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ESTIMATIONS OF STANDARDIZED CATCH RATES OF SWORDFISH (*XIPHIAS GLADIUS*) CAUGHT BY BRAZILIAN FLEET AS CALCULATED USING FIXED AND RANDOM EFFECTS

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SUMMARY

Estimations of standardized CPUE were calculated following three approaches: a) year was included in the models as main fixed effect only; b) year was included in the models as main fixed effect and also in fixed effect interactions; and c) year was included in the models as main fixed effect and in random effect interactions. We have used Generalized Linear Models (GLM) and Generalized Linear Mixed Models (GLMM) with Poisson distribution and logarithm link function. The response variable was the catch (number of fish), explanatory variables were year, area, flag and quarter, and logarithm of effort was included as offset. Convergence of GLMM was difficult to achieve probably due to the lack of balance of the Brazilian dataset. Time trend of the three standardized CPUE time series were not different. However, it is important to highlight that in this preliminary study we have analyzed only part of Brazilian dataset using simples model with few explanatory variables.

RÉSUMÉ

Les estimations de la CPUE standardisée ont été calculées selon trois approches : a) l'année a été incluse dans les modèles uniquement en tant qu'effet fixe principal, b) l'année a été incluse dans les modèles comme effet fixe principal et également dans les interactions à effets fixes et c) l'année a été incluse dans les modèles comme effet fixe principal et dans les interactions à effets aléatoires. Des modèles linéaires généralisés (GLM) et des modèles mixtes linéaires généralisés (GLMM) avec une distribution Poisson et une fonction logarithmique de lien ont été utilisés. La variable de réponse était la capture (nombre de poissons), les variables explicatives étaient l'année, la zone, le pavillon et le trimestre, et le logarithme de l'effort était inclus comme compensation. La convergence du GLMM était difficile à atteindre probablement en raison du manque d'équilibre du jeu de données brésilien. La tendance temporelle des trois séries temporelles de CPUE standardisée n'était pas différente. Cependant, il est important de souligner que dans cette étude préliminaire seule une partie du jeu de données du Brésil a été analysée en utilisant un modèle simple avec peu de variables explicatives.

RESUMEN

Se calcularon las estimaciones de la CPUE estandarizada siguiendo tres enfoques: a) se incluyó el año en los modelos solo como efecto fijo principal, b) se incluyó el año en los modelos como efecto fijo principal y también en las interacciones de efecto fijo y c) se incluyó el año en los modelos como efecto fijo principal y en las interacciones de efecto aleatorio. Hemos usado modelos lineales generalizados (GLM) y modelos lineales mixtos generalizados (GLMM) con distribución Poisson y una función de vínculo logarítmico. La variable de respuesta era la captura (número de ejemplares), las variables explicativas eran año, área, pabellón y trimestre y el logaritmo del esfuerzo se incluyó como compensación. La convergencia del GLMM era difícil de lograr, debido probablemente a la falta de equilibrio del conjunto de datos brasileño. Las tendencias temporales de las tres CPUE estandarizadas no era diferente. Sin embargo, es importante resaltar que en este estudio preliminar hemos analizado solo parte del conjunto de datos brasileño utilizando modelos simples con pocas variables explicativas.

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KEYWORDS

Catch/effort, Stock assessment, Abundance, Biomass, Fishing effort

1. Introduction

In the stock assessments the main objectives are to estimate abundance and the potential production of the population as the balance of recruitment, somatic growth and mortality (Hilborn and Walters 1992; Quinn and Deriso 1999). Stock assessment analyses are useful for decision makers and the fishery management. However, the stock size or abundance is often a latent variable, in the sense it cannot be directly measured. Therefore, in most of stock assessment analyses abundance is replaced by indices, which are supposed to be a proxy of abundance (King 1985; Sparre and Venema 1987; Hilborn and Walters 1992).

Often the commercial Catch per Unit Effort (CPUE) data is used to calculate relative abundance indices for highly migratory fishery resource like tuna and tuna like species. However, the catch rate (or CPUE) changes due to the abundance but also due to several factors like fishermen strategy or fishery technology. The analyses of CPUE to eliminate the effects of different factors and to estimate a time series of indices of relative abundance is usually called "standardization". Often the standardization of CPUE is based on estimations of parameters of the factor "year" as calculated using Generalized Linear Models (GLM) (Maunder and Punt 2004).

If year is considered only as fixed main effect (approach A), the estimations of standardized CPUEs are straightforward. However, if year is included in the model as fixed main effect but also in fixed effect interactions (approach B), the estimations of standardized CPUEs are more complex. In this case it is necessary some supposition concerning the weights to calculated a weighted average over the interactions (e.g. least square means) (e.g. Quinn II *et al.* 1982; Campbell 2004). However, if year is included as main fixed effect and also in random effect interactions (approach C), the calculations are simple, because the interactions are not necessary to estimate the standardized CPUE. In the past the approach A was popular, then the approach B replaced the approach A, and finally, the popularity of the approach C has increased. However, "Whether an effect should be considered fixed or random will depend on way the experimental treatments (levels of a factor) are selected and the kind of inferences one wishes to make from the analysis" (Sahai and Ageel 2000). "… clear answers to the question 'fixed or random?' are not necessarily the norm" (Searle *et al.* 1992). While in experimental studies it is more easy to decide if a main effect will considered fixed or random, in observational studies the decision between fixed or random may be not clear, specially if we are talking about an interaction that includes a factor of interest (e.g. year) and other factor that is not of interest (e.g. quarter). Hence the choice of one among the approaches A, B or C may be not easy. In this paper the objective was not to investigate and discuss which of the three approaches is best in the statistical and fishery theoretical grounds. We just called attention to the point that it maybe be difficult to answer the question "fixed or random?" when calculating standardized CPUE. We believe that investigations on the issue should be encouraged in the future. Here we show the results of an exercise to investigate what are the differences between standardized CPUEs calculated using the three approaches (A, B, and C) often used in the recent years. Our case of study is the swordfish (*X. gladius*) caught in the South Atlantic by the Brazilian fleet.

2. Materials and Methods

2.1 Data

Dataset we have analyzed is the "Banco Nacional de Atuns e Afins (BNDA)" of the Tuna and Tuna-Like Brazilian Scientific Committee of the Brazilian government. In this working paper we have analyzed the swordfish caught in the South Atlantic by the Brazilian fleet between 1990 a 2012. Brazilian fleet includes national vessels (BRA) but also vessels leased from more than fifteen countries. However we retained for analyses leased boats from Spain (BRA-ESP), Honduras (BRA-HND), Japan (BRA-JPN), Panama (BRA-PAN), China-Taipei (BRA-TAI) e Saint Vincent & Grenadines (BRA-VCT) (**Table 1**), because the sample size (number of longline sets) are high for these flags. Longline sets with missing values for catch or effort were discarded. Non sampling errors (e.g. fishing sets located on or too close to the land) were also discarded. After the exploratory analyses to identify and discard errors and suspected data only 35055 fishing sets were retained for the analysis concerning the standardization of the CPUE.

2.2 Analysis

In order to estimate standardized CPUE using the approach A (year is considered only as main fixed effect) and B (year is included in the models as main fixed effect but also in fixed effect interactions) we have used conventional GLM models. Generalized linear models were first published by Nelder and Wedderburn (1972). The MLGs have three components:

a) random – y is usually a vector of length n with independent realizations of a random variable Y with expectation μ. The distribution of Y is one of the exponential family with canonical structure;

b) linear predictor – systematic linear part of the model $\eta = X\beta$, in which $\eta_i = X_i\beta$ is the component concerning the *i*th observation; and

c) link function *g( )* – a function to link the expectation of Y and the linear predictor as $g(\mu_i) = \eta_i = x_i^T\beta$. Details on the structure and calculations of GLM can be find in textbooks like Dobson (2008).

In the approach C the fator year is included in the models as main fixed effect and also as part of random interactions. In order to estimate standardized CPUE we have a Generalized Linear Mixed Model (GLMM). The components of the GLMM are similar to those of the GLM (see above), but the linear predictor is $\eta = X\beta + Zu$, in which Z is a design matrix like X, and u is component to account for the random effect. In the GLMM the variance function $v(\mu_i, \emptyset)$ is used to model the residual variability, and the estimations are calculated using maximum likelihood (ML) algorithms. Details concerning GLMM can be found in Breslow and Clayton (1993), and in Pinheiro and Bates (2000).

We have assumed that the response variable (S), which is the catch as reported in number of fish, follows a Poisson distribution. We have used a logarithmic link function. The explanatory variables were: flag (F), year (Y), quarter (T) and fishing area (A). The levels of factor area were: North (northward of 10ºS), Central (between 10ºS and 25 ºS), South (southward of 25 ºS) (**Figure 1**). These levels of area were selected based on the data balance and on preliminary attempts to fit the GLMM. GLMM did not converge when we tried out other alternatives concerning levels of area. The unit of effort is the number of hooks of the longline. Logarithm of effort was used as offset. It is important to stress that the intention was just to compare approaches concerning the way we deal with year in interactions. We were not trying to calculate a useful standardized CPUE, hence we did not carried out tests concerning different explanatory variables, probability distributions and the excess of zeros.

In order to choose the order the explanatory variables are included in the models, the first step was to fit one simple model with only one of the factors year, quarter and area at a time. Residual deviance (Nelder and Wedderburn 1972) was the selected criterion to order the explanatory variables. In addition to the main effects we tried out to include all the first order interactions in the models when using the approaches B and C. In the approach A only the factors quarter, flag and area were included in interactions. However, due to convergence issues only two interactions were considered in the GLMM (approach C). Finally, the selection of explanatory variables and interactions in the three approaches, were based on the Akaike Information Criterion (AIC) (Akaike 1974), and on the Bayesian Information Criterion (BIC) (Schwarz 1978).

Conventional residual analysis (e.g. fitted x residual graphs, leverage and Cook's distances calculations) were used to assess the quality of the model fittings (Dobson 2008; Venables and Ripley 2002). Pseudo-R^2 (McFadden 1974) were calculated and the three standardized CPUEs (A, B e C) were compared. All the analyses and calculations were carried out using the software R (R 3.3.1 Core Team 2016) and the functions *glm( )* (GLM) and *glmer( )* of the package *lmer4* (Bates *et al.* 2015).

3. Results

Brazilian fleet operations cover a large part of the South Atlantic between longitudes 0º and 55ºW, and the latitudes 5ºN and 50ºS (**Figure 1**). The values showed in the map are summation of the number of fish caught from 1990 to 2012 as reported in the dataset. High catches (> 5000) were observed all over the South Atlantic, but mainly in the north and central areas. Boxplots of CPUE are shown in **Figure 2**. Notice the high variability of CPUE in 1998. Notice also that catch rates have increased after 2003 onwards. Overall values of CPUE in the first and fourth quarter tend to smaller than those of the second and third quarter. Catch rates were in general higher in the central area.

Selected models based on AIC and BIC for the approaches A, B, and C are shown in **Table 2**. Results of likelihood ratio hypothesis tests (approaches A and B) and of Wald test (approach C) for the selected models (Error! Reference source not found.**Table 3**) indicate that all the explanatory variables are important to model the variation of catch rates, but he factor quarter of the GLMM (approach C) is an exception.

Diagnostic of residuals of GLM model fitted following approach A are in **Figure 3**. Residuals were approximately homoscedastic (**Figure 3A**). There were not evidences that the model is biased in the sense the expectations of residuals are close to zero (**Figure 3B**). Distributions of the residuals are approximately normal but there are violations in the tails (**Figure 3C**). High values of residuals are associated a high leverage values (diagonal of hat matrix) (**Figure 3D**). Overall Cook's distances were lower than 0.5. Diagnostic of residuals calculated for the models fitted following the approach B (**Figure 4**) and C (**Figure 5**) were similar to those calculated for the model fitted based on the approach A (**Figure 3**).

Summary of estimations of the model fitted with year as main effect only (approach A) are in **Table 4**. Notice that most of estimations indicate that we reject the null hypothesis (parameters equal to zero). Estimations of parameters of factor flag were negative, but the estimation of level BRA-ESP is the exception. Hence there are evidence that the expectation of CPUE of vessels leased from Spain are higher than for national boats (base level). However the CPUE of national boats (BRA) and leased boats from Spain (BRA-ESP) are higher than the CPUEs of boats leased from other countries. Estimations of expectations of CPUE for 1991, 1998 and 2003 onwards were higher than the expectation of CPUE of the base level (year 1990). Notice also that the expectation of catch rates for the north area was higher than for the other regions. The estimations also indicate that the expectation was higher for the first quarter than for the other periods of the year.

Estimations of the parameters of models fitted with year included as main fixed effect and also in fixed effect interactions (approach B) are in **Table 5**. Similarly, the estimations of parameters of the mixed model with year included as main fixed effect and also in random effect interactions (approach C) are in **Table 6**. Estimations of the variance components for the approach C are in **Table 7**. Interpretations of the estimations showed in **Table 5 and Table 6** (approaches B and C) can be made based on the values, signals and hypothesis tests just like we did in the above paragraph for the **Table 4** (approach A). However, it is necessary to account for the interaction when assessing the estimations of the model fitted following the approach B. Usually some kind of weighted average calculation (e.g. least square means) is necessary to estimate the separated effect of a main factor also included in the model as interaction. In order to extract the separated effect of year factor as calculated with the approach B we assumed equal weights to all months, flags and areas when dealing with interactions year: month, year:flag and year:area. We choose this alternative in this exercise. However, it is important to stress in some situations there are not a clear answer concerning the question about which weights should be used. To assume equal weight to month may be appropriate (D. S. Butterworth apud Maunder and Punt 2004), but to select weights for other factors, like area, may be not as straightforward (Maunder and Punt 2004).

Standardized CPUEs calculated as calculated based on approaches A, B and C) are shown in **Figure 6**. Estimations were scaled as $z = (x - \bar{x})/s$ to make comparison easier. Overall there are not large among the three time series, but estimations for 1991, 1994 and 2008 are the exceptions. The three standardized catch rates as calculated decreased slightly between 1990 and 2001, but the estimations increased in the beginning of 2000's. Standardized catch rates in the end of the three time series were high.

4. Discussion

The convergence of the mixed model (GLMM) arose as an important issue. Some decisions concerning the model structure (e.g. levels of factor area, number of interactions included in the model) were selected in an attempt to achieve convergence. Convergence of mixed models may be not easy when the dataset and the design matrix are no not balanced. Estimators of maximum likelihood (ML) are usually sufficient statistics, consistent and asymptotically normally distributed and efficient (Harville 1977), but ML estimators of the variance components estimations of the fixed effects. In spite their biases, ML estimators are popular due to their asymptotic properties (Searle *et al.* 1992), and because there are empirical evidence that they perform better than other estimators (Swallow and Monaham 1984). However the estimations are computationally demanding. In addition convergence difficulties increase as the dimension of the models increase specially if the data is not well balanced (e.g. Brazilian dataset). Studies concerning comparisons of different methods to estimate the variance components of mixed models have been made since mid 1990's (e.g. Resende et. al. 1996; Marcelino and Lemma 2000). However, by the moment the ML estimator is probable one of the best alternative despite of the convergence issue.

Often the estimations of factor year is assumed to reflect annual variation of biomass in most of the papers concerning standardization of CPUE (Maunder and Punt 2004). There are two alternatives to cope with effects of interactions between year and other factors when estimating the standardized CPUE time series: 1) To ignore them by do not including year in fixed effect interactions (approach A) or by including year only in random effect interactions (approach C); or 2) To take them into account (approach B), but some kind of weighted average might be calculated over the interaction terms. In the ICCAT meetings both approaches concerning the inclusion of year in the interactions (fixed or random) have been used (e.g. fixed - Hazin *et al.* 2007; Carneiro *et al.* 2015; Tsai and Liu 2016; random - Chang 2003; Arocha *et al.* 2016; Walter and Lauretta 2016). However, the motivations for the choice for one or another alternative (to ignore or to take interactions into account) to standardize CPUE have been not discussed. In most of the papers concerning standardization of CPUE it is not clear if the choice of one among the three approaches (A, B or C) was based on theoretical grounds or if it was a convenient choice to make the calculations easier. If the time trend of estimations of standardized CPUEs time series (approaches A, B and C) are very different, decisions and diagnostics concerning the status of the stock may change.

Here we showed the results of a simple exercise we did with part of the Brazilian dataset. We assessed the main time trend signal of estimation of standardized CPUE, but we did analyzed the precision of the estimations (e.g. standard errors). The results indicate that time trends of standardized CPUEs as calculated based in the approaches A, B and C were not that different. This is an indication that in some situations the choice of the methodology will not strongly affect the understanding about the status of the stock. However, it is important to stress that we tried out a simple model (few explanatory variables) for a fleet (i.e. Brazilian) only. Similar investigations with other datasets and fleets should be encouraged to investigate if the differences among the estimations are as low as they were in this exercise with Brazilian fleet.

5. Remarks

- Convergence of mixed models (GLMM) was an issue in the analysis of Brazilian dataset which is unbalanced;

- In some situations to ignore or to include interactions with year as fixed or random effect does not result in quite different standardized CPUE time series.

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Table 1. Number of fishing sets by flag retained for analysis.

FLAG	Frequencies
BRA	8205
BRA-ESP	9581
BRA-HND	1238
BRA-JPN	994
BRA-PAN	2594
BRA-TAI	5526
BRA-VCT	6917

BRA= Brazil; BRA-ESP = Brazil – Spain; BRA-HND = Brazil – Honduras; BRA-JPN = Brazil – Japan; BRA-PAN = Brazil – Panama; BRA-TAI = Brazil – China Taipei; BRA-VCT = Brazil – St Vicente & Grenadines.

Table 2. Models selected To standardize the catch per unit effort of Xiphias gladius caught by Brazilian fleet from 1990 to 2012. S – number of swordfish caught; F – vessel flag; Y – year; A –area; T – quarter. AIC – Akaike Information Criterion; BIC – Bayesian Information Criterion; DF – degrees of freedom; Dev – Deviance; Res. Dev. – Residual Deviance; Loglik - Log-likelihood statistic.

Model	AIC	BIC	Dev.	GL	Dev. Res.	GL Res.	Pseudo-R^2	Loglik
GLM								
(A) S~F+Y+A+T	370430	370718.2	557907	35054	281137	35021	49,61%	-185181.2
(B) S~F+Y+A+T+Y:T+Y:A	344840	345949.2	557907	35054	255353	34924	54,23%	-172289.1
GLMM								
(C)S~F+Y+A+T+(1|Y:T)+(1|Y:A)	345475.5	345780.3	557907	35054	345403.5	35019	38,09%	-172701.8

(A) Model with year as fixed effect only; (B) Model with year as a fixed effect and also in fixed-effect interaction; (C) Model with year as fixed effect and also in random-effect iteration

Table 3. Analysis of deviance of the fitted models fitted. Approaches: (A) year as fixed effect only; (B) year as a fixed effect and also in fixed-effect interaction; (C) year as fixed effect and also in random-effect iteration. Likelihood Ratio tests (LR) were used for approaches A and B, and Wald test was used for approach C. The factors were: F –flag; Y – year; A –area; T – quarter. DL – degrees of freedom; Res. Dev. – Residual Deviance.

	GLM		
	LR Chisq	GL	Pr(>Chisq)
Approach A			
F	145146	6	< 2.2e-16
Y	31531	22	< 2.2e-16
A	3347	2	< 2.2e-16
T	996	3	< 2.2e-16
Approach B			
F	105419	6	< 2.2e-16
Y	31531	22	< 2.2e-16
A	4196	2	< 2.2e-16
T	874	3	< 2.2e-16
Y:T	13050	62	< 2.2e-16
Y:A	10414	35	< 2.2e-16
	GLMM		
	Chisq	GL	Pr(>Chisq)
Approach C			
F	87404.58	6	< 2.2e-16
Y	41.13	22	0.007955
A	19.61	2	5.508e-05
T	5.09	3	0.165611

Table 4. Estimations of parameters (approach A). F – flag; Y – year; A –area; T – quarter.

Coeficientes	Estimate	Std. Error	z value	Pr(>|z|)
(Intercept)	-4.93279	0.02223	-221.895	< 2e-16 ***
(F) BRA-ESP	0.468031	0.00565	82.84	< 2e-16 ***
(F) BRA-HND	-0.26306	0.012406	-21.205	< 2e-16 ***
(F) BRA-JPN	-0.98615	0.01777	-55.496	< 2e-16 ***
(F) BRA-PAN	-2.53471	0.017957	-141.156	< 2e-16 ***
(F) BRA-TAI	-1.27608	0.009427	-135.37	< 2e-16 ***
(F) BRA-VCT	-1.862	0.009529	-195.412	< 2e-16 ***
(Y) 1991	0.417579	0.026293	15.882	< 2e-16 ***
(Y) 1992	-0.39842	0.027894	-14.283	< 2e-16 ***
(Y) 1993	-0.27658	0.04566	-6.057	1.38e-09 ***
(Y) 1994	-0.26339	0.029646	-8.884	< 2e-16 ***
(Y) 1995	-0.01304	0.026167	-0.498	0.61815
(Y) 1996	-0.22848	0.036622	-6.239	4.41e-10 ***
(Y) 1997	-0.42632	0.025906	-16.456	< 2e-16 ***
(Y) 1998	0.605429	0.023392	25.882	< 2e-16 ***
(Y) 1999	-0.25526	0.02357	-10.83	< 2e-16 ***
(Y) 2000	-0.15588	0.022958	-6.79	1.12e-11 ***
(Y) 2001	-0.62953	0.023439	-26.858	< 2e-16 ***
(Y) 2002	-0.35116	0.025379	-13.837	< 2e-16 ***
(Y) 2003	0.145584	0.027749	5.246	1.55e-07 ***
(Y) 2004	0.203979	0.023816	8.565	< 2e-16 ***
(Y) 2005	0.361746	0.023088	15.668	< 2e-16 ***
(Y) 2006	0.392119	0.023479	16.701	< 2e-16 ***
(Y) 2007	0.322761	0.025364	12.725	< 2e-16 ***
(Y) 2008	0.552303	0.028472	19.398	< 2e-16 ***
(Y) 2009	0.250013	0.023146	10.802	< 2e-16 ***
(Y) 2010	0.401379	0.025724	15.603	< 2e-16 ***
(Y) 2011	0.471368	0.024095	19.563	< 2e-16 ***
(Y) 2012	0.587533	0.051834	11.335	< 2e-16 ***
(A) C	-0.08724	0.005018	-17.385	< 2e-16 ***
(A) S	-0.39617	0.00705	-56.19	< 2e-16 ***
(T) 2	-0.01517	0.005616	-2.701	0.00691 **
(T) 3	-0.07196	0.0063	-11.423	< 2e-16 ***
(T) 4	-0.17505	0.006045	-28.958	< 2e-16 ***

Table 5. Estimations of parameters (approach B). F – flag; Y – year; A –area; T – quarter.

	Estimate	Std. Error	z value	Pr(>|z|)
(Intercept)	-5.07446	0.067325	-75.373	< 2e-16 ***
(F) BRA-ESP	0.495597	0.006158	80.483	< 2e-16 ***
(F) BRA-HND	-0.41447	0.013503	-30.696	< 2e-16 ***
(F) BRA-JPN	-1.0409	0.021454	-48.517	< 2e-16 ***
(F) BRA-PAN	-2.39612	0.018921	-126.638	< 2e-16 ***
(F) BRA-TAI	-1.10499	0.010497	-105.269	< 2e-16 ***
(F) BRA-VCT	-1.7467	0.010065	-173.546	< 2e-16 ***
(Y) 1991	0.739832	0.074996	9.865	< 2e-16 ***
(Y) 1992	-0.7335	0.079626	-9.212	< 2e-16 ***
(Y) 1993	-0.95297	0.098095	-9.715	< 2e-16 ***
(Y) 1994	-1.59937	0.113136	-14.137	< 2e-16 ***
(Y) 1995	-0.15777	0.072983	-2.162	0.030637 *
(Y) 1996	-0.54676	0.16009	-3.415	0.000637 ***
(Y) 1997	-0.36711	0.077253	-4.752	2.01e-06 ***
(Y) 1998	1.238418	0.069746	17.756	< 2e-16 ***

(continuation)

	Estimate	Std. Error	z value	Pr(>|z|)

(Y) 1999	0.004599	0.069262	0.066	0.947063
(Y) 2000	0.066304	0.068257	0.971	0.331356
(Y) 2001	-0.2138	0.068512	-3.121	0.001805 **
(Y) 2002	-0.63882	0.070853	-9.016	< 2e-16 ***
(Y) 2003	0.474803	0.078353	6.06	1.36e-09 ***
(Y) 2004	-0.28181	0.074582	-3.779	0.000158 ***
(Y) 2005	0.249724	0.069142	3.612	0.000304 ***
(Y) 2006	0.354296	0.069592	5.091	3.56e-07 ***
(Y) 2007	0.308924	0.072751	4.246	2.17e-05 ***
(Y) 2008	0.775437	0.071138	10.9	< 2e-16 ***
(Y) 2009	0.231912	0.068931	3.364	0.000767 ***
(Y) 2010	0.471997	0.070043	6.739	1.60e-11 ***
(Y) 2011	0.433417	0.071371	6.073	1.26e-09 ***
(Y) 2012	0.450219	0.084977	5.298	1.17e-07 ***
(A) C	0.169907	0.02065	8.228	< 2e-16 ***
(A) S	0.147509	0.040588	3.634	0.000279 ***
(T) 2	-0.61476	0.095608	-6.43	1.28e-10 ***
(T) 3	0.126615	0.077236	1.639	0.101143
(T) 4	0.252503	0.074502	3.389	0.000701 ***
(Y) 1991: (T) 2	0.006294	0.105712	0.06	0.952523
(Y) 1992: (T) 2	1.191529	0.11196	10.642	< 2e-16 ***
(Y) 1993: (T) 2	1.836874	0.137105	13.398	< 2e-16 ***
(Y) 1994: (T) 2	2.903251	0.137937	21.048	< 2e-16 ***
(Y) 1995: (T) 2	0.634585	0.105977	5.988	2.12e-09 ***
(Y) 1996: (T) 2	1.414172	0.17905	7.898	2.83e-15 ***
(Y) 1997: (T) 2	0.260871	0.103626	2.517	0.011822 *
(Y) 1998: (T) 2	0.642135	0.097701	6.572	4.95e-11 ***
(Y) 1999: (T) 2	0.124562	0.098761	1.261	0.207221
(Y) 2000: (T) 2	0.102722	0.097085	1.058	0.290025
(Y) 2001: (T) 2	0.708585	0.097005	7.305	2.78e-13 ***
(Y) 2002: (T) 2	0.661004	0.102271	6.463	1.02e-10 ***
(Y) 2003: (T) 2	0.745126	0.106863	6.973	3.11e-12 ***
(Y) 2004: (T) 2	1.047115	0.102909	10.175	< 2e-16 ***
(Y) 2005: (T) 2	0.708868	0.097113	7.299	2.89e-13 ***
(Y) 2006: (T) 2	0.732643	0.097512	7.513	5.76e-14 ***
(Y) 2007: (T) 2	1.190184	0.10061	11.83	< 2e-16 ***
(Y) 2008: (T) 2	0.350577	0.101759	3.445	0.000571 ***
(Y) 2009: (T) 2	0.570721	0.097157	5.874	4.25e-09 ***
(Y) 2010: (T) 2	0.937175	0.101254	9.256	< 2e-16 ***
(Y) 2011: (T) 2	0.64712	0.098574	6.565	5.21e-11 ***
(Y) 1991: (T) 3	-0.35786	0.089278	-4.008	6.11e-05 ***
(Y) 1992: (T) 3	1.019362	0.09705	10.503	< 2e-16 ***
(Y) 1993: (T) 3	1.261743	0.213396	5.913	3.37e-09 ***
(Y) 1994: (T) 3	2.218941	0.130417	17.014	< 2e-16 ***
(Y) 1995: (T) 3	0.100161	0.088765	1.128	0.259158
(Y) 1996: (T) 3	-0.2016	0.183653	-1.098	0.272335
(Y) 1997: (T) 3	0.593599	0.087251	6.803	1.02e-11 ***
(Y) 1998: (T) 3	-0.35888	0.08069	-4.448	8.68e-06 ***
(Y) 1999: (T) 3	-0.21516	0.081594	-2.637	0.008365 **
(Y) 2000: (T) 3	-0.59231	0.079006	-7.497	6.53e-14 ***
(Y) 2001: (T) 3	-0.56826	0.081442	-6.978	3.00e-12 ***
(Y) 2002: (T) 3	0.446394	0.083826	5.325	1.01e-07 ***
(Y) 2003: (T) 3	-0.94327	0.099504	-9.48	< 2e-16 ***
(Y) 2004: (T) 3	0.403911	0.084897	4.758	1.96e-06 ***
(Y) 2005: (T) 3	-0.22516	0.079413	-2.835	0.004578 **
(Y) 2006: (T) 3	-0.05411	0.080623	-0.671	0.502089
(Y) 2007: (T) 3	0.054233	0.087124	0.622	0.533628
(Y) 2009: (T) 3	-0.20368	0.080103	-2.543	0.010999 *
				(continuation)
	Estimate	Std. Error	z value	Pr(>|z|)

(Y) 2010: (T) 3	-0.63599	0.089105	-7.138	9.50e-13 ***
(Y) 2011: (T) 3	-0.04494	0.083777	-0.536	0.591702
(Y) 1991: (T) 4	-1.48312	0.09294	-15.958	< 2e-16 ***
(Y) 1992: (T) 4	0.009259	0.088688	0.104	0.916855
(Y) 1993: (T) 4	1.355852	0.127614	10.625	< 2e-16 ***
(Y) 1994: (T) 4	1.697438	0.120745	14.058	< 2e-16 ***
(Y) 1995: (T) 4	-0.44521	0.083964	-5.302	1.14e-07 ***
(Y) 1996: (T) 4	0.000357	0.169779	0.002	0.998321
(Y) 1997: (T) 4	-0.38193	0.087575	-4.361	1.29e-05 ***
(Y) 1998: (T) 4	-1.21245	0.077829	-15.578	< 2e-16 ***
(Y) 1999: (T) 4	-0.27606	0.076873	-3.591	0.000329 ***
(Y) 2000: (T) 4	-0.19313	0.07579	-2.548	0.010827 *
(Y) 2001: (T) 4	-0.93902	0.077027	-12.191	< 2e-16 ***
(Y) 2002: (T) 4	-0.24593	0.084955	-2.895	0.003793 **
(Y) 2003: (T) 4	-1.235	0.093732	-13.176	< 2e-16 ***
(Y) 2004: (T) 4	0.25338	0.082434	3.074	0.002114 **
(Y) 2005: (T) 4	-0.47888	0.07684	-6.232	4.60e-10 ***
(Y) 2006: (T) 4	-0.22813	0.078056	-2.923	0.003471 **
(Y) 2007: (T) 4	0.166102	0.088312	1.881	0.059991 .
(Y) 2009: (T) 4	-0.26786	0.078389	-3.417	0.000633 ***
(Y) 2010: (T) 4	-0.85737	0.099533	-8.614	< 2e-16 ***
(Y) 2011: (T) 4	-0.45732	0.080658	-5.67	1.43e-08 ***
(Y) 2012: (T) 4	-0.60168	0.281427	-2.138	0.032519 *
(Y) 1991: (A) C	-1.39639	0.085839	-16.268	< 2e-16 ***
(Y) 1992: (A) C	-0.51586	0.046116	-11.186	< 2e-16 ***
(Y) 1993: (A) C	-0.53303	0.710934	-0.75	0.453398
(Y) 1994: (A) C	0.423759	0.110096	3.849	0.000119 ***
(Y) 1995: (A) C	-0.54847	0.080967	-6.774	1.25e-11 ***
(Y) 1996: (A) C	-1.29186	0.294635	-4.385	1.16e-05 ***
(Y) 1997: (A) C	-0.31845	0.038172	-8.343	< 2e-16 ***
(Y) 1998: (A) C	-0.65821	0.025866	-25.447	< 2e-16 ***
(Y) 1999: (A) C	-0.68169	0.028176	-24.194	< 2e-16 ***
(Y) 2000: (A) C	-0.32939	0.024254	-13.581	< 2e-16 ***
(Y) 2001: (A) C	-0.37514	0.025209	-14.881	< 2e-16 ***
(Y) 2002: (A) C	-0.80864	0.048273	-16.752	< 2e-16 ***
(Y) 2003: (A) C	-0.14876	0.05832	-2.551	0.010749 *
(Y) 2004: (A) C	0.037776	0.034401	1.098	0.272165
(Y) 2005: (A) C	0.129323	0.025398	5.092	3.55e-07 ***
(Y) 2006: (A) C	-0.06438	0.027035	-2.381	0.017252 *
(Y) 2007: (A) C	-0.61795	0.034766	-17.774	< 2e-16 ***
(Y) 2009: (A) C	0.060129	0.025897	2.322	0.020240 *
(Y) 2010: (A) C	0.323123	0.049652	6.508	7.63e-11 ***
(Y) 1991: (A) S	0.061088	0.056534	1.081	0.279893
(Y) 1992: (A) S	-0.86657	0.063473	-13.653	< 2e-16 ***
(Y) 1993: (A) S	-2.24325	0.300093	-7.475	7.71e-14 ***
(Y) 1994: (A) S	-1.97839	0.069934	-28.29	< 2e-16 ***
(Y) 1995: (A) S	-0.18796	0.055675	-3.376	0.000735 ***
(Y) 1997: (A) S	-0.60899	0.061674	-9.874	< 2e-16 ***
(Y) 1998: (A) S	-1.66477	0.050135	-33.206	< 2e-16 ***
(Y) 1999: (A) S	-0.72812	0.049503	-14.709	< 2e-16 ***
(Y) 2000: (A) S	-0.32238	0.044426	-7.257	3.97e-13 ***
(Y) 2001: (A) S	-1.81747	0.049512	-36.708	< 2e-16 ***
(Y) 2002: (A) S	0.140314	0.050246	2.793	0.005229 **
(Y) 2003: (A) S	-0.48253	0.089635	-5.383	7.32e-08 ***
(Y) 2004: (A) S	-0.09558	0.051027	-1.873	0.061043 .
(Y) 2005: (A) S	-0.18621	0.045338	-4.107	4.01e-05 ***
(Y) 2006: (A) S	-0.62916	0.047026	-13.379	< 2e-16 ***
(Y) 2007: (A) S	-1.67698	0.116964	-14.338	< 2e-16 ***

Table 6. Estimations of parameters (approach C). F – flag; Y – year; A –area; T – quarter.

	Estimate	Std. Error	z value	Pr(>|z|)
(Intercepto)	-5.21345	0.371228	-14.04	< 2e-16 ***
(F) BRA-ESP	0.495026	0.006154	80.44	< 2e-16 ***
(F) BRA-HND	-0.414317	0.013491	-30.71	< 2e-16 ***
(F) BRA-JPN	-1.045821	0.021419	-48.83	< 2e-16 ***
(F) BRA-PAN	-2.396636	0.018916	-126.7	< 2e-16 ***
(F) BRA-TAI	-1.107157	0.010492	-105.52	< 2e-16 ***
(F) BRA-VCT	-1.747708	0.010061	-173.71	< 2e-16 ***
(Y) 1991	0.224517	0.484605	0.46	0.643
(Y) 1992	-0.260225	0.483128	-0.54	0.59
(Y) 1993	-0.422948	0.513381	-0.82	0.41
(Y) 1994	-0.049023	0.479228	-0.1	0.919
(Y) 1995	0.0512	0.48339	0.11	0.916
(Y) 1996	-0.629945	0.524024	-1.2	0.229
(Y) 1997	-0.180397	0.481345	-0.37	0.708
(Y) 1998	0.610795	0.480592	1.27	0.204
(Y) 1999	-0.178489	0.476038	-0.37	0.708
(Y) 2000	0.056957	0.479051	0.12	0.905
(Y) 2001	-0.764767	0.479427	-1.6	0.111
(Y) 2002	-0.266229	0.465471	-0.57	0.567
(Y) 2003	0.285172	0.484657	0.59	0.556
(Y) 2004	0.502767	0.482079	1.04	0.297
(Y) 2005	0.6099	0.467124	1.31	0.192
(Y) 2006	0.613721	0.487479	1.26	0.208
(Y) 2007	0.283913	0.481852	0.59	0.556
(Y) 2008	0.700381	0.621968	1.13	0.26
(Y) 2009	0.653628	0.481106	1.36	0.174
(Y) 2010	0.684309	0.50858	1.35	0.178
(Y) 2011	0.660301	0.51162	1.29	0.197
(Y) 2012	0.827209	0.639339	1.29	0.196
(A) C	-0.210572	0.130841	-1.61	0.108
(A) S	-0.604828	0.137089	-4.41	1.02e-05 ***
(T) 2	0.164778	0.115397	1.43	0.153
(T) 3	0.182008	0.117553	1.55	0.122
(T) 4	-0.027673	0.11568	-0.24	0.811

Table 7. Estimation of variance components for random effects (year x quarter interaction and year x area interaction). Y – year; A – area; T – quarter.

Group	Variance	Std. Dev.
Y:T	0.1506	0.3881
Y:A	0.1709	0.4134

Number of observations: 35055; Groups: Y: T = 88; Y: A = 60.

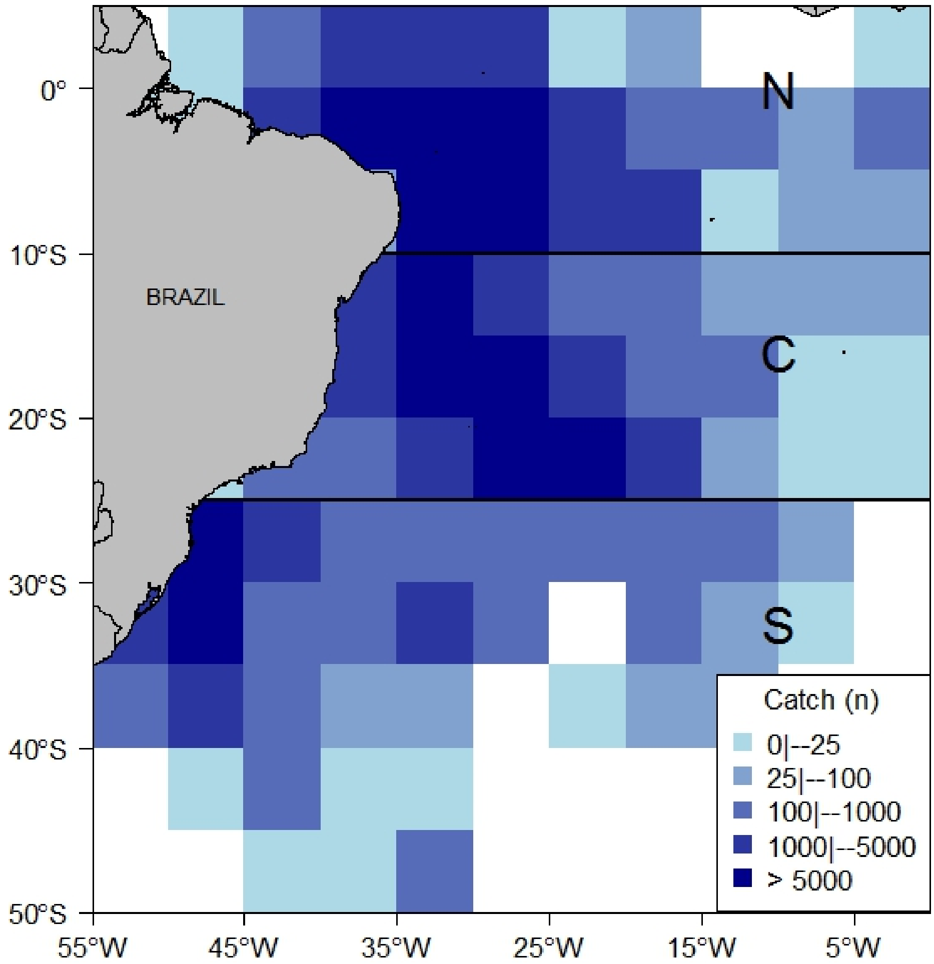

Figure 1. Distribution of catches of *Xiphias gladius* from 1990 to 2012. Fishing areas: N - North; C - Central and S - South.

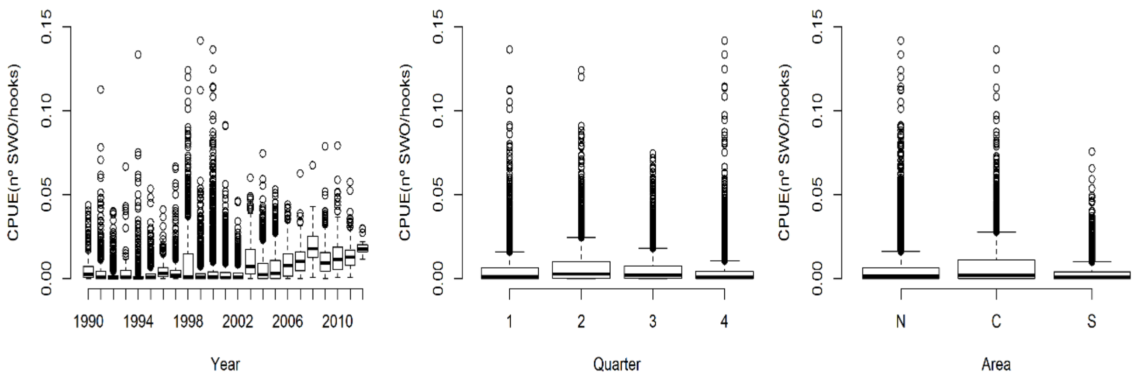

Figure 2. Catch per unit effort (CPUE) by year, quarter and area (N-north, C-central, S-south).

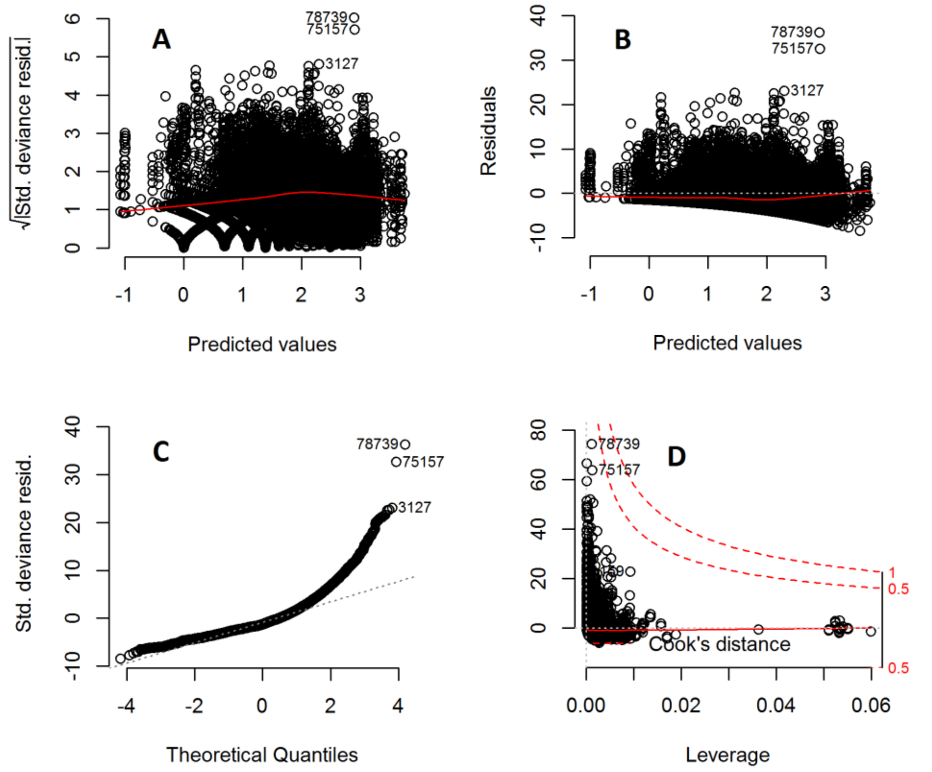

Figure 3. Diagnostic of residuals (approach A).

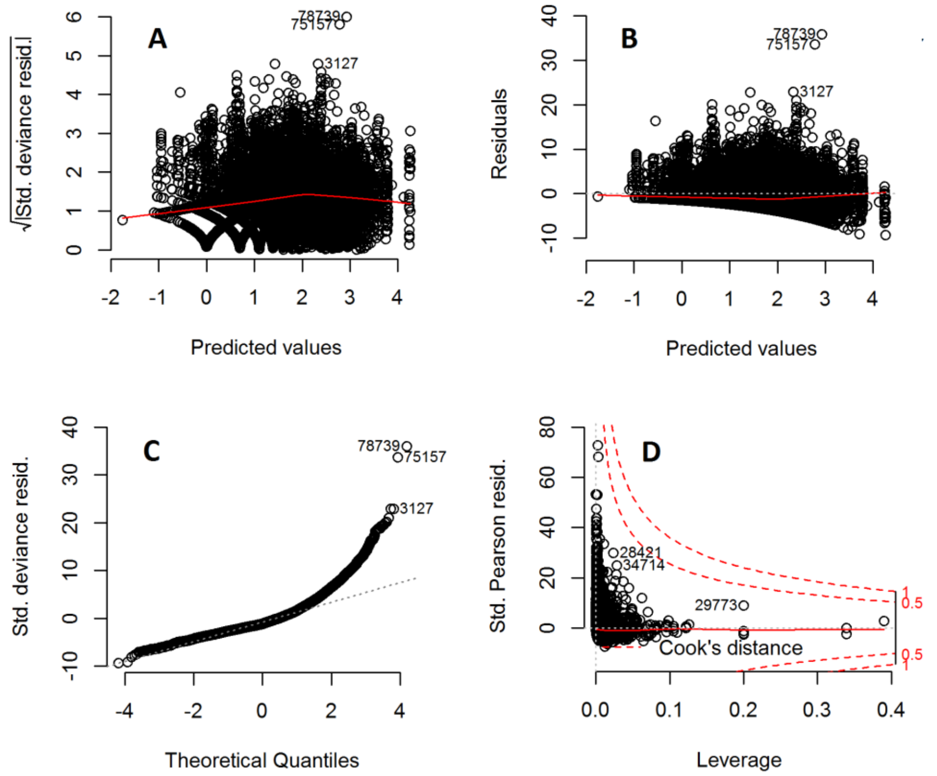

Figure 4. Diagnostic of residuals (approach B).

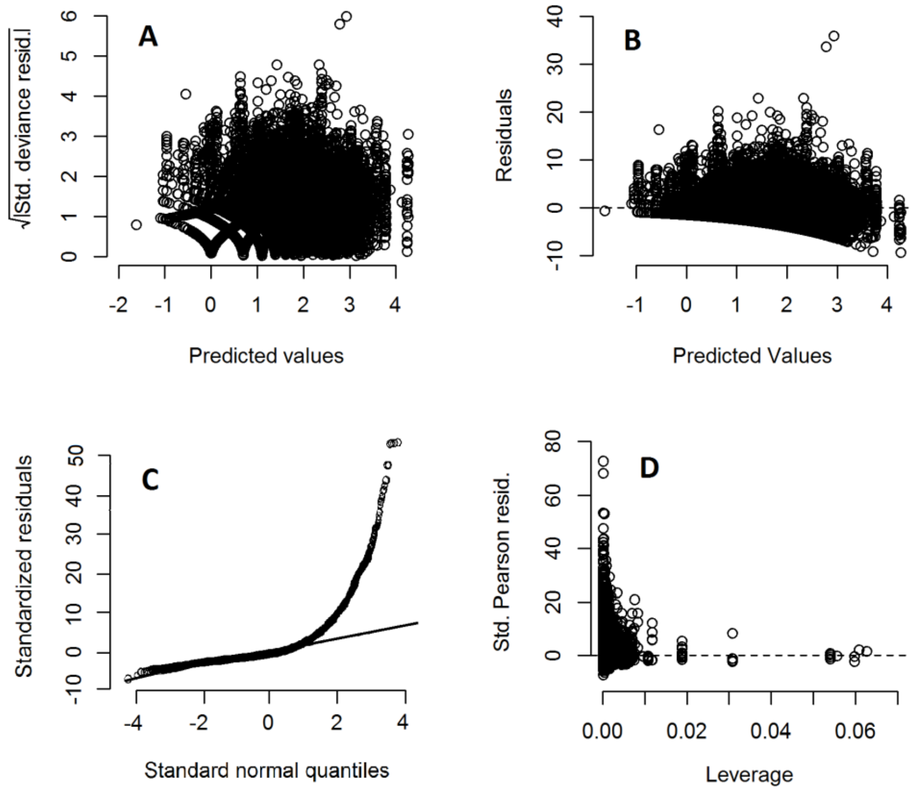

Figure 5. Diagnostic of residuals (approach C).

.

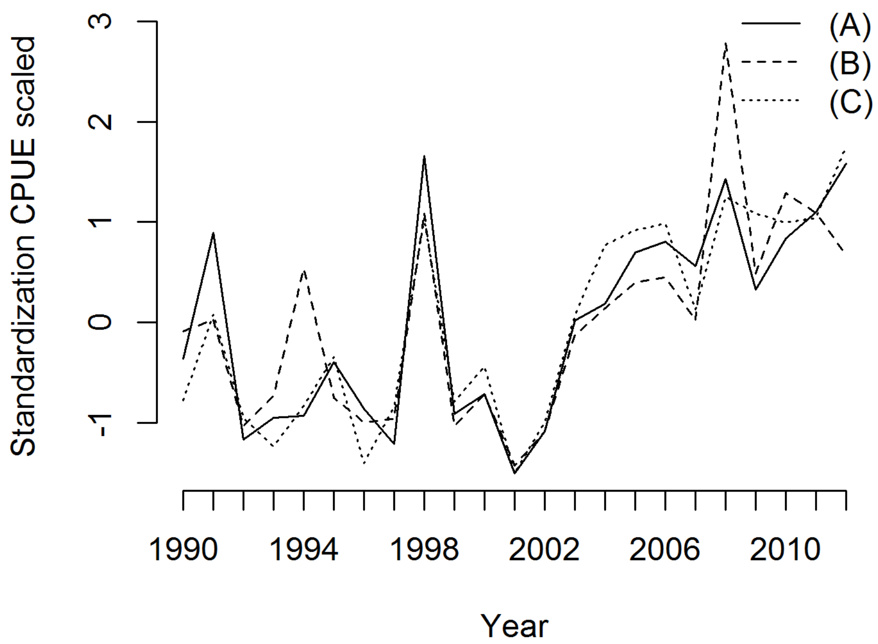

Figure 6. Standardized CPUE as calculated following the approaches A, B and C. Estimations were scaled by calculating the difference between the original value and the mean of the series, divided by the standard deviation of the series.