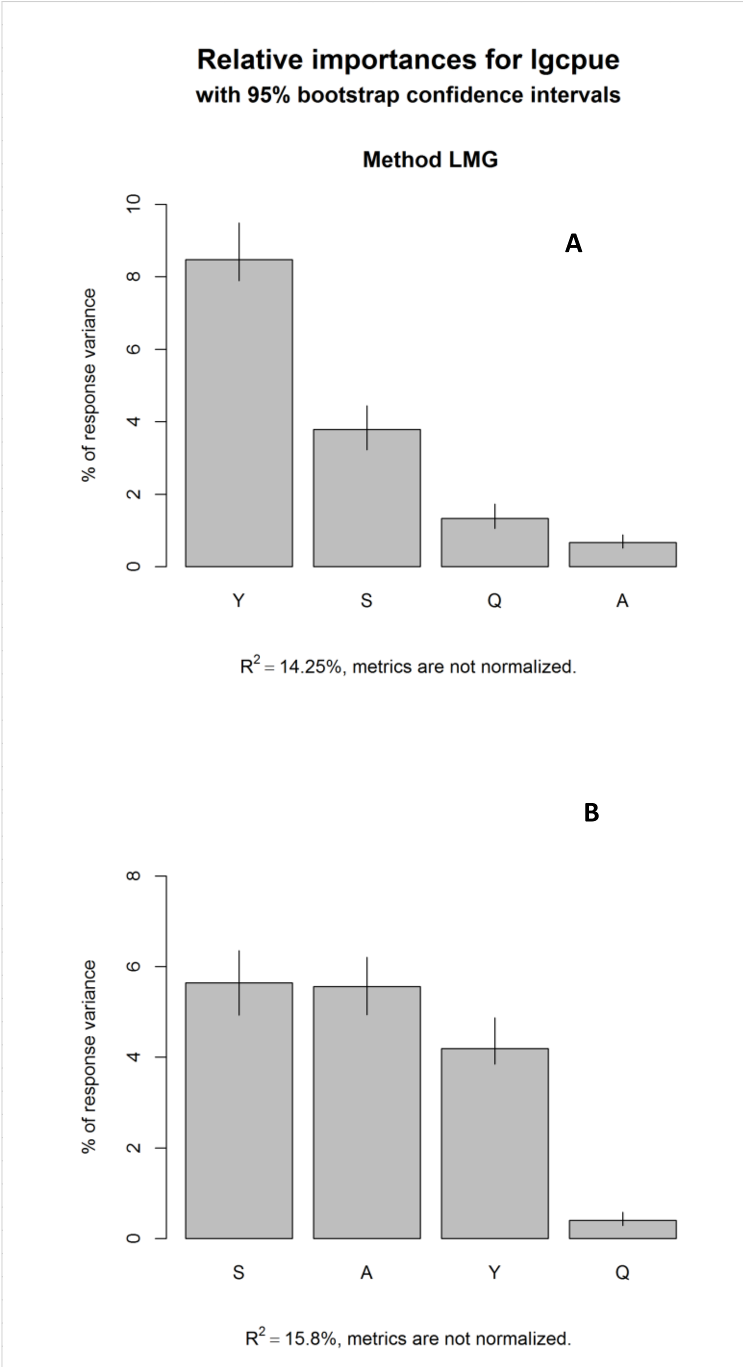

Figure 2. Bar plots of LMG the relative importance with confidence intervals (S: strategy, Y: year, Q: quarter, A: area) for white marlin (A) and blue marlin (B).

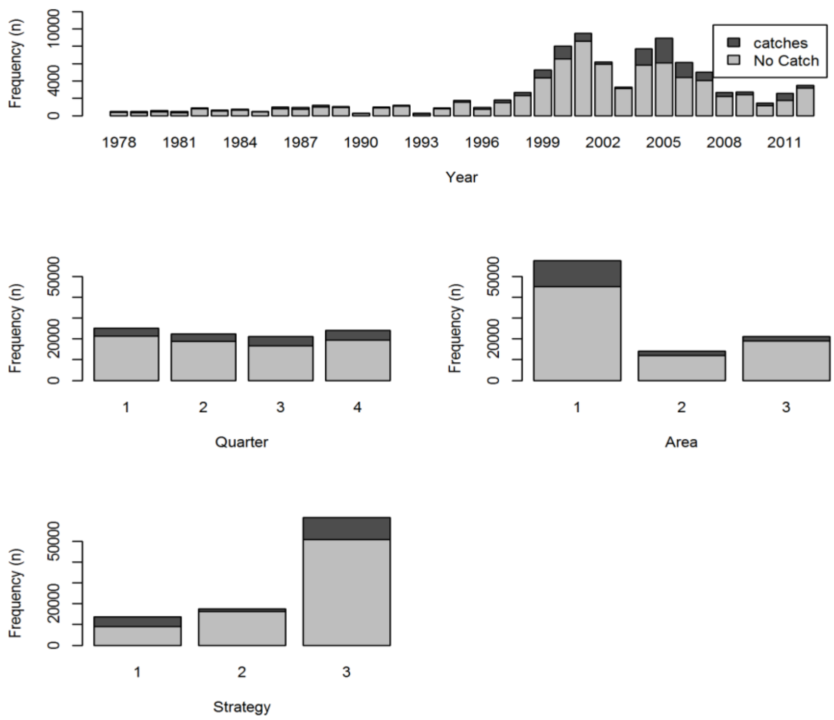

Figure 3. Proportion of sets with positive and zero catches of white marlin, by year, quarter, area and fishing strategy, of the Brazilian tuna longline fleet, from 1978 to 2012.

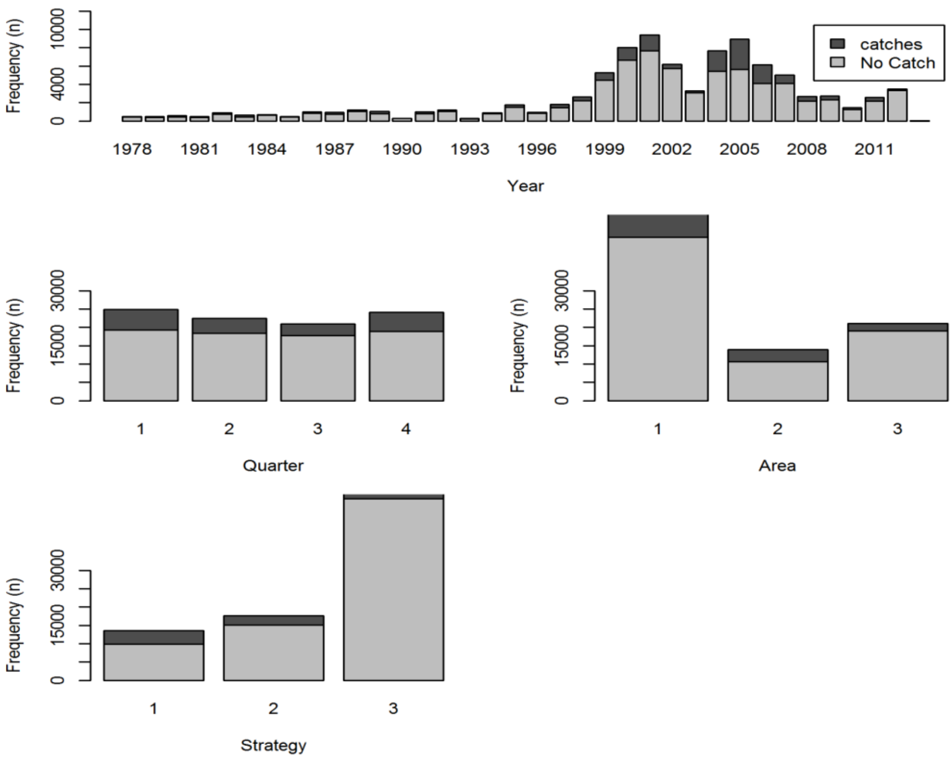

Figure 4. Proportion of sets with positive and zero catches of blue marlin, by year, quarter, area and fishing strategy, of the Brazilian tuna longline fleet, from 1978 to 2012.

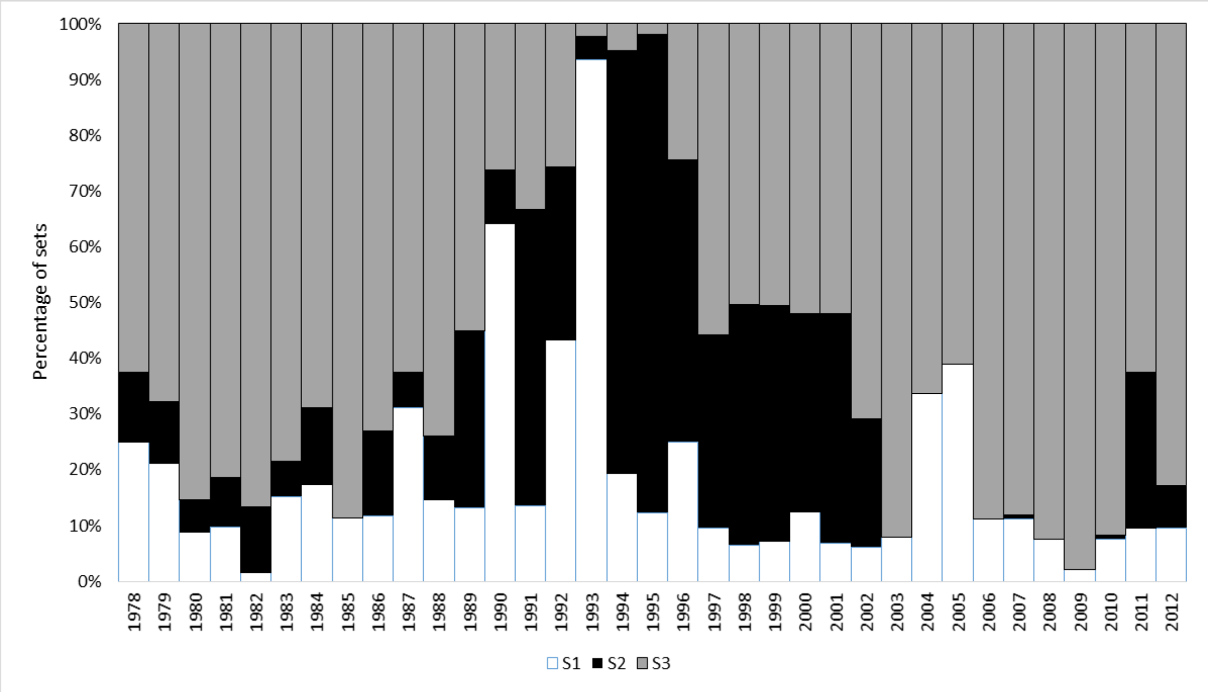

Figure 5. Relative frequency of Strategy 1 to 3 by year of longliners operating from Brazil, from 1978 to 2012.

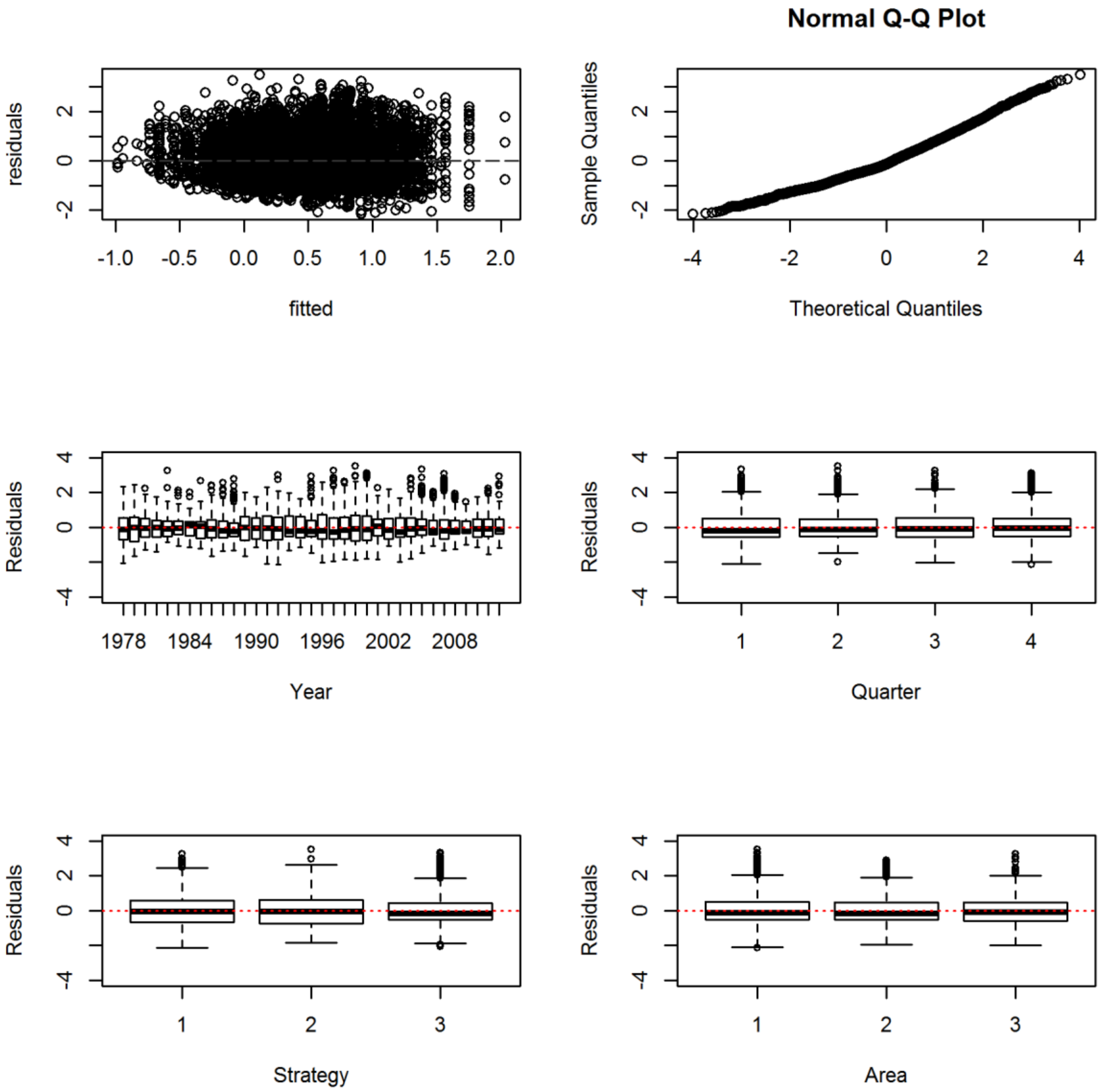

Figure 6. Residual analysis of the log-normal model fitting of white marlin caught by the Brazilian tuna longline fleet, 1978 to 2012.

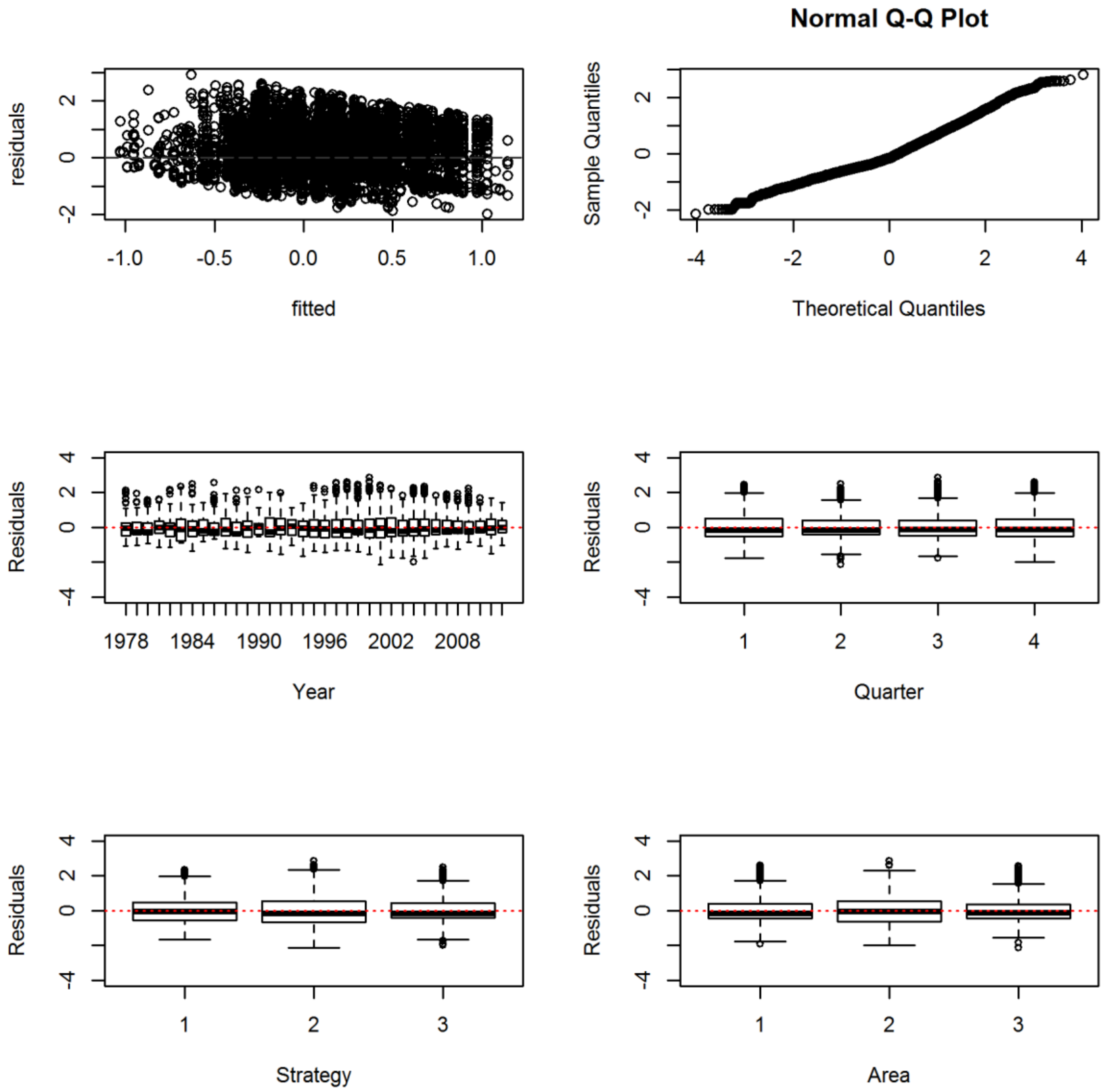

Figure 7. Residual analysis of the log-normal model fitting of blue marlin caught by the Brazilian tuna longline fleet, from 1978 to 2012.

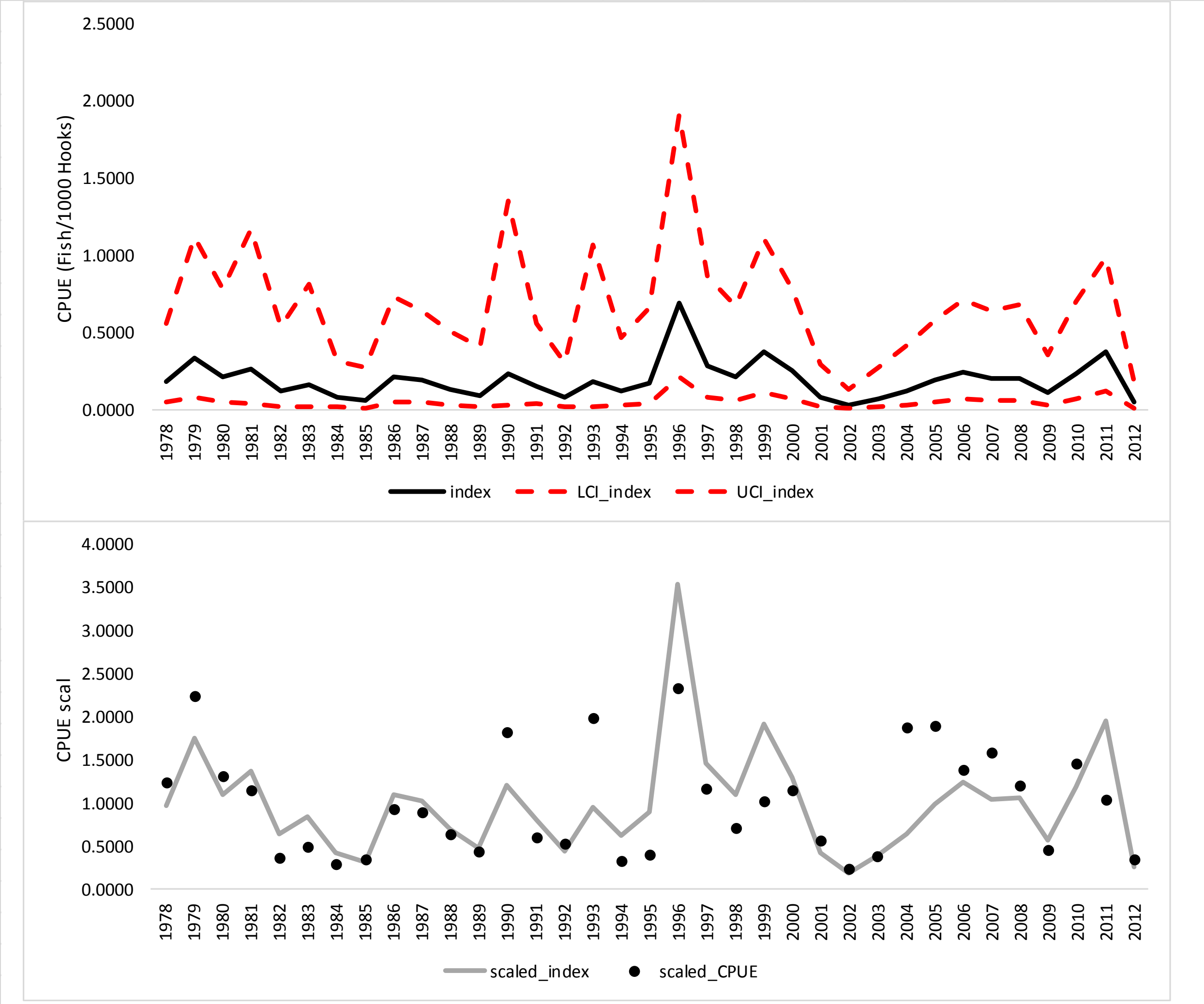

Figure 8. Nominal and standardized CPUE of white marlin for Brazilian tuna longliners, from 1978 to 2012.

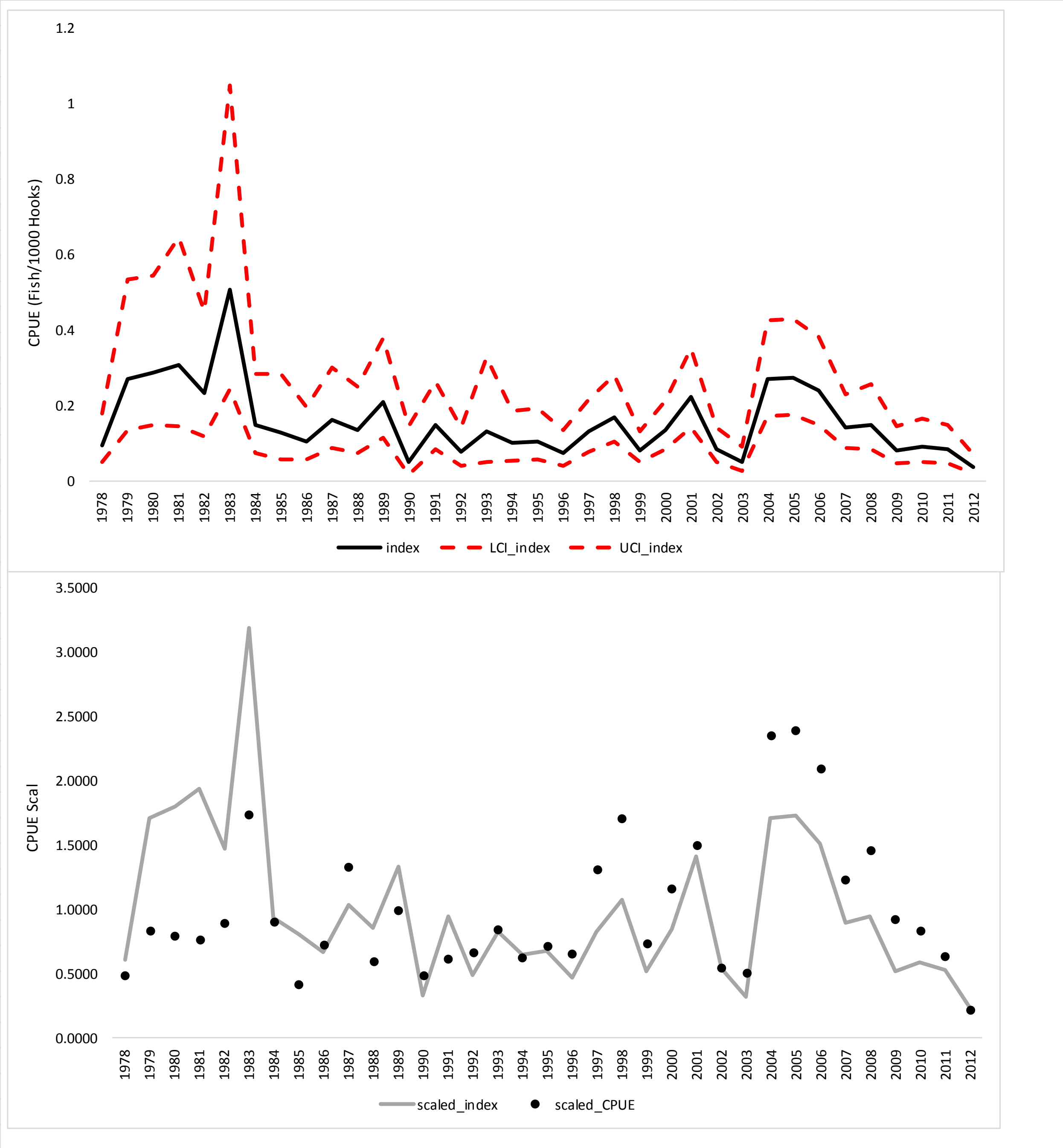

Figure 9. Nominal and standardized CPUE of blue marlin for Brazilian tuna longliners, from 1978 to 2012.