STANDARDIZED CATCH RATES OF ALBACORE (*THUNNUS ALALUNGA*) CAUGHT BY THE BRAZILIAN FLEET (1978-2012) USING GENERALIZED LINEAR MIXED MODELS (GLMM) - DELTA LOG APPROACH

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SUMMARY

Catch and effort information from the Brazilian tuna longline fleet (national and chartered) in the equatorial and Southwestern Atlantic Ocean were collected during the period from 1978 to 2012, more than 75,000 sets were analyzed. The CPUE of albacore tuna was standardized by a Generalized Linear Mixed Models (GLMM) using a Delta Lognormal approach. The factors used in the model were: quarter, year, area, and fishing strategy. The standardized CPUE series shows a significant oscillation over time, with a general increasing trend from the final of the eighties to 2000, then a sharp decrease until 2003, remaining low until 2010, and after this period, it was observed an increasing behavior again.

RÉSUMÉ

L'information sur la prise et l'effort provenant de la flottille palangrière brésilienne (nationale et affrétée) ciblant les thonidés dans l'océan Atlantique équatorial et du Sud-Ouest a été recueillie pendant la période 1978 à 2012, et plus de 75.000 opérations ont été analysées. La CPUE du germon a été standardisée en utilisant les modèles mixtes linéaires généralisés (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. La série de CPUE standardisée présente une oscillation importante au cours du temps, avec une tendance générale à la hausse à partir de la fin des années 80 jusqu'en 2000, avant de connaître une forte diminution jusqu'en 2003, de rester faible jusqu'en 2010 ; après cette période, un comportement à la hausse a une fois de plus été observé.

RESUMEN

Se recopiló la información sobre captura y esfuerzo de la flota atunera de palangre brasileña (nacional y fletada) en el Atlántico suroccidental y ecuatorial entre 1978 y 2012, analizando más de 75.000 lances. Se estandarizó la CPUE del atún blanco 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 muestra una oscilación importante en el tiempo, con una tendencia general creciente desde finales de los ochenta hasta los 2000, posteriormente un marcado descenso hasta 2003, permaneciendo baja hasta 2010 y después se ha observado una tendencia creciente de nuevo.

KEYWORDS

Catch, effort, Thunnus alalunga, albacore, Longlining, Pelagic fisheries, Logbooks, Stock assessment, GLMM, CPUE

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1. Introduction

Stock assessments for large pelagic 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 efficiency. Since 1956, when longline fishing operations began in the Southern Atlantic Ocean, a number of changes in fishing operations and strategies have been observed which directly reflect on catch compositions (Amorim e 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. 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, thus, to update a standardized CPUE series for albacore tuna caught by Brazilian longliners in the Atlantic Ocean, which may be utilized in the next albacore stock assessment, scheduled for April, 2016.

2. Material and Methods

In the present study, catch and effort data from 75,195 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. 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 moderate proportion of sets with zero catches of albacore tuna (48.8%) and the absence of some factors sampled in a feel years, a GLMM using the Delta Lognormal approach was used for the standardized 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). 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 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>15ºS; A2<25ºS), "Fishing strategy" (3). The fleet strategy was estimated in two steps (Hazin *et al*., 2012, Hazin, *et al*., in preparation).

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

The proportion of null catches of albacore for the Brazilian fleet during the period of the present study was 48.8%. Positive catches proportion varied during the period of study between 17.5% and 80.6% of the sets (**Table 1**). **Figure 2** showed the number of positive catches by factors.

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 the both cases, the interactions year:quarter, year:strategy and year:area explained most of 5% of the total deviance. Thus, all interactions were tested in the GLMM as random variables. Contrasting the models considering different combinations of interactions were conducted and its summaries was presented in **Table 3**. The selected models for the Lognormal and Binomial components were:

- Lognormal Model: log(CPUE)= Year+Strategy+Quarter+Area+Year:Area+Year:Strategy+Year:Quarter
- Binomial Model: log(CPUE)= Year+Strategy+Quarter+Area+Year:Area+Year:Strategy+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 3**). 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 3**).

The standardized CPUE series shows a significant oscillation over time, with a general increasing trend from the final of the eighties to 2000, then a sharp decrease until 2003, remaining low until 2010, and after this period, it was observed a increasing behavior again (**Table 4 and Figure 4**).

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

Year	Zero	Total	% of zeros
1978	146	449	32.52%
1979	157	410	38.29%
1980	299	531	56.31%
1981	287	465	61.72%
1982	532	877	60.66%
1983	291	607	47.94%
1984	288	708	40.68%
1985	272	457	59.52%
1986	475	963	49.33%
1987	338	878	38.50%
1988	509	1207	42.17%
1989	314	1011	31.06%
1990	113	290	38.97%
1991	388	895	43.35%
1992	529	1100	48.09%
1993	46	263	17.49%
1994	342	1074	31.84%
1995	686	1952	35.14%
1996	213	980	21.73%
1997	582	1745	33.35%
1998	855	2614	32.71%
1999	1921	5244	36.63%
2000	2768	7978	34.70%
2001	3944	9710	40.62%
2002	3993	6538	61.07%
2003	2641	3276	80.62%
2004	2969	5285	56.18%
2005	2388	3991	59.83%
2006	1631	2877	56.69%
2007	1751	2505	69.90%
2008	1106	1523	72.62%
2009	1280	1954	65.51%
2010	493	761	64.78%
2011	523	1050	49.81%
2012	1685	3027	55.67%

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

Model	DF	Residual Deviance	Chance in Deviance	% of total Deviance
Positive catch rates				
NULL	2	78734.17		
Year	36	64206.10	14528.07	57.61%
Year + Quarter	39	64006.01	200.09	0.79%
Year + Quarter + Area	40	63488.23	517.77	2.05%
Year + Quarter + Area + Strategy	42	62301.51	1186.73	4.71%
Year + Quarter + Area + Strategy + Year:Area	70	59814.78	2486.73	9.86%
Year + Quarter + Area + Strategy + Year:Area + Year:Strategy	188	55408.97	4405.81	17.47%
Year + Quarter + Area + Strategy + Year:Area + Year:Strategy + Year:Quarter	216	53516.50	1892.46	7.50%
Proportion of positive				
NULL	1	18941.03		
Year	35	12793.55	6147.48	44.76%
Year + Quarter	38	12719.06	74.49	0.54%
Year + Quarter + Area	39	12694.69	24.37	0.18%
Year + Quarter + Area + Strategy	41	11713.14	981.55	7.15%
Year + Quarter + Area + Strategy + Year:Area	70	10911.24	801.90	5.84%
Year + Quarter + Area + Strategy + Year:Area + Year:Strategy	118	6550.31	4360.93	31.75%
Year + Quarter + Area + Strategy + Year:Area + Year:Strategy + Year:Quarter	219	5205.34	1344.98	9.79%

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

Model	AIC	BIC	logLik	LRT
Positive catch rates				
Year + Strategy + Quarter + Area + Year:Area	126442.93	126810.87	-63178.46	
Year + Strategy + Quarter + Area + Year:Strategy	124762.80	125130.74	-62338.40	<0.0001
Year + Strategy + Quarter + Area + Year:Quarter	126781.05	127148.99	-63347.52	1
Year + Strategy + Quarter + Area + Year:Area + Year:Strategy	123436.07	123812.57	-61674.04	<0.0001
Year + Strategy + Quarter + Area + Year:Area + Year:Quarter	125408.76	125785.26	-62660.38	1
Year + Strategy + Quarter + Area + Year:Strategy + Year:Quarter	123988.90	124365.40	-61950.45	<0.0001
Year + Strategy + Quarter + Area + Year:Area + Year:Strategy + Year:Quarter	122786.72	123171.78	-61348.36	<0.0001
Proportion of positive				
Year + Strategy + Quarter + Area + Year:Area	13309.24	13486.84	-6612.62	
Year + Strategy + Quarter + Area + Year:Strategy	10195.01	10372.61	-5055.51	<0.0001
Year + Strategy + Quarter + Area + Year:Quarter	12410.66	12588.26	-6163.33	1
Year + Strategy + Quarter + Area + Year:Area + Year:Strategy	9307.69	9489.52	-4610.84	<0.0001
Year + Strategy + Quarter + Area + Year:Area + Year:Quarter	11709.96	11891.79	-5811.98	1
Year + Strategy + Quarter + Area + Year:Strategy + Year:Quarter	9159.88	9341.70	-4536.94	<0.0001
Year + Strategy + Quarter + Area + Year:Area + Year:Strategy + Year:Quarter	8314.34	8500.39	-4113.17	<0.0001

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

Year	Nominal CPUE	Standardized CPUE	CV	LCI	UCI	Scaled Index	Scaled LCI	Scaled UCI
1978	5.796	2.562	0.201	0.533	9.316	0.838	0.174	3.047
1979	6.781	3.856	0.146	0.545	18.597	1.261	0.178	6.083
1980	2.989	1.437	0.317	0.155	8.580	0.470	0.051	2.807
1981	2.261	1.394	0.451	0.085	11.630	0.456	0.028	3.804
1982	1.943	1.227	0.505	0.075	10.230	0.401	0.025	3.347
1983	3.434	2.411	0.301	0.181	16.800	0.789	0.059	5.496
1984	5.476	2.941	0.142	0.479	12.616	0.962	0.157	4.127
1985	3.437	1.694	0.205	0.216	9.090	0.554	0.071	2.973
1986	5.442	3.382	0.091	0.623	13.827	1.106	0.204	4.523
1987	7.493	4.264	0.081	0.859	16.031	1.395	0.281	5.244
1988	5.856	3.125	0.120	0.717	10.655	1.022	0.234	3.485
1989	10.393	4.945	0.078	1.187	16.378	1.618	0.388	5.358
1990	6.336	4.262	0.107	0.628	20.316	1.394	0.206	6.646
1991	6.142	2.429	0.136	0.482	9.286	0.795	0.158	3.038
1992	4.907	1.322	0.176	0.176	7.654	0.433	0.057	2.504
1993	17.136	7.881	0.063	1.464	31.078	2.578	0.479	10.166
1994	16.365	5.518	0.065	1.205	19.516	1.805	0.394	6.384
1995	9.048	4.621	0.079	0.999	16.440	1.512	0.327	5.378
1996	15.322	5.949	0.080	1.189	22.145	1.946	0.389	7.244
1997	10.095	5.967	0.061	1.336	20.736	1.952	0.437	6.783
1998	15.878	5.363	0.068	1.208	18.557	1.754	0.395	6.070
1999	8.539	4.892	0.075	1.110	16.842	1.600	0.363	5.509
2000	9.371	6.141	0.060	1.409	20.981	2.009	0.461	6.863
2001	11.254	3.703	0.086	0.727	14.323	1.211	0.238	4.685
2002	5.470	2.030	0.133	0.353	8.898	0.664	0.116	2.911
2003	0.982	1.051	0.190	0.117	7.247	0.344	0.038	2.371
2004	1.471	1.459	0.259	0.220	6.715	0.477	0.072	2.197
2005	1.060	1.019	0.371	0.154	4.690	0.333	0.050	1.534
2006	1.754	1.201	0.340	0.191	5.247	0.393	0.063	1.717
2007	1.348	0.605	0.310	0.065	4.374	0.198	0.021	1.431
2008	2.529	0.978	0.240	0.112	6.327	0.320	0.037	2.070
2009	0.905	0.895	0.331	0.113	5.006	0.293	0.037	1.638
2010	0.810	0.628	0.432	0.072	3.923	0.205	0.024	1.283
2011	4.971	2.268	0.178	0.510	7.792	0.742	0.167	2.549
2012	5.636	3.572	0.102	0.776	12.624	1.168	0.254	4.129

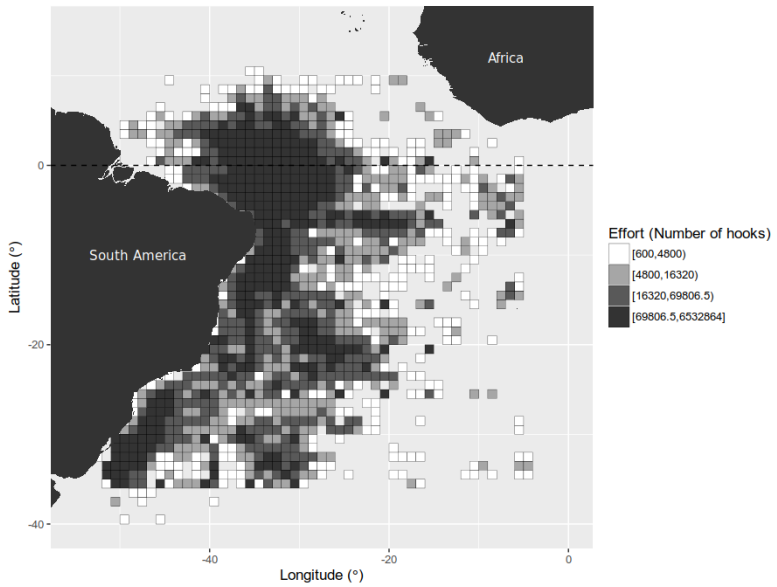

Figure 1. Distribution of the effort done by the Brazilian tuna longline fishery in the Atlantic Ocean from 1978 to 2012 (35 years).

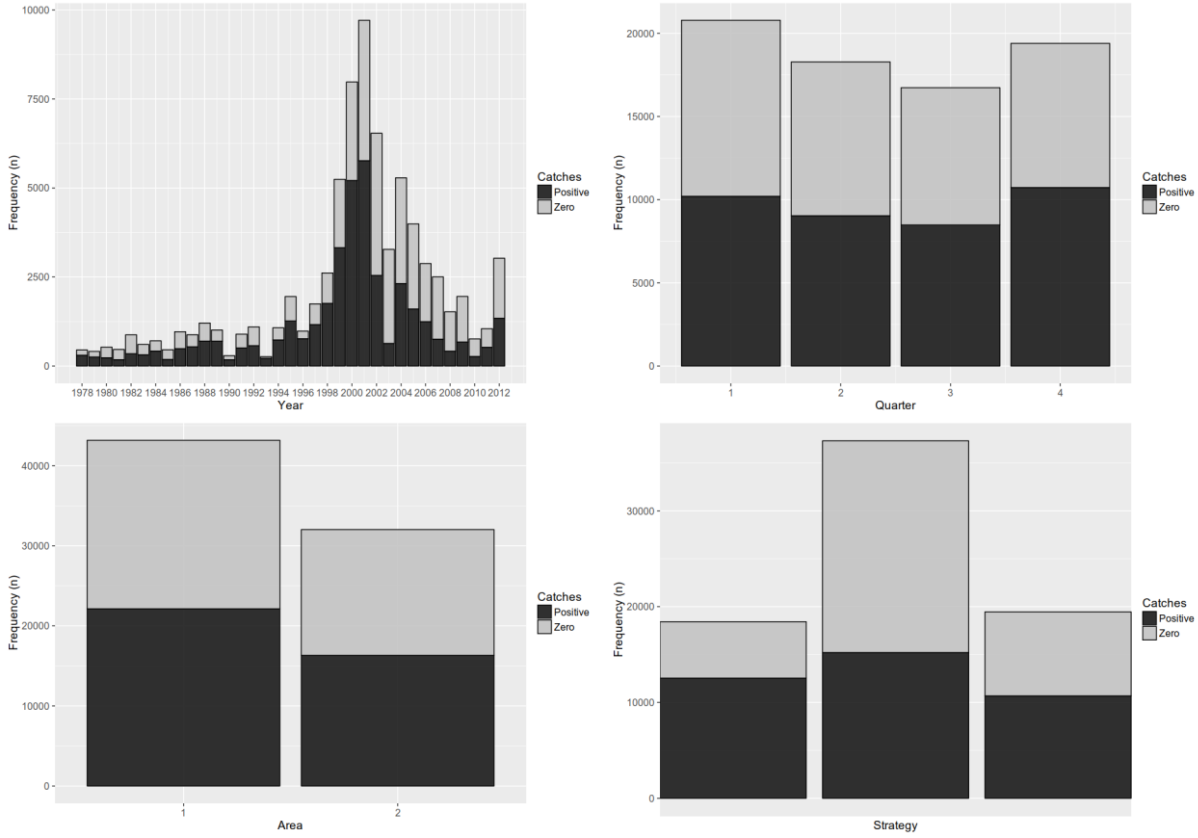

Figure 2. Proportion of positive captures and negative sets by year, quarter, area and strategy.

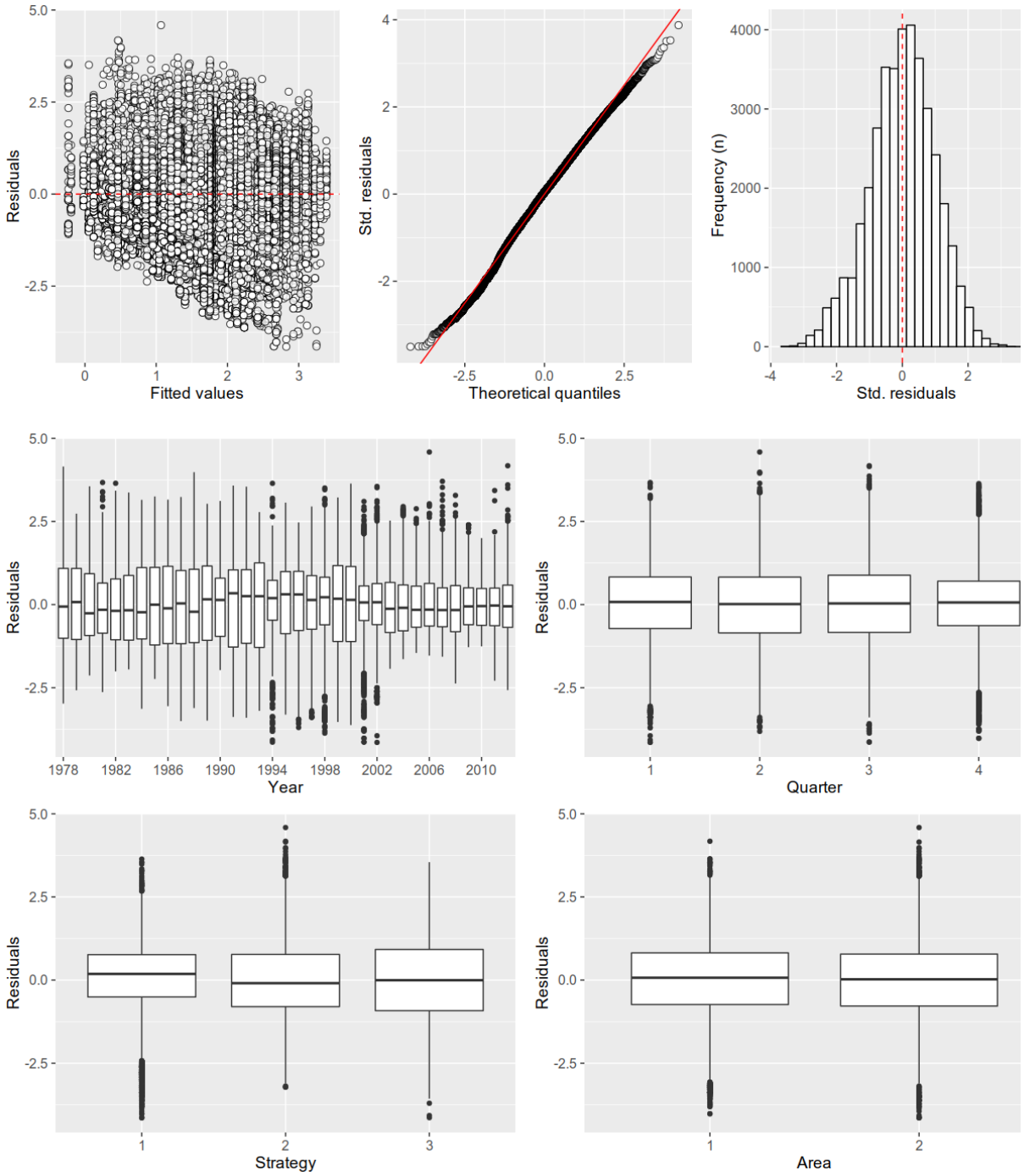

Figure 3. Residual analysis of the Lognormal model fitting of ALB caught by the Brazilian tuna longline fleet 1978 to 2012.

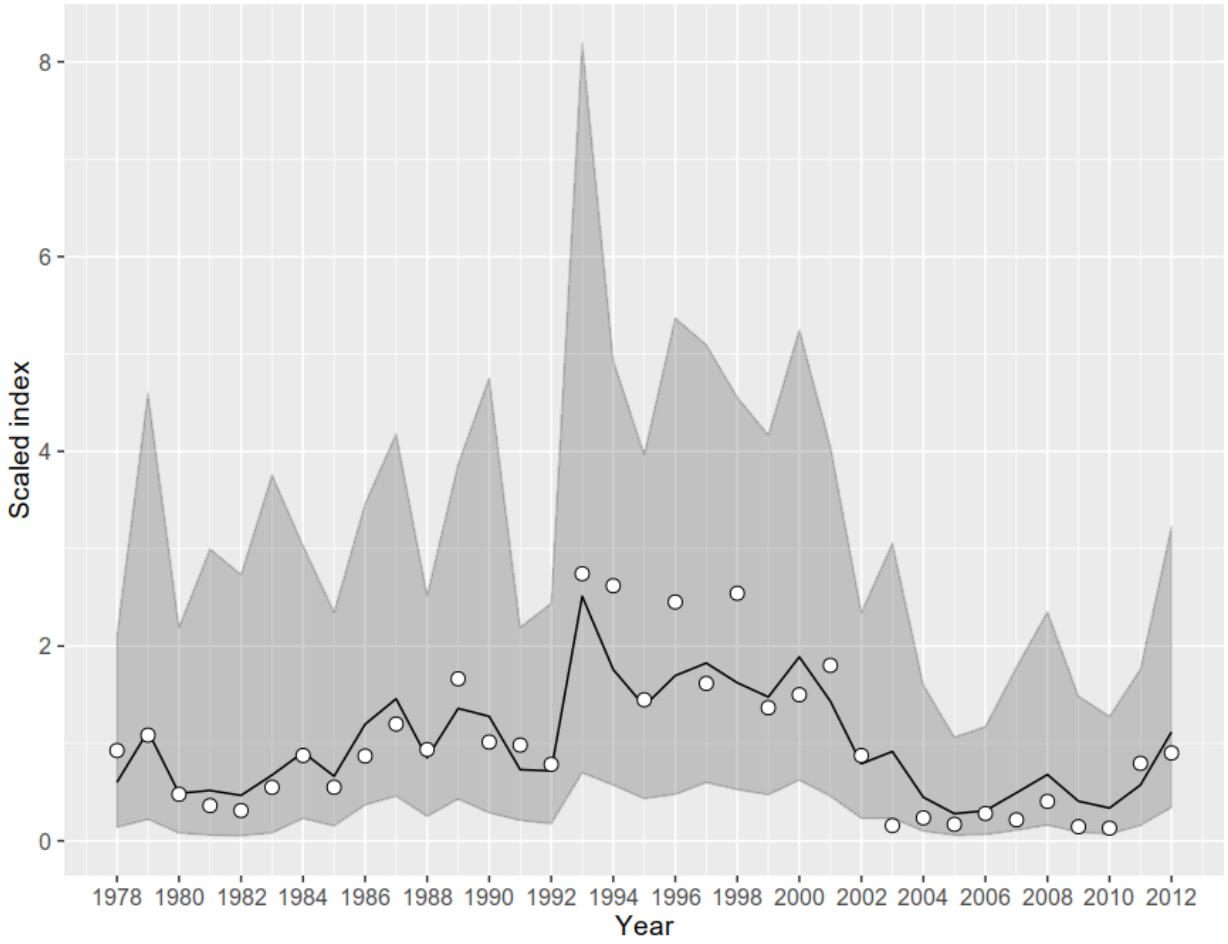

Figure 4. Nominal and standardized scaled CPUE of ALB for Brazilian tuna longliners from 1978 to 2012.