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STANDARDIZED CPUE SERIES OF SHORTFIN MAKO CAUGHT BY BRAZILIAN TUNA LONGLINE FISHERIES IN THE EQUATORIAL AND SOUTHWESTERN ATLANTIC OCEAN (1978-2012)

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SUMMARY

In the present study, catch and effort data from 88.423 sets done by the Brazilian tuna longline fleet (national and chartered) in the equatorial and Southwestern Atlantic Ocean, from 1978 to 2012 (35 years) were analyzed. The CPUE of mako was standardized by a GLM, assuming a Zero Inflated Negative Binomial (ZINB) distribution. The factors used in the model were: quarter, year, area, and strategy. The standardized CPUE series obtained for mako sharks by the zero inflated negative binomial was not much different from the one done in 2008. Abundance indices showed a moderate inter-annual oscillation, with a gradual increase in values of CPUE until 2003, and a decreasing trend from that year on.

RÉSUMÉ

L'étude présente l'analyse les données de prise et d'effort provenant de 88.423 opérations à la palangre de la flottille brésilienne (nationale et affrétée) ciblant les thonidés dans l'océan Atlantique équatorial et du Sud-Ouest entre 1978 et 2012 (35 ans). La CPUE du requin-taupe bleu a été standardisée au moyen d'un GLM postulant une distribution binomiale négative à inflation de zéros (ZINB). Les facteurs utilisés dans le modèle étaient les suivants: trimestre, année, zone et stratégie. La série standardisée de la CPUE obtenue pour les requins-taupes bleus au moyen de la distribution binomiale négative à inflation de zéros n'était pas très différente de celle obtenue en 2008. Les indices d'abondance présentaient une oscillation interannuelle modérée, les valeurs de la CPUE augmentant graduellement jusqu'en 2003 et présentant une tendance à la baisse à partir de cette année.

RESUMEN

En este estudio se analizan los datos de captura y esfuerzo de 88.423 lances realizados por la flota atunera de palangre brasileña (nacional y fletada) en el Atlántico suroccidental y ecuatorial entre 1978 y 2012 (35 años). Se estandarizó la CPUE de los marrajos mediante un GLM asumiendo una distribución binomial negativa de ceros aumentados (ZINB). Los factores utilizados en el modelo fueron trimestre, año, área y estrategia. La serie de CPUE estandarizada obtenida para los marrajos mediante la distribución binomial negativa de ceros aumentados no era muy diferente de la obtenida en 2008. Los índices de abundancia mostraban una oscilación interanual moderada, con un aumento gradual en los valores de la CPUE hasta 2003, y una tendencia descendente desde ese año en adelante.

KEYWORDS

CPUE, shortfin mako, abundance indices

1. Introduction

The shortfin mako, *Isurus oxyrinchus*, is a common epipelagic species found in tropical and warm-temperate seas (Compagno, 1999). In spite of its relatively low catches, because of its high commercial value, together with the blue shark, it is one of the best recorded shark species in commercial operations (Clarke *et al*., 2004).

Since 1956, when the tuna longline fishery began in the South Atlantic, several changes in both gear design and structure, as well as in fishing operation and targeting strategies, have been observed, with a strong influence on catch composition (Amorim and Arfelli, 1984; Arfelli, 1996; Hazin, 1993; Hazin and Hazin, 1999; Menezes de

Lima *et al*., 2000). Such changes, together, may lead to strong variations in catchability, which, in turn, can introduce serious errors in the estimation of abundance indices (Fréon and Misund, 1999).

One way to overcome this bias is by standardizing the CPUE series by a Generalized Linear Model (GLM), incorporating the factors that are known to influence catchability (Gulland, 1983). Catch and effort databases, however, often include high proportions of records in which the catch is zero, even though effort is recorded to be non-zero. This is particularly the case for less abundant species and for by-catch species (Maunder and Punt, 2004), like the mako sharks.

The objective of this paper, therefore, was to update a standardized CPUE series of the mako shark, caught by Brazilian longliners, with the application of a zero inflated negative binomial GLM, in preparation for the stock assessment of the species, by the International Commission for the Conservation of Atlantic Tunas- ICCAT.

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 (35 years) were analyzed. All the data were obtained from the logbooks filled in by the skippers of the vessels. The longline sets were distributed along a wide area of the Equatorial and South Atlantic Ocean, ranging from 20ºW to 52ºW of longitude, and from 010ºN to 40ºS of latitude **(Figure 1)**. The resolution of 1º latitude x 1º longitude, per fishing day, was used for the analysis of the geographical distribution of catches.

The factors considered as explanatory variables were “Year” (35), “Quarter” (4), “Area” (A1>15ºS; A2<15ºS), and “Fleet strategy” (4). Due to the very large proportion of sets with zero catches of shortfin mako (~87%), stemming from its bycatch nature in this fishery, the standardized CPUE series was generated, assuming a Zero Inflated Negative Binomial distribution (Lambert, 1992). The fleet strategy was estimated in two steps (Hazin, et al, in press, ANNEX 01): 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 (MathSoft, 1995). Accordingly, 88,423the fishing sets were thus analyzed, with about 25 species reported on the observer log-books, and 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 (Mac Queen 1967; Kaufman and Rousseeuw 2005) was applied to find coherent patterns that may discriminate groups of boats with similar fishing strategies. These "fishing strategy", equal to four, were then used as a factor in the CPUE standardization by GLM. The model can then be described as:

– Part 1: Count models: Catch= Year + Quarter + Area + Strategy + offset (effort) + ε
– Part 2: Binomial models: Catch= Year + Area + Strategy + ε

The residual plots of zero inflated models are difficult to interpret because the response variable has a mixed distribution (Albert and Chib, 1995). This fact accounts for unusual residual distribution, i.e., the Q-Q plot shows a straight line fragmented into two sections. To convert the residuals into a form which is easier to interpret, a binned plot was constructed. The data were divided into categories (bins) of different fitted values with the mean fitted value being then plotted against the mean residual for each bin (Gelman and Hill, 2007). The dotted lines on the binned plot represent the bounds of the standard errors (i.e. 95% of the points should be found within these bounds). The Dynamic Factor Analysis (DFA), with 1 common trend plus noise, was used to characterize the trends of the standardized CPUE series for shortfin mako. The DFA is a technique, modeled by a “random walk trend”, for identification of trends based on the reduction of dimensions specially designed for relatively short temporal and non-stationary series (Chartfield, 1989; Harvey, 1989; Zuur, *et al*., 2003). It has the ability to assume distributions different from the Gaussian, such as the binomial, being also applicable to other distributions by changes in the algorithms (“Kalman filtering” e “smoothers”) (Fahrmeir e Tutz, 1994; Zuur *et al*., 2003).

3. Results

The zero inflated negative binomial explained 43% of the total variance of the model and it is slightly under-dispersed (φ= 0.53). The estimated parameter values and their respective errors and associated p-values are shown in **Table 1**. In general, the estimated coefficients for both parts were significantly different from zero. The distribution of residuals appeared to be quite close to normal (**Figure 2 and 3**). These results indicate that good fits were obtained for all distributions and that assumed errors were quite satisfactory for the models.

The standardized CPUE series for mako by the zero inflated negative binomial was not much different from the one obtained in 2008, by a delta-lognormal distribution (**Table 2** and **Figure 4 to 5**). Abundance indices showed a moderate inter-annual oscillation, with a gradual increase in values of CPUE until 2003, with a decreasing trend from that year on.

Table 1. Estimative coefficients of predictors for the Zero Inflated Negative Binomial.

	Count models				*Zero Models*			
	Estimate	*Std. Error*	*z value*	*Pr(>|z|)*	*Estimate*	*Std. Error*	*z value*	*Pr(>|z|)*
(Intercept)	-9.88	0.29	-34.42	0.00	1.78	0.38	4.66	0.00
fy1979	-1.04	0.54	-1.92	0.05	-0.46	1.00	-0.46	0.64
fy1980	0.34	0.35	0.98	0.33	-0.70	0.56	-1.25	0.21
fy1981	0.52	0.44	1.16	0.25	1.38	0.51	2.69	0.01
fy1982	0.04	0.38	0.11	0.92	0.45	0.53	0.86	0.39
fy1983	-0.11	0.48	-0.22	0.83	0.96	0.57	1.68	0.09
fy1984	-0.10	0.30	-0.32	0.75	-5.93	1.45	-4.09	0.00
fy1985	1.40	0.36	3.90	0.00	-0.29	0.46	-0.62	0.53
fy1986	0.96	0.32	3.02	0.00	-1.48	0.48	-3.09	0.00
fy1987	0.07	0.34	0.21	0.83	-2.01	0.62	-3.24	0.00
fy1988	1.02	0.36	2.88	0.00	-1.21	0.61	-1.98	0.05
fy1989	1.17	0.33	3.58	0.00	-0.45	0.43	-1.06	0.29
fy1990	1.57	0.54	2.92	0.00	-0.24	0.62	-0.40	0.69
fy1991	0.20	0.31	0.65	0.52	-2.49	0.47	-5.34	0.00
fy1992	0.50	0.37	1.34	0.18	-0.66	0.53	-1.26	0.21
fy1993	1.18	0.75	1.57	0.12	0.04	0.78	0.05	0.96
fy1994	0.34	0.31	1.10	0.27	-2.44	0.45	-5.36	0.00
fy1995	1.13	0.31	3.66	0.00	-2.03	0.43	-4.74	0.00
fy1996	1.18	0.33	3.62	0.00	-2.27	0.50	-4.57	0.00
fy1997	2.01	0.34	5.93	0.00	0.25	0.44	0.56	0.58
fy1998	0.85	0.29	2.94	0.00	-4.26	0.45	-9.40	0.00
fy1999	1.18	0.30	3.93	0.00	-2.06	0.46	-4.48	0.00
fy2000	-0.05	0.29	-0.17	0.87	-2.67	0.47	-5.66	0.00
fy2001	2.66	0.29	9.26	0.00	-0.03	0.38	-0.07	0.95
fy2002	2.15	0.28	7.54	0.00	-0.87	0.37	-2.31	0.02
fy2003	2.34	0.29	8.06	0.00	-0.79	0.38	-2.09	0.04
fy2004	1.73	0.28	6.10	0.00	-1.86	0.38	-4.88	0.00
fy2005	1.26	0.28	4.44	0.00	-2.67	0.40	-6.69	0.00
fy2006	1.11	0.28	3.90	0.00	-4.32	0.77	-5.58	0.00
fy2007	1.19	0.28	4.17	0.00	-3.25	0.51	-6.33	0.00
fy2008	0.54	0.29	1.83	0.07	-14.71	551.02	-0.03	0.98
fy2009	0.82	0.29	2.82	0.00	-4.27	1.08	-3.95	0.00
fy2010	1.42	0.30	4.75	0.00	-2.01	0.45	-4.52	0.00
fy2011	0.61	0.29	2.10	0.04	-4.88	0.54	-9.03	0.00
fA2	0.69	0.03	20.21	0.00	-1.67	0.08	-20.01	0.00
fFF2	0.94	0.07	13.67	0.00	2.52	0.17	14.43	0.00
fFF3	-0.02	0.05	-0.42	0.68	-0.44	0.10	-4.28	0.00
fFF4	0.04	0.05	0.70	0.48	0.53	0.10	5.46	0.00
fq2	0.02	0.03	0.64	0.52	-	-	-	-
fq3	0.59	0.03	18.14	0.00	-	-	-	-
fq4	0.46	0.03	13.73	0.00	-	-	-	-
Log(theta)	-1.10	0.04	-27.47	0.00	-	-	-	-

Table 2. Nominal and standardized CPUE values and DFA CPUE trend for mako sharks caught by Brazilian longliners, from 1978 to 2011. CV: Coefficient of variance; lower and upper: IC 95%

Year	*CPUE.nominal*	*Index*	*Lower*	*Upper*	*CV*	*DFA_Trend_2012*
1978	0.048	0.031	0.021	0.046	20.927	0.15
1979	0.029	0.014	0.007	0.023	30.170	0.15
1980	0.116	0.064	0.045	0.090	18.229	0.21
1981	0.066	0.020	0.012	0.032	26.626	0.18
1982	0.066	0.024	0.017	0.033	17.076	0.2
1983	0.041	0.015	0.009	0.023	25.050	0.28
1984	0.123	0.126	0.088	0.158	13.892	0.5
1985	0.177	0.151	0.106	0.212	18.080	0.64
1986	0.133	0.166	0.127	0.216	13.797	0.68
1987	0.060	0.082	0.055	0.114	18.423	0.61
1988	0.163	0.160	0.114	0.207	14.565	0.69
1989	0.124	0.130	0.099	0.173	14.735	0.69
1990	0.068	0.174	0.083	0.356	41.454	0.71
1991	0.124	0.108	0.084	0.137	12.539	0.6
1992	0.047	0.074	0.052	0.100	16.475	0.55
1993	0.015	0.100	0.032	0.256	61.965	0.62
1994	0.120	0.123	0.095	0.155	12.683	0.77
1995	0.191	0.238	0.189	0.295	11.462	1.03
1996	0.166	0.271	0.199	0.366	15.539	1.17
1997	0.184	0.201	0.152	0.263	14.440	1.16
1998	0.273	0.288	0.249	0.332	7.327	1.28
1999	0.133	0.253	0.213	0.292	7.977	1.26
2000	0.056	0.088	0.076	0.101	7.200	1.25
2001	0.260	0.455	0.396	0.520	7.006	1.8
2002	0.422	0.424	0.375	0.478	6.236	2.01
2003	0.479	0.494	0.425	0.574	7.671	2.13
2004	0.335	0.413	0.367	0.463	5.940	2
2005	0.269	0.326	0.289	0.365	5.999	1.82
2006	0.281	0.376	0.298	0.438	9.447	1.78
2007	0.313	0.346	0.287	0.402	8.474	1.65
2008	0.116	0.248	0.000	0.289	50.271	1.46
2009	0.172	0.282	0.190	0.342	13.796	1.42
2010	0.265	0.318	0.256	0.393	11.019	1.38
2011	0.186	0.241	0.205	0.281	8.186	1.19

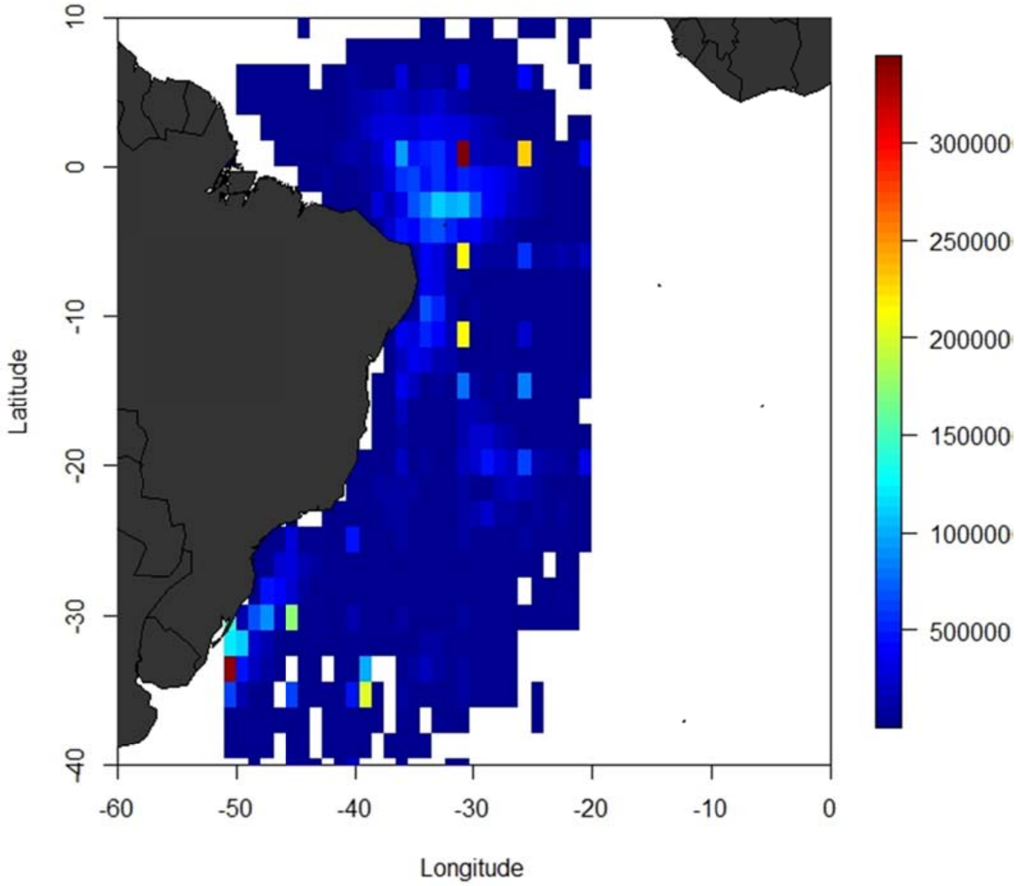

Figure 1. Distribution of fishing effort, in number of hooks, from Brazilian tuna longliners (national and chartered vessels), from 1978 to 2012.

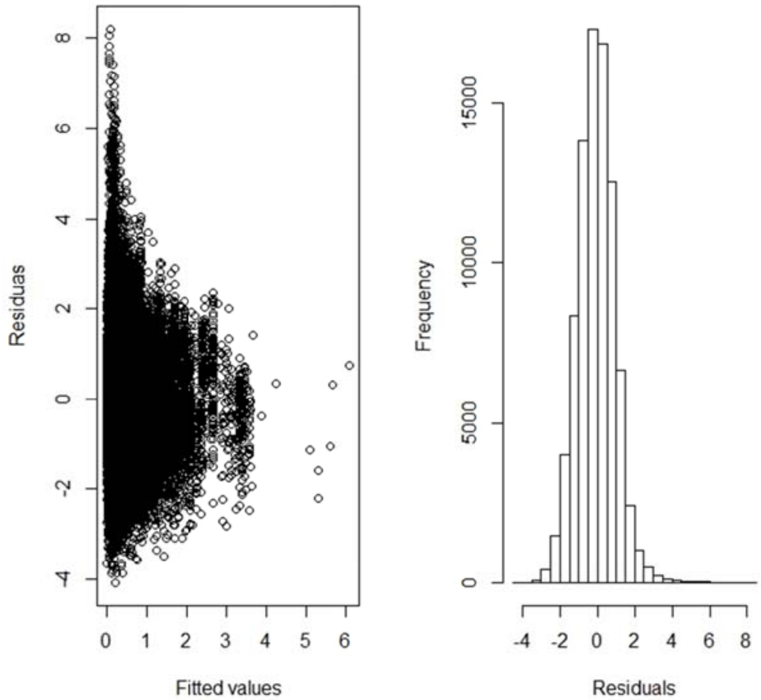

Figure 2. Residual analysis of the models used for fitting mako shark catches, from Brazilian tuna longliners (national and chartered vessels), from 1978 to 2012.

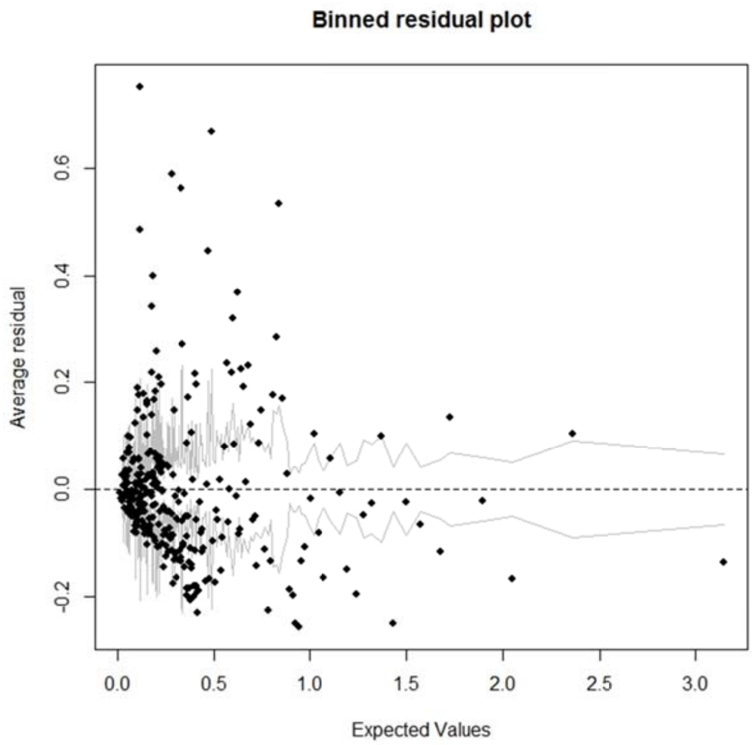

Figure 3. Binned plot with data divided into categories. There appears to be a slight pattern in the residuals; lower values are consistently underestimated by the model but not to a significant degree.

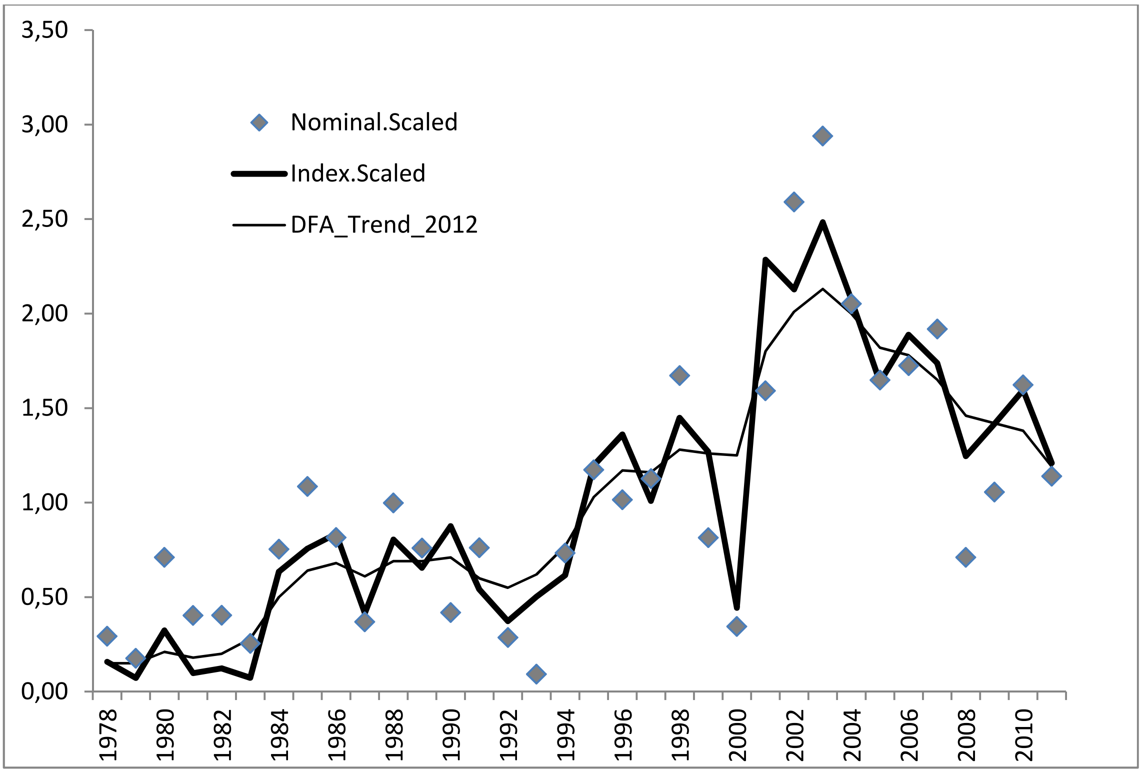

Figure 4. Nominal and standardized CPUE, and DFA CPUE trend, of mako sharks caught by Brazilian tuna longliners, from 1978 to 2011.

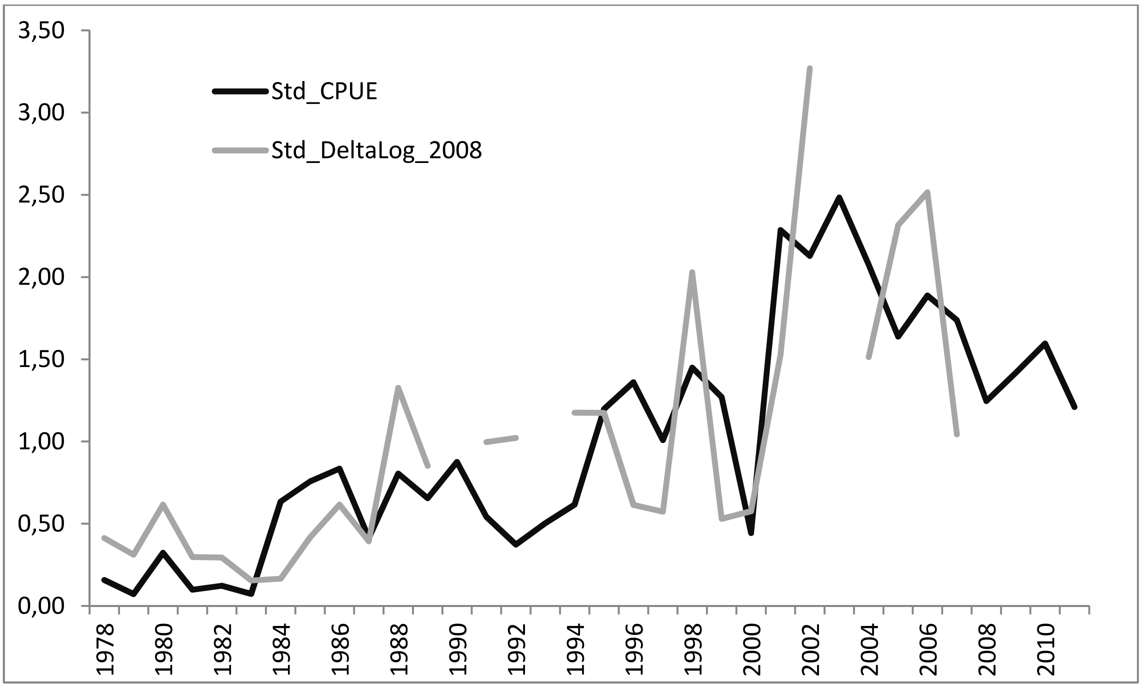

Figure 5. Standardized CPUE of mako sharks caught by Brazilian tuna longliners, from 1978 to 2008 (grey line) and from 1978 to 2011 (black line).

Annex

A DETAILED EXPLANATION OF THE CPUE STANDARDIZATION DONE ON THE BRAZILIAN TUNA LONGLINE DATA

During previous meetings, various SCRS working groups recognized the complex nature of the Brazilian tuna longline fleet, particularly the fact that it presents a large variety of vessels, flags and consequently operational characteristics. Because of that, the standardization methods commonly used by the SCRS might not be appropriate to standardize the Brazilian CPUE, as it has already been argued by the authors. Recently, cluster analyses have been applied to Brazilian tuna longline fishing data, aiming at categorizing fishing effort based on the proportion of the several species in the catches, as a way to detect changes in fishing strategy (target species). Presented for the first time in 2007, this approach has generated a lively discussion. The main advantage of such method, instead of using the percentage of a single species as an expression of the targeting strategy, relies in the fact that it considers the frequency distribution of all species in each set, thus providing, at least in principle, a much more reliable estimation of targeting (catch profile). However, it may have the caveat of overestimating the indices of abundance since the fishing sets with low catches of the target species may not be included in its respective cluster, thus potentially resulting in an artificially higher CPUE. On the other hand, however, the use of aggregated data by fleet, not considering the proportion of each species caught in each set, may cause an opposite bias, since a variable part of the fishing effort deployed might not have been directed to the expected target species, thus artificially lowering its relative abundance. In order to mitigate such bias, for the last yellowfin tuna assessment, done in 2011, the different fishing strategies applied by different fleets operating in Brazil were incorporated as a factor in the standardization process by an alternative methodology hereby explained.

Since 1956, when longline operations in the Southern Atlantic begun, several changes in fishing technology and strategies have occurred, strongly influencing catch composition and relative abundance of the target species. A number of models, such as GLM (General Linear Model), have been applied to minimize the effects of operational variables (fishing tactics) on the estimation of CPUE, through standardization processes. However, information on fishing tactics and even on significant technological changes is often not available, leading to serious errors in the estimation of abundance indices.

Previous analyses of the Brazilian longline fishery (Hazin, 2006, Carvalho *et al*., 2011) have clearly indicated that the different fleets operating in the Southwestern Atlantic Ocean choose different fishing tactics, targeting different resources (catch profile), from time to time. It is very important, therefore, to take this factor into consideration, in any attempt to standardize the CPUE of the species caught. In the approach hereby proposed, the analysis is done in two steps: (*i*) identifying the different clusters of sets with similar species composition from the catch data; and (*ii*) identifying the different fishing fleets that have similar fishing strategies and are consequently associated to the different clusters.

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 (MathSoft, 1995). Accordingly, a total of 57,365 fishing sets were thus analyzed, with about 25 species reported on the observer log-books, and 6 clusters were identified (**Annex-Table 1**), 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 was applied to find coherent patterns that may discriminate groups of boats with similar fishing strategies (**Annex-Table 2**). These “fishing fleets” were then used as a factor in the CPUE standardization by GLM.

Annex-Table 1. Distribution of longline sets from the Brazilian tuna longline fishery in the Atlantic Ocean, between 1980 and 2010, by clusters of main species caught (Target Strategies-TS).

Species	*TS 1*	*TS 2*	*TS 3*	*TS 4*	*TS 5*	*TS 6*
YFT	**54%**	13%	2%	13%	6%	8%
ALB	9%	5%	3%	7%	**75%**	5%
BET	8%	**53%**	2%	5%	4%	7%
SWO	10%	15%	16%	9%	3%	**56%**
SAI	3%	1%	1%	5%	2%	3%
WHM	1%	1%	0%	2%	1%	1%
BUM	2%	1%	1%	1%	1%	2%
SPF	0%	0%	0%	0%	0%	0%
OTH.BIL	0%	0%	1%	1%	0%	1%
SPG.n	0%	0%	0%	0%	0%	0%
BSH	4%	4%	**59%**	6%	2%	10%
SPL	0%	0%	2%	1%	0%	0%
BTH	0%	0%	0%	0%	0%	0%
MAK	0%	0%	4%	2%	0%	1%
FAL	0%	0%	0%	3%	0%	1%
OCS	0%	0%	0%	0%	0%	0%
OTH.SHARKS	3%	3%	2%	6%	2%	2%
OTH.TEL	6%	3%	6%	**40%**	4%	4%

Annex-Table 2. 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 3-6	Target strategie 5	Target strategie 2-4