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STANDARDIZED CATCH RATES OF SWORDFISH (*XIPHIAS GLADIUS*) CAUGHT BY THE BRAZILIAN FLEET (1978-2012) USING GENERALIZED LINEAR MIXED MODELS (GLMM) USING 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 was collected. During the 1978 to 2012 period, 88423 sets were analyzed. The CPUE of swordfish 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 end of the 1980s to 2007, then a sharp decrease from that year on.

RÉSUMÉ

L'information sur la prise et l'effort provenant de la flottille palangrière brésilienne de thonidés (nationale et affrétée) opérant dans l'océan Atlantique équatorial et du Sud-Ouest a été recueillie. Au cours de la période 1978-2012, 88.423 opérations ont été analysées. La CPUE de l'espadon était 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. Les séries de CPUE standardisées font apparaître une oscillation considérable dans le temps, avec une tendance générale à la hausse de la fin des années 80 à 2007, suivie d'une brusque chute à partir de cette année-là.

RESUMEN

Se recopiló la información sobre captura y esfuerzo de la flota atunera de palangre brasileño (nacional y fletada) en el Atlántico suroccidental y ecuatorial. Durante 1978 a 2012, se analizaron 88.423 operaciones. Se estandarizó la CPUE de pez espada mediante modelos mixtos lineales generalizados (GLM) utilizando un enfoque delta lognormal. Los factores utilizados en el modelo fueron trimestre, año, área y estrategia de pesca. Las series de CPUE estandarizadas mostraban una oscilación significativa en el tiempo con una tendencia ascendente general desde finales de los 80 hasta 2007, seguida de un marcado descenso desde ese año en adelante.

KEYWORDS

Abundance indices, Fishery indicators, Swordfish, Longline gear

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 generate a standardized CPUE series for swordfish caught by Brazilian longliners in the Atlantic Ocean, which may be utilized in the next swordfish stock assessment, scheduled for June, 2013.

2. Material and Methods

In the present study, catch and effort data from 88,423 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 10ºE to 52ºW of longitude, and from 010ºN 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 moderate proportion of sets with zero catches of swordfish (24.5%), 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). We calculated the relative importance of each explanatory variable to set the order of entry for each variable, (R^2 - contribution averaged over ordering among regressors LMG) (**Figure 2**), which provides a decomposition of the model variance into non explained - negative contributions (Groemping, 2006).*

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 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 (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. 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 and Ortiz (2012) for two-stage CPUE estimator.

The factors considered as explanatory variables were "Year" (35), "Quarter" (4), "Area" (A1>25ºS; A2<25ºS), "Fishing strategy" (4). The fleet strategy was estimated in two steps (Hazin, *et al*., in preparation): 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 88,423 fishing sets done, with about 25 species reported on the observer 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 percentage of sets done by each fishing boat, within each cluster. Then, a MDS (Multidimensional Scaling) method (Kaufman and Rousseeuw 2005) was applied to find coherent patterns that may discriminate groups of boats with similar fishing strategies, with four different strategies being identified. These four different "fishing strategies" (description in **Table 1**) were then used as a factor in the CPUE standardization by GLMM. The spatial distribution of the set by strategy was plotted (**Figure 3**). This methodology has been used in several other instances, such as during the last assessments of yellowfin tuna and both mako and blue sharks.

Results

The proportion of null catches of swordfish for the study area was 24.5% for the entire period. In most cases, the proportion of positive catches of swordfish was between 61% and 96% of the sets (**Table 2**). **Figure 4** depicts the number the positive observations by factors. **Table 3** shows an example of the deviance table for swordfish. Estimated standardized CPUE was estimated as the product of the estimated proportion of positive sets per year times the mean catch rate per year for positive sets for each year. The selected models for the lognormal and binomial components were:

Lognormal Model: log(CPUE)=Strategy+Year+Quarter+Area+ random(Year:Quarter)
Binomial Model: proportion=Strategy+Year+Quarter+Area+ random(Year:Quarter)+random (Year:Area)

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 5**). 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 6**).

The standardized CPUE series shows a significant oscillation over time, with a general increasing trend from final eighties to 2007, then a sharp decrease from that year on (**Table 4 and Figure 6**).

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Table 1. General characteristics of fishery operations and strategies of the Brazilian longline fleet obtained from cluster analysis, from 1980 to 2010.

Strategy	***Fishing fleet 1***	***Fishing fleet 2***	***Fishing fleet 3***	***Fishing fleet 4***
Fleet	6	9	8	16
Boats	41	72	53	97
LOA	24	32	39	33
TBA	84	212	281	257
Setting time (h)	13	16	7	13
Setting duration (h)	5	5	6	5
Hook per basket	7	5	13	7
Effort (n)	1481	1282	2981	1639
Day	18%	11%	72%	23%
Night	82%	89%	28%	77%
Total of the sets (n)	7789	15263	8490	21648
Sets (%)	15%	29%	16%	41%
Target Strategies	Target strategie 1	Target strategie 5	Target strategie 4-6	Target strategie 2-3

Table 2. Catch and effort information of the Brazilian longline fleet from 1978 to 2012.

Year	*Sets*	*Proportion positive*	*SWO catch*	*Effort*	*CPUE_n*
1978	502	0.82	4908	1231307	3.986
1979	482	0.80	3884	900557	4.313
1980	581	0.90	6850	963985	7.106
1981	466	0.90	9154	863548	10.600
1982	889	0.86	18153	1690871	10.736
1983	618	0.88	7364	1258404	5.852
1984	716	0.81	4961	1586165	3.128
1985	471	0.82	4354	974801	4.467
1986	992	0.90	10018	2033997	4.925
1987	925	0.83	9049	1570570	5.762
1988	1221	0.82	11504	2393556	4.806
1989	1032	0.68	6159	2284831	2.696
1990	289	0.79	2205	397434	5.548
1991	992	0.74	7295	2387370	3.056
1992	1210	0.66	4688	3363172	1.394
1993	205	0.74	849	393482	2.158
1994	1055	0.61	5624	2477418	2.270
1995	1917	0.68	8443	4734581	1.783
1996	953	0.65	3854	1731013	2.226
1997	1818	0.71	12125	3276959	3.700
1998	2666	0.70	31998	6064386	5.276
1999	5254	0.74	23975	10821006	2.216
2000	8027	0.73	43857	15072643	2.910
2001	9768	0.67	43459	19371323	2.243
2002	6598	0.76	28004	10841530	2.583
2003	3362	0.93	27911	3714476	7.514
2004	7780	0.80	53665	10843063	4.949
2005	9040	0.77	71192	13006069	5.474
2006	6260	0.91	84142	8089053	10.402
2007	4149	0.83	51132	4756186	10.751
2008	1835	0.96	25333	2284616	11.089
2009	2196	0.96	30087	2746747	10.954
2010	1258	0.94	20102	1569777	12.806
2011	2466	0.81	21514	4961294	4.336
2012*	43	0.95	816	71607	11.396
Total	**88,036**	**0.78**	**698,628**	**150,727,797**	**4.64**

*Partial

Table 3. Deviance analysis of explanatory variables by Delta Lognormal and Generalized Linear Mixed Models used to standardize the CPUE series of swordfish caught by the Brazilian tuna longline fleet, from 1978 to 2012. A=area; Q=quarter; S= fleet strategy and Y=Year

DELA LOGNORMAL	***df***	***Resid deviance***	***Deviance***	***% of total deviance***
Model positive				
NULL	1	109560		
S	3	76669	32892	82.1
S+Y	34	72432	4236	10.6
S+Y+Q	3	72215	217	0.5
S+Y+Q+A	43	72144	71	0.2
S+Y+Q+A+Y:Q	143	70362	2758	6.9
S+Y+Q+A+Y:A	74	71287	857	2.1
S+Y+Q+A+Y:Q+Y:A	174	69477	885	2.2
Model proportion				
NULL		22713		
S	3	10652	12061	80.6
S+Y	34	9441	1211	8.1
S+Y+Q	3	9318	123	0.8
S+Y+Q+A	1	9289	28	0.2
S+Y+Q+A+Y:Q	100	7758	1532	10.2
S+Y+Q+A+Y:A	32	8396	893	6.0

GLMM	***Df***	***AIC***	***BIC***	***logLik***	***Pr(>Chisq)***
Model positive					
S+Y+Q+A+(1|Y:Q)	44	197500	197903	-98706	
S+Y+Q+A+(1|Y:A)	44	198183	198585	-99047	>0.05
S+Y+Q+A+(1|Y:Q)+(1|Y:Q)	45	196851	197262	-98380	0.00
Model proportion	Df	AIC	BIC	logLik	Pr(>Chisq)
S+Y+Q+A+(1|Y:A)	43	8704	8893	-4309	
S+Y+Q+A+(1|Y:Q)	43	8286	8475	-4100	0.00
S+Y+Q+A+(1|Y:Q)+(1|Y:Q)	44	7616	7810	-3764	0.00

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

Year	*index*	*LCI_index*	*UCI_index*	*se_index*	*CV_index*	*scaled_index*	*scaled_CPUE*
1978	1.068	0.541	1.879	0.401	0.376	0.477	0.714
1979	1.067	0.442	2.164	0.490	0.459	0.477	0.772
1980	1.411	0.692	2.506	0.571	0.405	0.630	1.273
1981	1.587	0.652	3.214	0.727	0.458	0.709	1.899
1982	1.777	0.720	3.671	0.813	0.458	0.794	1.923
1983	1.431	0.668	2.650	0.618	0.432	0.640	1.048
1984	1.281	0.712	2.106	0.449	0.351	0.572	0.560
1985	1.308	0.673	2.268	0.480	0.367	0.584	0.800
1986	1.771	1.084	2.729	0.583	0.329	0.791	0.882
1987	1.733	0.966	2.840	0.605	0.349	0.774	1.032
1988	1.737	0.968	2.851	0.604	0.348	0.776	0.861
1989	1.191	0.622	2.052	0.427	0.359	0.532	0.483
1990	2.257	1.049	4.213	1.009	0.447	1.008	0.994
1991	2.139	1.275	3.357	0.720	0.337	0.956	0.547
1992	1.342	0.728	2.251	0.476	0.355	0.600	0.250
1993	2.124	1.058	3.790	0.892	0.420	0.949	0.386
1994	1.798	0.990	2.979	0.632	0.351	0.803	0.407
1995	2.826	1.704	4.402	0.938	0.332	1.262	0.319
1996	2.359	1.310	3.883	0.831	0.352	1.054	0.399
1997	1.873	1.030	3.105	0.654	0.349	0.837	0.663
1998	3.363	1.928	5.413	1.146	0.341	1.502	0.945
1999	1.687	0.976	2.700	0.571	0.339	0.754	0.397
2000	2.225	1.287	3.560	0.752	0.338	0.994	0.521
2001	1.870	1.052	3.051	0.641	0.343	0.835	0.402
2002	1.712	1.022	2.681	0.568	0.332	0.765	0.463
2003	3.155	1.991	4.774	1.012	0.321	1.409	1.346
2004	2.427	1.484	3.742	0.794	0.327	1.084	0.886
2005	2.406	1.410	3.813	0.807	0.335	1.075	0.980
2006	3.645	2.257	5.578	1.182	0.324	1.628	1.863
2007	2.987	1.633	4.971	1.040	0.348	1.334	1.926
2008	5.017	3.250	7.468	1.589	0.317	2.242	1.986
2009	4.289	2.787	6.373	1.348	0.314	1.916	1.962
2010	4.551	2.879	6.857	1.465	0.322	2.033	2.294
2011	2.183	1.267	3.482	0.740	0.339	0.975	0.777
2012	2.748	0.986	5.525	1.482	0.539	1.228	2.041

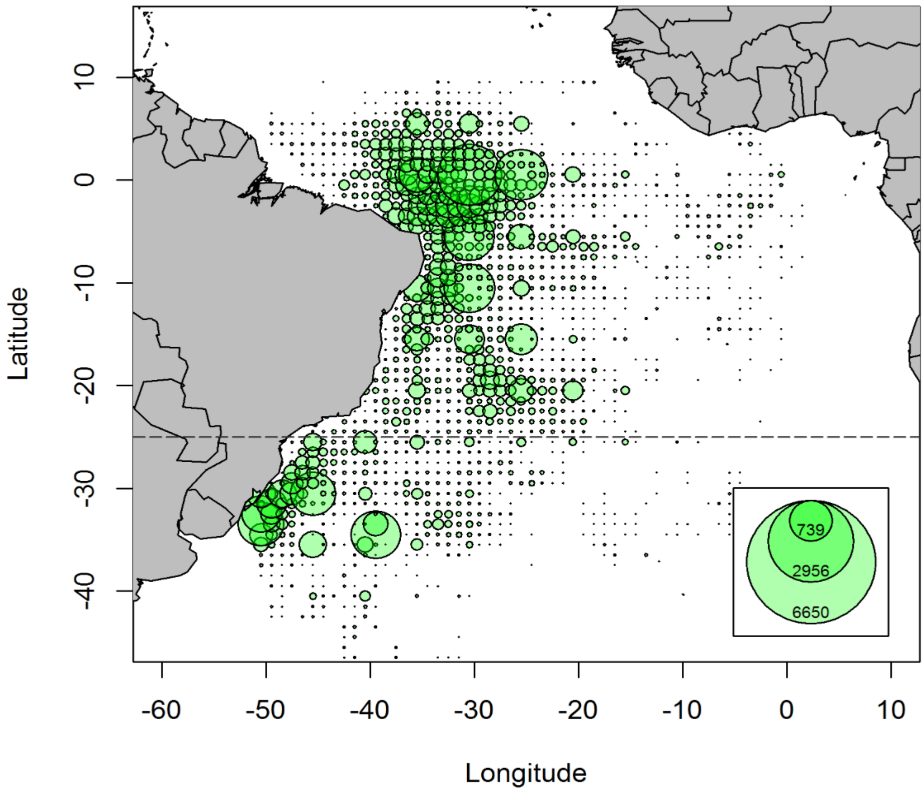

Figure 1. Distribution of the effort done by the Brazilian tuna longline fishery in the Atlantic Ocean, from 1978 to 2012 (35 years).

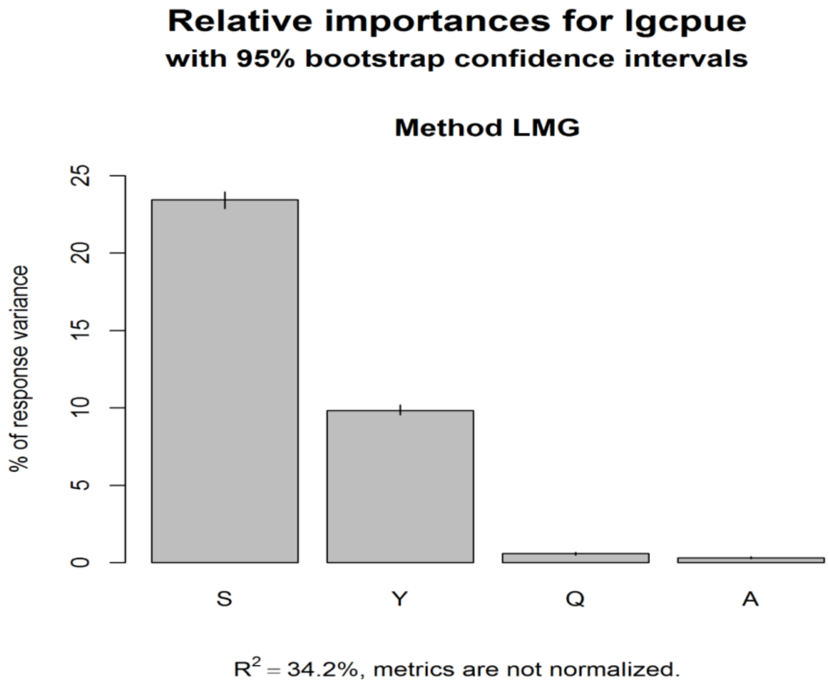

Figure 2. Bar plots of lmg the relative importance with confidence intervals (S: strategy, Y: year, Q: quarter, A: area).

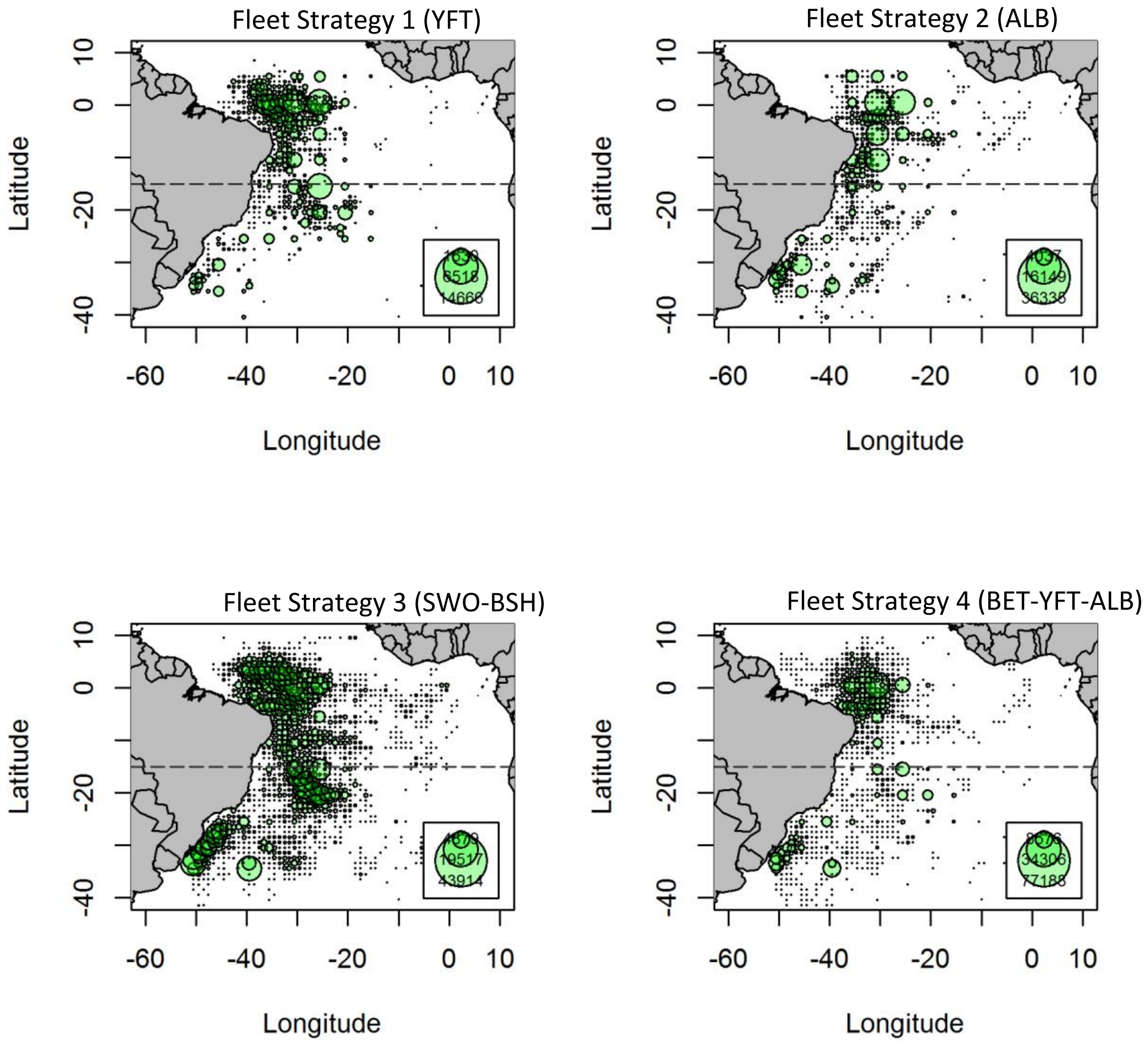

Figure 3. Distribution of the Brazilian sets categorized by strategies (1 to 4 clockwise). Note that the SWO target profile is included into the strategy 2.

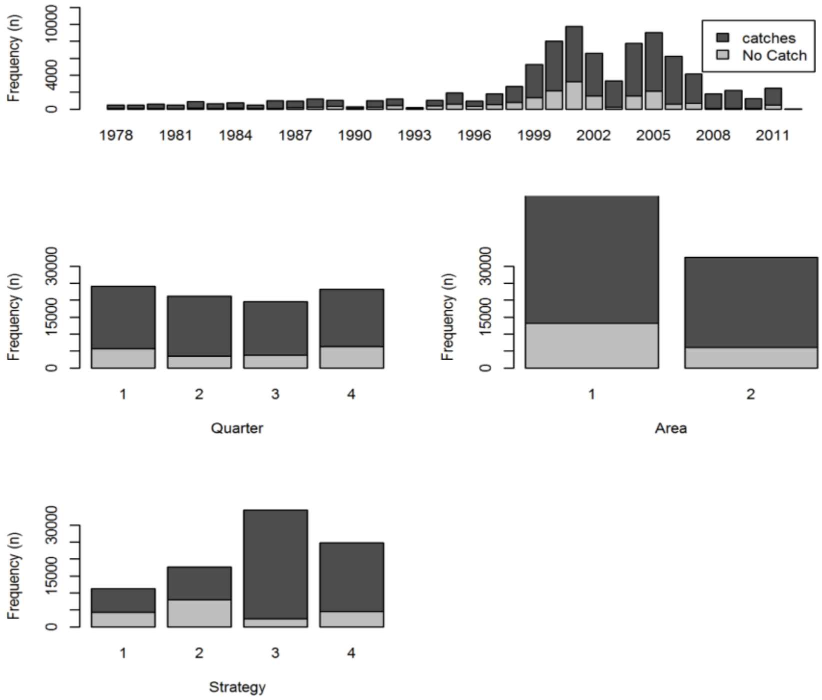

Figure 4. Proportion of positive captures and negative sets by year, quarter, area and strategy.

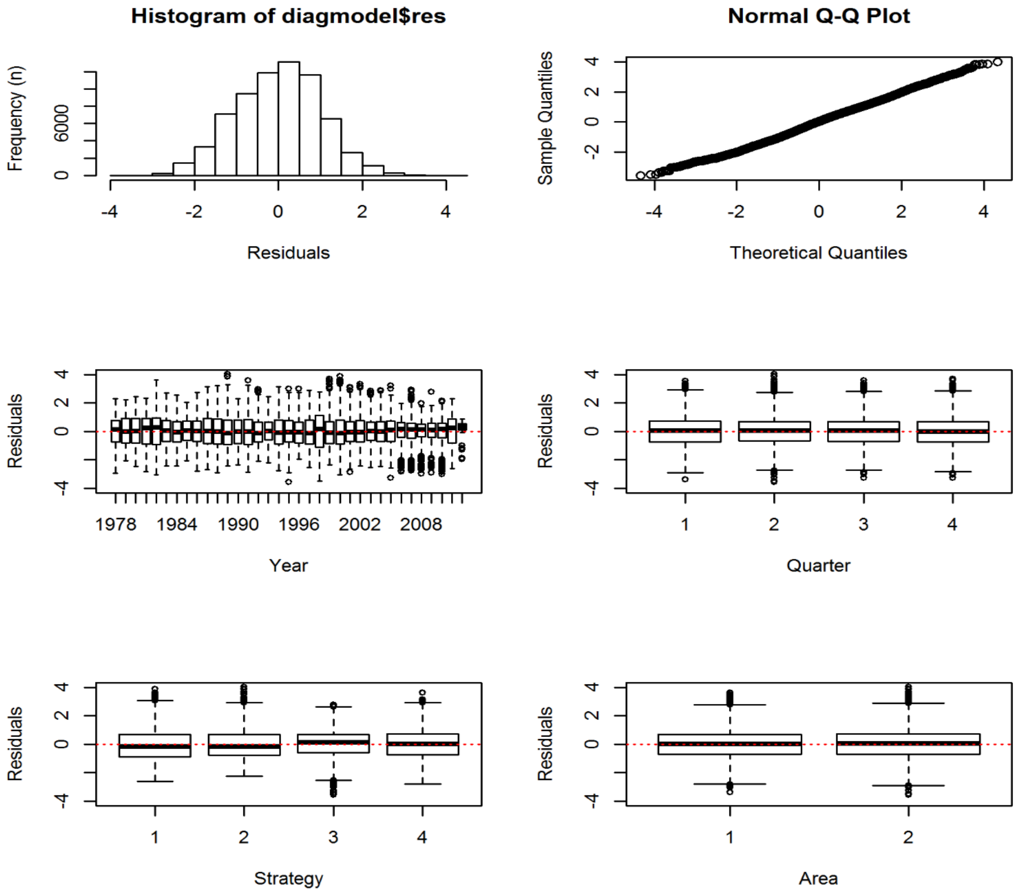

Figure 5. Residual analysis of the log-normal model fitting of swordfish caught by the Brazilian tuna longline fleet, 1978 to 2012.

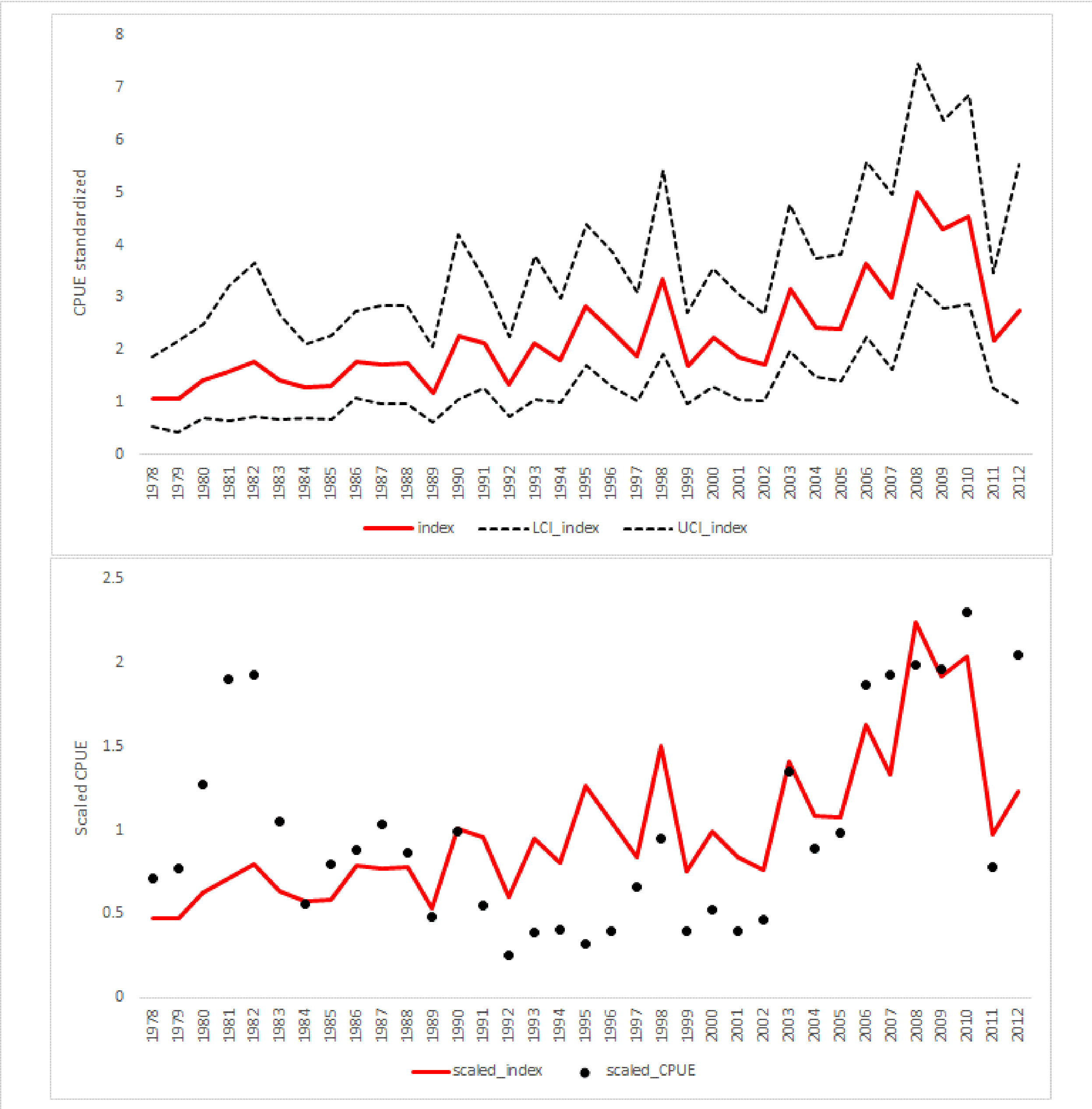

Figure 6. Nominal and standardized CPUE of swordfish for Brazilian tuna longliners, from 1978 to 2012.