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STANDARDIZED CPUE SERIES OF SWORDFISH, *XIPHIAS GLADIUS*, CAUGHT BY BRAZILIAN TUNA FISHERIES IN THE SOUTHWESTERN ATLANTIC OCEAN

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SUMMARY

*Relative abundance indices in numbers of swordfish (*Xiphias gladius*) caught by the Brazilian longline tuna fishery in the South Atlantic Ocean were obtained from the standardization of catch and effort data from 1978-2008 (~68,000 individual sets). The CPUE series (fish/1000 hooks) was standardized using two models of the exponential family (log link): quasi-Poisson and Tweedie. Both models are a special case of var= $m\mu^p$, for the quasi-Poisson model p=1, for the Tweedie model 1<p<2. The quasi-Poisson model explained 57% of the variance and the Tweedie model explained 54.4%. The cross-validation showed a correlation of 0.50 between observed values and those predicted for the quasi-Poisson model, and 0.76 for the Tweedie model. For both models, the factors "Target"and "Years" explained most of the deviance. The results obtained in the present paper are similar to the ones presented during the last swordfish stock assessment, in 2006, and seem to confirm the optimistic scenario of a continuing trend of CPUE increase for the species, in the southwestern Atlantic, in recent years.*

RÉSUMÉ

*Les indices d'abondance relative en nombres d'espadon (*Xiphias gladius*) capturés par la pêcherie thonière palangrière du Brésil dans l'océan Atlantique Sud ont été obtenus de la standardisation des données de capture et d'effort de 1978-2008 (environ 68.000 opérations individuelles). La série de CPUE (poisson/1.000 hameçons) a été standardisée à l'aide de deux modèles de la famille exponentielle (lien logarithmique) : quasi-Poisson et Tweedie. Les deux modèles sont un cas spécial de var= $m\mu^p$, pour le modèle quasi-Poisson p=1, pour le modèle Tweedie 1<p<2. Le modèle quasi-Poisson a expliqué 57% de la variance et le modèle Tweedie en a expliqué 54,4%. La validation croisée a montré une corrélation de 0,50 entre les valeurs observées et celles prédites pour le modèle quasi-Poisson, et 0,76 pour le modèle Tweedie. Pour les deux modèles, les facteurs « cible » et « années » ont expliqué la plupart de l'écart. Les résultats obtenus dans le présent document sont similaires à ceux présentés lors de la dernière évaluation du stock d'espadon, de 2006, et semblent confirmer le scénario optimiste d'une tendance continue de la hausse de la CPUE de l'espèce, dans l'Atlantique Sud-Ouest, au cours de ces dernières années.*

RESUMEN

*Se obtuvieron índices de abundancia relativa en número de peces espada (*Xiphias gladius*) capturados por la pesquería atunera de palangre brasileña en el Atlántico sur mediante la estandarización de los datos de captura y esfuerzo de 1978-2008 (~68.000 lances individuales). La serie de CPUE (peces/1000 anzuelos) fue estandarizada utilizando dos modelos de la familia exponencial (vínculo logarítmico): quasi-Poisson y Tweedie. Ambos modelos son un caso especial de var= $m\mu^p$, para el modelo quasi-Poisson p=1, para el modelo Tweedie 1<p<2. El modelo quasi-Poisson explicaba el 57% de la varianza y el modelo Tweedie explicaba el 54,4%. La verificación cruzada mostró una correlación de 0,50 entre los valores observados y los predichos para el modelo quasi-Poisson, y de 0,76 para el modelo Tweedie. Para ambos modelos, los factores "objetivo" y "años" explicaban la mayoría de la desvianza.*

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Los resultados obtenidos en este documento son similares a los presentados durante la última evaluación de stock de pez espada, en 2006, y parecen confirmar el escenario optimista de una continua tendencia de aumento de la CPUE para esta especie en el Atlántico sudoccidental en años recientes.

KEYWORDS

Catch/effort, abundance, regression analysis, Atlantic swordfish, long lining

1. Introduction

Catch per unit of effort (CPUE) is often the main information used in the assessment of fish stocks. Generally assumed to be proportional to the actual number of fish available to the fishery, the CPUE is commonly included in the models as a relative index of abundance, a premise, however, that is rarely, if ever, entirely true (Harley et al. 2001). Nevertheless, since many factors affect CPUE, such as season, area, gear configuration, targeting strategy, environmental factors, among others, nominal CPUEs are of little value as they do not express the actual abundance of the exploited stock. A common way to compensate for such influences is to use Generalized Linear Models (GLM) to standardize CPUE series. In the present paper, a GLM analysis was used to standardize the swordfish CPUE trend in the Brazilian Tuna longline fishery, from 1978 to 2008, considering two different distributions: Tweedie and quasi-Poisson. Besides, in order to take the targeting strategy into account, the target species was included in both models, as inferred from a cluster analysis previously run.

2. Material and methods

In the present study, catch and effort data from 67,854 tuna longline sets done by the Brazilian tuna longline fleet, including both national and foreign chartered vessels, from 1978 to 2008 (31 years) were analyzed. The logbooks were filled in by the skippers of the vessels and delivered to the Special Secretariat of Fisheries and Aquaculture (SEAP). The longline sets were distributed along a wide area of the Equatorial and South Atlantic Ocean, ranging from 0º to 60ºW of longitude, and from 07ºN to 50ºS 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 fishing ground was subdivided into 2 areas, according to the biological and spatial fishing characteristics of the species, reported by Hazin *et al.* (2008): A1, from 10ºN to 15ºS, and A2, to the south of 15ºS.

Although the number of zero catch sets was relatively low in the data set (24.1%), the commercial longline tuna fishery has high variability in catches, which translates into a variance higher than the mean, particularly for the target species of the fishery. The fit of exponential family dispersion models (quasi-likelihood and Tweedie) is an alternative to reduce the overdispersion of the final model fit. The quasi-family models the variance parameter as a linear function of the mean (e.g. quasi-Poisson; var=$m\mu$) which, for some practical problems, may not adequately accommodate the overdispersion. Gelfand and Dalal (1990) extended this family to capture overdispersion by including a dispersion parameter (power parameter-*p)* in the variance function (Tweedie; var= $m\mu^p$).

In order to examine what it the best distribution to be used (e.g. Poisson, gamma), the scaled residuals from quasi-likelihood fits for the log link function and variance as a power function (var= $m\mu^p$, where p=0 Gaussian, p=1 Poisson, $1<p<2$ compound Poisson-gamma and p=2 gamma) were plotted. In the present analysis the best value of p was between 1 (quasi-Poisson) and 1.2 (compound gamma-Poisson distribution) (**Figure 2**). For all models, four main effects (Year, Target, Area, Quarter) and one interaction (Year:Quarter) were considered.

The accuracy of the two models was evaluated using *n*-fold cross-validation that (1) divide all data into *n*th sub datasets randomly (2) calculate the predicted values concealing the observed ones of each sub-dataset on purpose. We used the correlation coefficient between the observed and the corresponding predicted values for cross-validation of the candidate models.

Forward and backward stepwise model selection, using the AIC protocol, was used to quantify the relative importance of the main factors explaining the CPUE variance and concluded that the four main factors and one interaction were significant ($p<0.05$). The covariate “target species” was defined by a cluster analysis previously run on catch proportion of different species caught by each fishing sets (Wor *et al.*, 2009, *in press*) (Table 1). The Generalized Linear Models (GLMs) were fitted using S-Plus 7 (Insightful Corp., Seattle, WA, USA). The predictions were obtained for every Year, fixing the level of remaining factors at the level with the highest number of observations. The general formulation used in the present study was expressed by the following equation:

g(CPUE (fish/1000 hooks)) = Year+Quarter+Area+Target+Year:Quarter

where g() is the log link function.

3. Results and discussion

The proportion of positive swordfish catches varied little over the years, with smaller values occurring in 1994 (**Figure 3**). The minimum proportion of positive catches was on fishing sets corresponding to the level 4 of "target" factor (**Figure 3**).

The Tweedie model (p =1.2) explained 54.4% of the variance **(Table 2)**. Similarly to previous works, the target species was the most important factor, explaining 50 % of the deviance followed by year (39%) and year*quarter (6%), while quarter (3%) and area (2%) played a minor role **(Tables 2)**. The quasi-Poisson model explained 57.0% of the variance (**Table 3**). The target species had the predominant influence (49%), yielding significant reduced deviance (**Tables 2**).

Figure 4 shows the standard diagnostic plots for Tweedie and quasi-Poisson models models. The residuals distribution and QQ-normal plots show that the residual distribution is quite close to normal. These results indicate that good fits were obtained and the assumed error was quite satisfactory for Tweedie models.

Table 3 shows the overall values of Pearson's correlation coefficient between the observed and the predicted CPUE values. The correlation between the predicted and concealed observed values for the Tweedie model was higher than those for the quasi-Poisson model (**Table 3**). The mean SE and dispersion parameter for the Tweedie model (SE=0.55; Dispersion Parameter=1.1) were slightly smaller than the ones for the quasi-Poisson model (SE=0.74; Dispersion Parameter=2.38) (**Tables 4**), indicating they might be a better option for the standardization of CPUE for this species.

The scaled nominal CPUE series showed a clear difference to the scaled standardized values estimated by both methods (**Table 3** and **Figure 5**). The CPUE series standardized by the quasi-Poisson and the Tweedie, however, were not much different from each other, showing a strong oscillation over time, with an increasing trend from 2000 on. The results were also close to a CPUE series standardized up to 2007 (Hazin *et al.* 2008), which also showed an increase in CPUE for the most recent years.

The results obtained in the present paper are similar to the ones presented during the last swordfish stock assessment, in 2006 (Hazin *et al.*, 2007), and seem to confirm the optimistic scenario of a continuing trend of CPUE increase for the species, in the southwestern Atlantic, in recent years (**Figure 5**).

Acknowledgements

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Table 1. Distribution of longline sets done by the Brazilian tuna longline fishery in the Atlantic Ocean, from 1978 to 2008, by cluster.

Species	*Target_1*	*Target_2*	*Target_3*	*Target_4*	*Target_5*	*Target_6*
Sets (%)	**38.0%**	**24.8%**	**1.1%**	**17.8%**	**15.5%**	**2.8%**
Other tunas	10.6%	0.2%	0.0%	0.8%	0.1%	2.3%
Yellowfin tuna	5.0%	**43.9%**	4.2%	6.2%	11.9%	8.2%
Albacore	4.4%	8.5%	0.3%	**73.8%**	5.3%	7.1%
Bigeye tuna	4.3%	8.0%	0.7%	4.5%	**56.3%**	5.9%
Swordfish	**36.7%**	7.8%	8.2%	3.2%	13.2%	9.5%
Sailfish	1.9%	3.5%	1.4%	1.4%	1.4%	2.6%
White marlin	0.9%	1.6%	0.6%	0.7%	1.0%	2.0%
Blue marlin	1.4%	1.5%	0.4%	0.6%	1.3%	1.1%
Other billfish	1.1%	0.1%	0.0%	0.4%	0.1%	0.7%
Wahoo	1.0%	5.2%	0.2%	0.7%	0.7%	1.1%
Dolphin fish	2.5%	1.5%	0.2%	0.4%	0.6%	2.0%
Blue shark	**21.2%**	3.7%	4.5%	1.8%	3.2%	4.0%
Hammerhead sharks	1.2%	0.3%	0.7%	0.1%	0.1%	0.5%
Bigeye thresher shark	0.2%	0.1%	0.2%	0.0%	0.0%	0.1%
Shortfin mako	1.8%	0.5%	0.4%	0.5%	0.2%	0.5%
Silky shark	0.5%	0.3%	**75.6%**	0.0%	0.2%	0.3%
Oceanic whitetip shark	0.1%	0.0%	0.1%	0.0%	0.0%	0.0%
Other sharks	1.3%	1.7%	1.3%	1.7%	1.9%	**49.3%**
Other teleosts	3.9%	11.7%	0.9%	3.1%	2.5%	2.7%

Table 2. Deviance analysis of explanatory variables in the quasi-Poisson model and Tweedie models of *swordfish* caught by Brazilian longline fleet during 1978 to 2008.

a) Quasi-Poisson model

	Df	*Deviance*	*Residual Df*	*Residual Deviance*	*Pr(Chi)*	*Explained Deviance*	*Explained Model*
NULL			56386	299238.5			
Year	30	68047.8	56356	231190.7	0.0000	40%	23%
Area	1	5109.3	56355	226081.4	0.0000	3%	24%
Quarter	3	4256.8	56352	221824.6	0.0000	2%	26%
Target	5	83639.7	56347	138184.9	0.0000	49%	54%
Year:Quarter	90	10298.1	56257	127886.8	0.0000	6%	57%

b) Tweedie model

	Df	*Deviance*	*Residual Df*	*Residual Deviance*	*Pr(Chi)*	*Explained Deviance*	*Explained Model*
NULL			56386	242489.7			
Year	30	51208.6	56356	191281.0	0.0000	39%	21%
Area	1	3750.0	56355	187531.0	0.0000	3%	23%
Quarter	3	3257.4	56352	184273.6	0.0000	2%	24%
Target	5	65726.5	56347	118547.1	0.0000	50%	51%
Year:Quarter	90	7636.2	56257	110910.9	0.0000	6%	54%

Table 3. Nominal and standardized (quasi-Poisson and Tweedie) CPUE series (number of fish/ 1000 hooks) for swordfish catch rates from the Brazilian tuna longline.

	Nominal	*Tweedie models*			*Quasi-Poisson model*			*CPUE nominal*	*Tweedie models*	*Quasi-Poisson model*
Year	*CPUE*	*CPUE_STD*	*SE*	*CV*	*CPUE_STD*	*SE*	*CV*	*Scaled*	*Scaled*	*Scaled*
1978	3.65	6.92	0.741	10.7%	8.786	0.84	10%	0.96	0.93	0.79
1979	3.44	5.32	0.793	14.9%	8.462	0.954	11%	0.90	0.72	0.76
1980	5.69	7.41	0.498	6.7%	8.873	0.513	6%	1.50	1.00	0.80
1981	8.20	1.77	0.503	28.3%	5.81	1.578	27%	2.15	0.24	0.52
1982	7.74	13.00	1.022	7.9%	14.811	0.83	6%	2.03	1.75	1.33
1983	4.33	9.69	1.075	11.1%	12.985	1.382	11%	1.14	1.31	1.17
1984	2.68	3.63	0.426	11.7%	8.328	0.679	8%	0.70	0.49	0.75
1985	4.04	10.58	0.893	8.4%	11.204	0.916	8%	1.06	1.43	1.01
1986	3.91	7.39	0.485	6.6%	8.92	0.565	6%	1.03	1.00	0.80
1987	4.02	5.96	0.677	11.3%	9.928	0.838	8%	1.06	0.80	0.89
1988	3.07	12.01	0.913	7.6%	14.311	0.784	5%	0.81	1.62	1.29
1989	1.80	6.41	0.663	10.3%	9.427	0.879	9%	0.47	0.86	0.85
1990	4.01	15.13	2.701	17.8%	20.671	2.769	13%	1.05	2.04	1.86
1991	2.06	5.37	0.567	10.6%	10.742	0.953	9%	0.54	0.72	0.97
1992	1.05	2.15	0.267	12.4%	4.61	0.608	13%	0.28	0.29	0.42
1993	1.66	1.98	0.361	18.2%	4.168	0.854	20%	0.44	0.27	0.38
1994	1.41	2.22	0.241	10.8%	5.001	0.557	11%	0.37	0.30	0.45
1995	1.43	3.22	0.328	10.2%	6.476	0.51	8%	0.37	0.43	0.58
1996	1.46	5.35	0.590	11.0%	10.713	0.868	8%	0.38	0.72	0.97
1997	2.06	6.95	0.518	7.4%	13.098	0.625	5%	0.54	0.94	1.18
1998	2.33	8.00	0.445	5.6%	21.296	0.565	3%	0.61	1.08	1.92
1999	1.55	4.98	0.186	3.7%	10.513	0.349	3%	0.41	0.67	0.95
2000	1.98	5.04	0.131	2.6%	10.531	0.241	2%	0.52	0.68	0.95
2001	1.66	8.64	0.194	2.2%	14.399	0.248	2%	0.44	1.17	1.30
2002	1.88	3.40	0.087	2.6%	8.083	0.2	2%	0.49	0.46	0.73
2003	6.10	5.27	0.185	3.5%	10.113	0.592	6%	1.60	0.71	0.91
2004	3.47	9.64	0.270	2.8%	13.967	0.315	2%	0.91	1.30	1.26
2005	3.93	6.22	0.156	2.5%	11.549	0.236	2%	1.03	0.84	1.04
2006	9.14	13.59	0.339	2.5%	14.928	0.33	2%	2.40	1.83	1.34
2007	8.80	15.97	0.354	2.2%	15.48	0.28	2%	2.31	2.15	1.39
2008	9.44	16.67	0.443	2.7%	15.90	0.34	2%	2.48	2.25	1.43

Table 4. Model comparison based on the results of Pearson´s correlation for the 5-fold cross validation, dispersion parameter *(m)* and average standard error of the predicted CPUEs (SE).

Models	*m*	*SE*	*Cor*
Quasi-Poisson	2.38	0.74	0.50
Tweedie	1.1	0.55	0.76

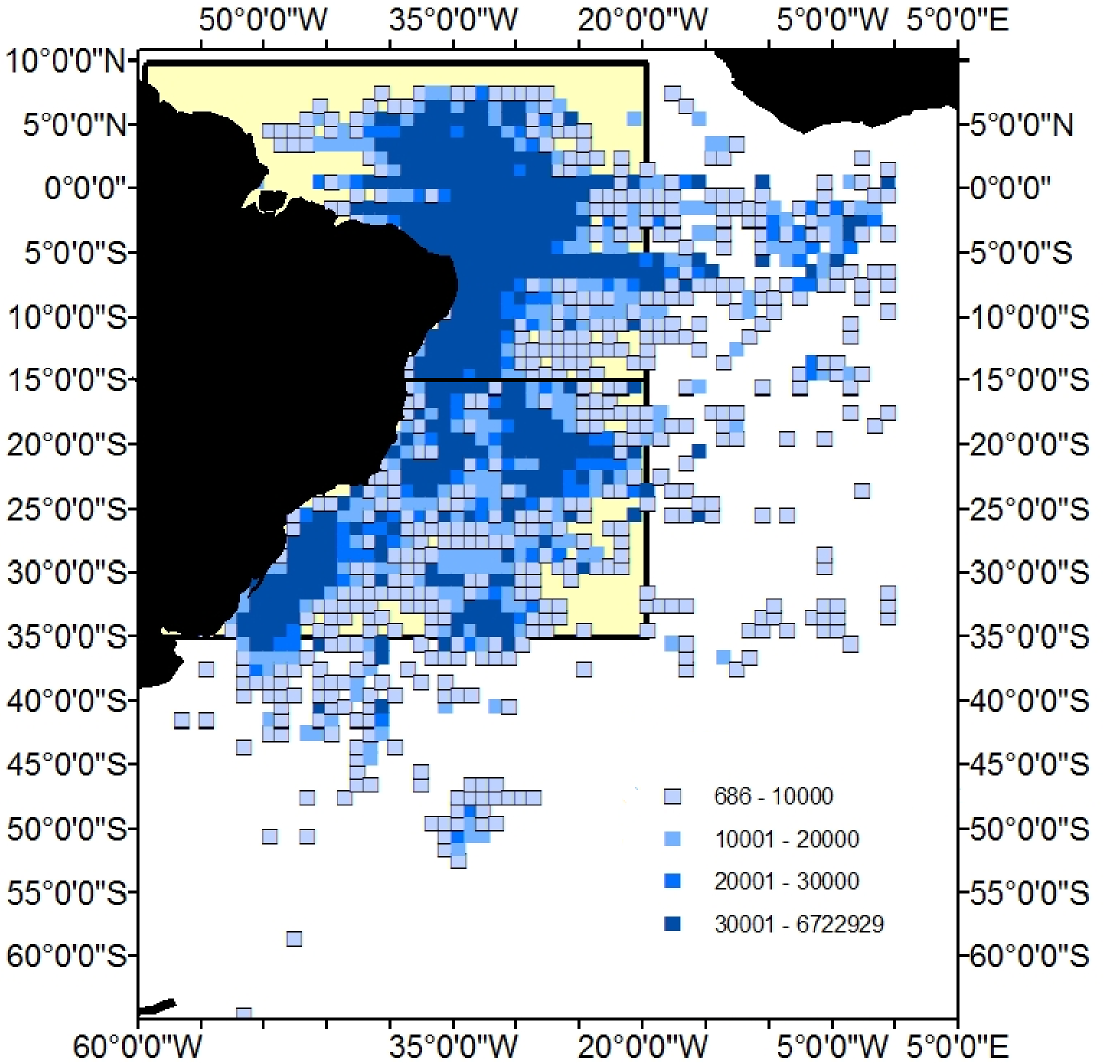

Figure 1. Distribution of effort, in number of hooks from Brazilian tuna longliners (national and chartered vessels) from 1978 to 2008.

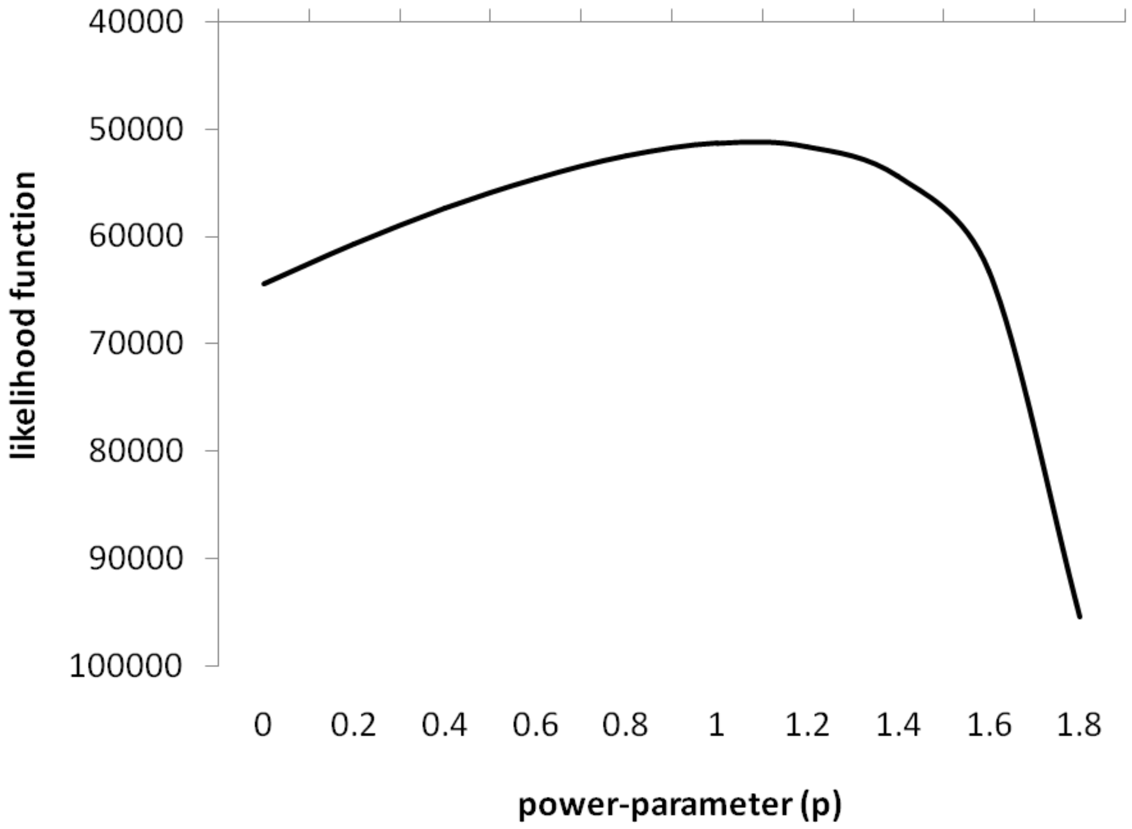

Figure 2. Value of likelihood function changing the power-parameter (*p*) of the Tweedie model

Figure 2. Value of likelihood function changing the power-parameter (p) of the Tweedie model for CPUE standardization of swordfish in the South Atlantic Ocean caught by Brazilian tuna longline.

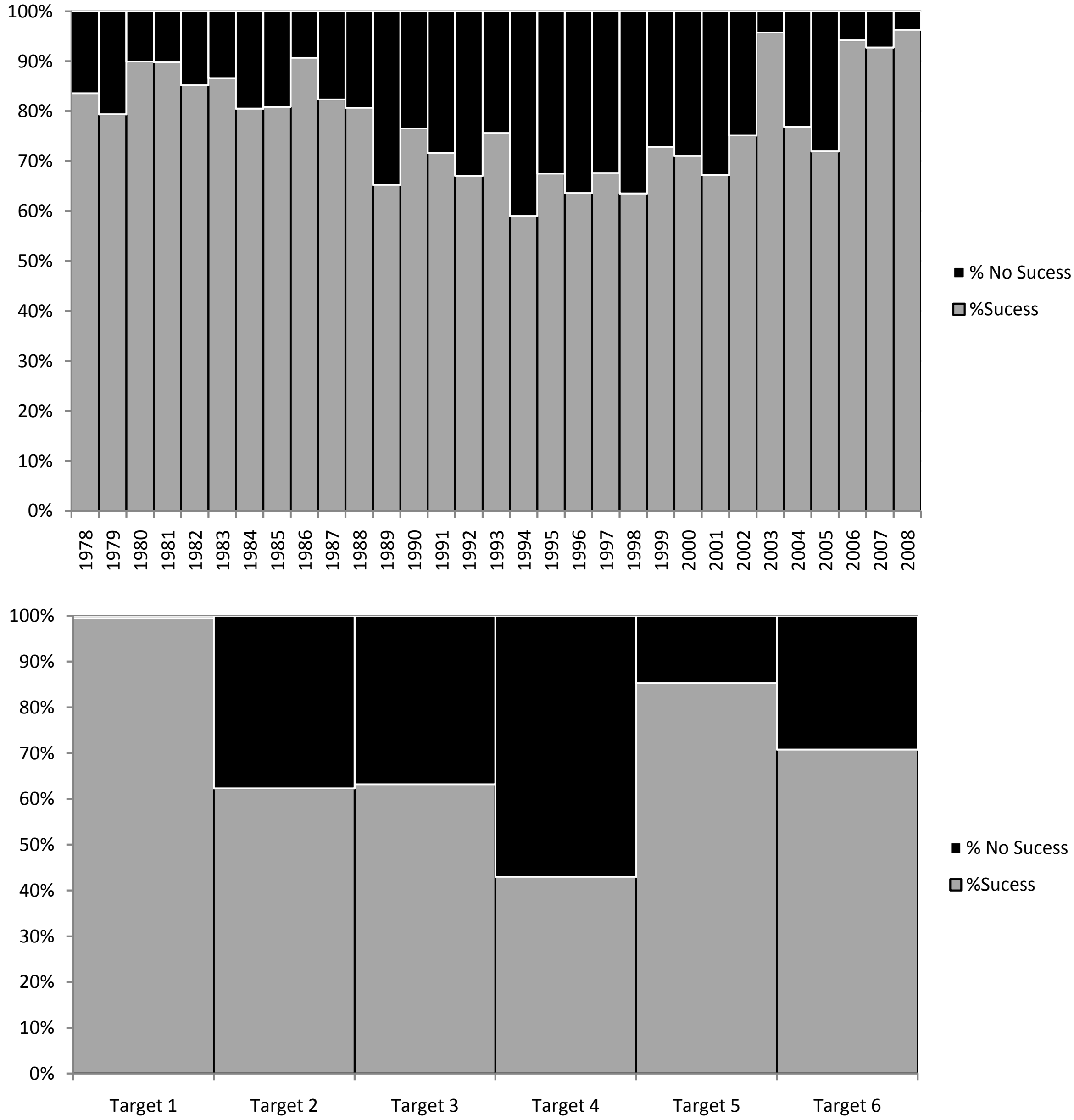

Figure 3. Proportion of positive catches of swordfish caught by Brazilian longline fleet during 1978 to 2008.

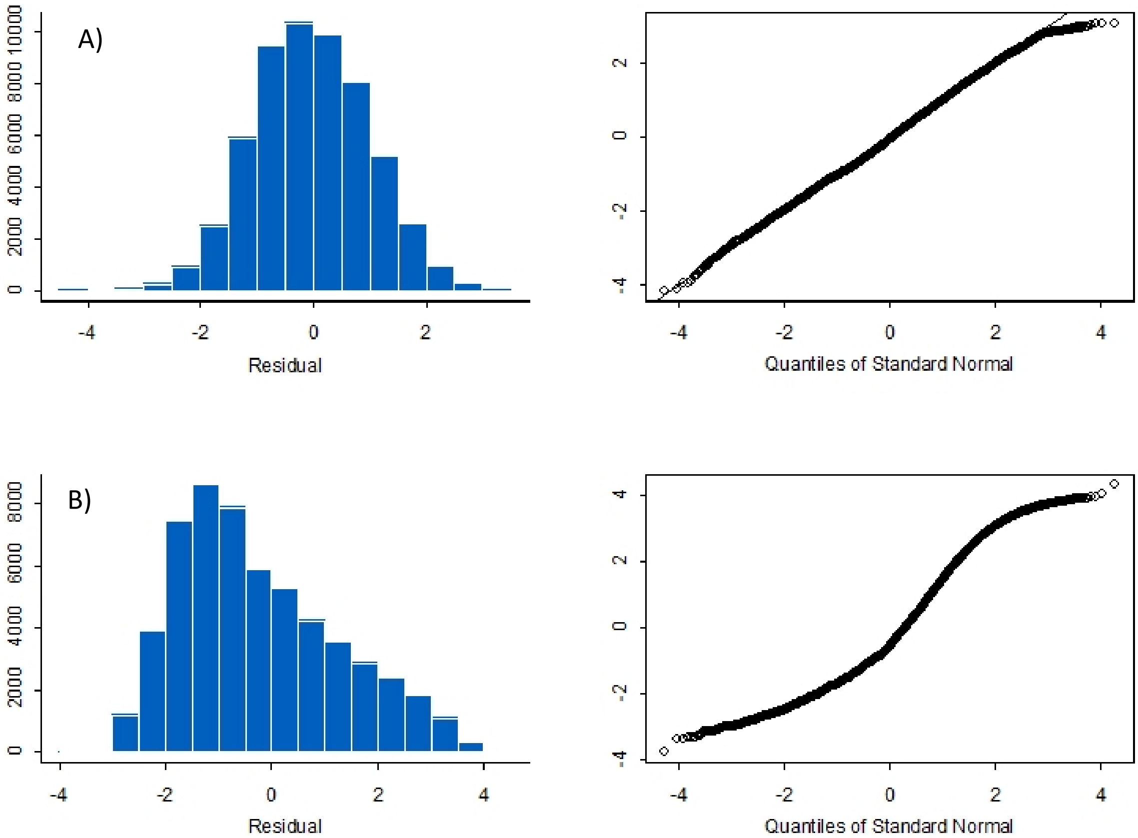

Figure 4. Residual analysis for the swordfish catches. A) Tweedie model; B) quasi-Poisson model.

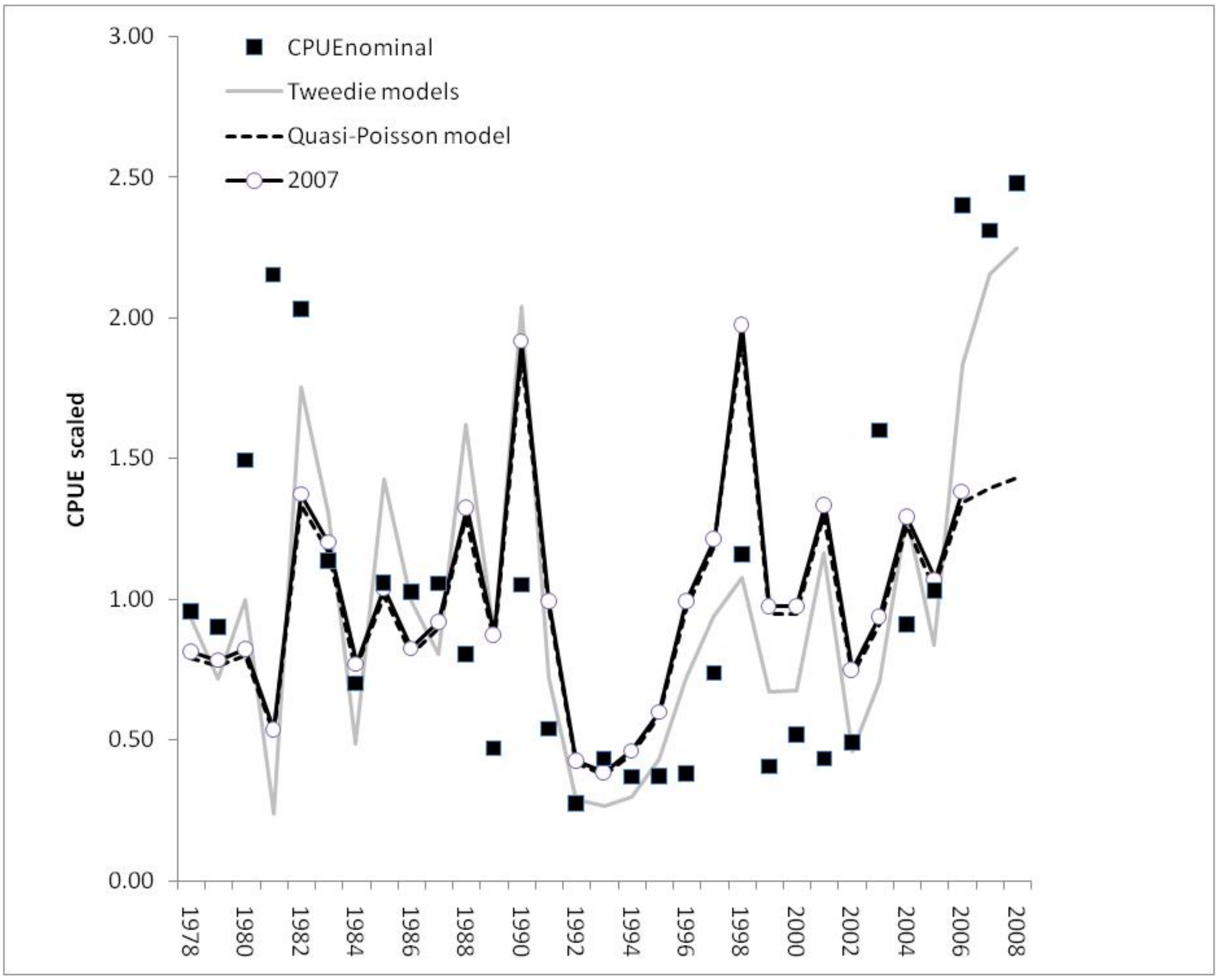

Figure 5. Nominal and standardized CPUE of *swordfish* for Brazilian tuna longliners, from 1978 to 2008 and comparison with the 2007 series (quasi-Poisson).

Figure 5. Nominal and standardized CPUE of swordfish for Brazilian tuna longliners, from 1978 to 2008 and comparison with the 2007 series (Quasi-Poisson).