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UPDATED STANDARDIZED CATCH RATE OF SWORDFISH (*XIPHIAS GLADIUS*) CAUGHT IN THE SOUTH ATLANTIC BY THE BRAZILIAN FLEET

Vívian Graziela Oliveira Carneiro[1], Silvaneide Luzinete Rodrigues[1], Evelyn Souza Chagas Oliveira[1], Humber Agrelli Andrade[1]

SUMMARY

Longline Brazilian fleet is composed of national and leased vessels from different countries. In addition the target species has changed across the years, which make difficult to estimate relative abundance indices based on commercial catch per unit effort. In this paper standardized CPUE was calculated based on four different approaches concering the variables flag and number of hooks per basket. Ancillary information about the historial development of the fishery was also considered. Overall the four standardized CPUE series showed similar time trends from 1978 to 2012. However the estimations presented in this paper and the previous one calculated in 2013 were conflictive, probably due to the different explanatory variables included in the analyses. While cluster analysis was used in the previous calculation to account for the "target" effect, in this paper we relied on a physical characteristic of the longline as a proxy of the target.

RÉSUMÉ

La flottille palangrière brésilienne est composée de navires nationaux et de navires affrétés de différents pays. De plus, l'espèce cible a changé au fil des ans, ce qui complique l'estimation des indices d'abondance relative fondés sur les captures commerciales par unité d'effort. Dans ce document, la CPUE standardisée a été calculée sur la base de quatre approches différentes concernant les variables du pavillon et du nombre d'hameçons par panier. Des informations complémentaires sur le développement historique de la pêcherie ont également été prises en compte. Dans l'ensemble, les quatre séries de CPUE standardisée présentaient des tendances temporelles similaires de 1978 à 2012. Cependant, les estimations présentées dans le présent document et dans le document précédent calculées en 2013 étaient conflictuelles, probablement en raison des différentes variables explicatives incluses dans les analyses. Alors que l'analyse de groupement a été utilisée dans le calcul précédent pour tenir compte de l'effet « cible », une caractéristique physique de la palangre comme approximation de la cible a été utilisée dans le présent document.

RESUMEN

La flota de palangre de Brasil se compone de buques nacionales y fletados de diferentes países. Además, la especie objetivo ha cambiado a lo largo de los años, lo que hace difícil estimar los índices de abundancia relativa basándose en la captura comercial por unidad de esfuerzo. En este documento, la CPUE estandarizada se calculó basándose en cuatro enfoques diferentes de las variables pabellón y número de anzuelos por cesta. También se consideró la información asociada sobre el desarrollo histórico de la pesquería. En total, las cuatro series de CPUE estandarizadas presentaban tendencias temporales similares desde 1978 hasta 2012. Sin embargo, las estimaciones presentadas en este documento y el anterior calculadas en 2013 eran conflictivas debido probablemente a las diferentes variables explicativas incluidas en los análisis. Aunque en el cálculo anterior se utilizó el análisis de conglomerados para tener en cuenta el efecto "objetivo", en este documento confiamos en una característica física del palangre como una aproximación del objetivo.

KEYWORDS

Swordfish, CPUE, GLM, Longline, Brazilian fleet

[1] UFRPE – DEPAq – Av. Dom Manuel de Medeiros, s/n – 52171-030 – Recife-PE – Brazil. carneirovivian0@gmail.com

Introduction

Often standardized catch per unit effort (CPUE) as calculated based on commercial data is assumed to be an relative abundance índices in stock assessment analyses. Ideally the variation of standardized CPUE across the years should not reflect changes in factors like technology or fishermen strategy, but only changes of stock biomass (Maunder and Punt 2004). Generalized Linear Models (GLM) are often used to estimate standardized CPUE which is supposed to be a usefull relative abundance indices (Walsh and Brodziak 2015). The assumption holds if the main factors that affect CPUE are included in the models. Otherwise the standardized CPUEs are biased relative abundance indices.

Whenever there are not fishery independent estimations of relative abundance indices, tuna stock assessments are often based on standardized CPUEs as calculated for commercial fleets. Hence the quality of the stock assessment depends, at least in part, of the quality of the standardized CPUE time series. Hence all the standardized time series are carefully assessed and revised. Only those series that are considered useful as relative abundance indices are considered in the stock assessment analyses. In the last assessment of the South Atlantic stock of swordfish (*Xiphias gladius*), six CPUE time series were available (Brazil, Japan, Spain, Uruguay, Chinese Taipei and South Africa).

In the calculation of the standardized CPUE of Brazil, besides the conventional explanatory variables (e.g. year, quarter and area) the authors have included in the model an index based on cluster analyses to account for fishermen intention concerning the species they were aiming at (target) (see Hazin *et al.* 2014). Despite the recent use of this approach it remains controversial. The use of cluster may be usefulness to estimate "target" indices for each of the fishing sets, but we think there are drawbacks when this indices is used as explanatory variable when standardizing CPUE of species that are indeed one of targets of some fleets (e.g. swordfish). In this case the proportion of target species in the catches will drive the results of cluster analysis and the estimation of the explanatory variable "target". This way the proportion of the target species is in some sense used as the explanatory variable to model the catch of this same target species. In our understanding it sounds like a circular line of reasoning.

Standardized CPUEs as calculated for Brazilian fleet with the inclusion of target indices estimated based on cluster analysis were presented in the last swordfish stock assessment. In spite the catches of swordfish have increased before mid 1990's, the Brazilian standardized CPUE showed a monotonous increasing time trend across the last four decades (Hazin *et al.* 2014). The swordfish Working Group (WG) considered "that the increase in the abundance index for the species may be an overly optimistic representation of the recent trend in southern Atlantic swordfish biomass. Therefore, the Group decided not to include this series in the stock assessment modelling process" (ICCAT 2014).

Brazilian fishing fleet operations cover a large part of the South Atlantic. In addition, Brazilian catches of South Atlantic swordfish ranked second in the last years. Therefore estimations of Brazilian standardized catch rates maybe important in the assessment of South Atlantic stock of swordfish. Consequently it is of major importance to revise the dataset and to try out different approaches to estimate useful standardized CPUE for the Brazilian fleet. In this working paper we have used different approaches to account for the "target" effect based on the available information concerning the number of hooks per basket, and on ancillary information published about historical changes concerning fishermen strategies (e.g. Meneses de Lima *et al.* 2000). Standardized CPUES of Brazilian fleet calculated in this paper are compared to the previous estimations presented in last stock assessment meeting. The results may be useful for the 2017 stock assessment of South Atlantic stock of swordfish.

2. Material and Methods

2.1 Database

Information concerning catches of swordfish by Brazilian longline fishery (national plus leased boats) from 1978 to 2012 are in the "Banco Nacional de Dados de Atuns e Afins" (BNDA) ("National Tuna and Tuna-Like fish Dataset"), which includes two sources of information: a) Logbooks; and b) forms of the Programa Nacional de Observadores de Bordo (PROBORDO) (Onboard Observer National Program). There are available information concerning catch (often in number of fish), effort (number of hooks), flag of the boat, dates when the longline was deployed and retrieved from the water, latitude and longitude of the fishing operation, and number of hooks per basket (HPB).

Data entries with missing values of catch or effort and non-sampling errors (e.g. position of fishing sets on land) were discarded. After the preliminar exploratory analysis 58,777 fishing sets were retained for analyses. Dataset of longline Brazilian fleet is a mosaic with reports of boats with twenty different flags (**Table 1**) which operate with different fishing strategies aiming at different targets. Furthermore, the targets have changed across the years for at least part of the fleet (see Rodrigues *et al.* 2017).

2.2 Approaches

We have revised data concerning the variables catch, effort, year, quarter, flag, HPB, latitude and longitude, which were considered as offset (effort), response (catch) or explanatory (e.g. year) variables. However, we are still working on the revision and on the rescue of data concerning other variables (e.g. bait) to attempt to recover more information. Hopefully in the future we can improve the estimation of standardized CPUE by taking into account more important variables. After some preliminary exploratory analyses we opted to calculate a factor "area" to account for the fishing set position. The levels of factor area were: North (latitude ≤ 15°S), Central (15°S < latitude ≤ 25°S) and South (latitude > 25°S). These geographical limits were selected in order to achieve balance of data among the three levels of area. Each subarea include one of the three core position were the Brazilian fleet effort have been concentrated across the last decades (core areas).

There are papers concerning the historical development of the longline Brazilian fleet, which includes information about fishermen target and changes in fishing strategies (e.g. Meneses de Lima *et al.* 2000). There are also information about Brazilian fishery monitoring programs. Samples of fishermen logbooks were available from 1978 to 2012. In addition, in the end of 2004 onboard observers were mandatory for leased boats. However, the onboard observer program was active only until the end of 2011/beginning of 2012. Qualities of data reported in periods with and without onboard observers are probable different. We took into account all the available information when selecting the approaches used in this paper to standardize CPUE.

Year, quarter and area were always considered as factors in all approaches. The differences are related to the way the variables HPB and flag were used to build the models. Follows a description of the the four approaches we have considered in the paper:

Approach 1 – Whole dataset is used including all flags. In addition to the explanatory variables year, area and quarter we used:
HPB – covariable (quantitative);
Flag – factor (qualitative) with levels as shown in **Table 1**.

Approach 2 – Only the flags with large number of fishing sets (> 2% of the total dataset) were retained for analysis, namely, leased boats fom Spain (BRA-ESP), national boats (BRA), leased boats from Japan (BRA-JPN), Saint Vincent (BRA-VCT), Panama (BRA-PAN), China-Taipei (BRA-TAI), Belize (BRA-BLZ) and Honduras (BRA-HND). The number of hooks per basket was assumed as proxy of fishery strategy. Hence we identified fishery phases for each flag based on the frequency distributions of HPB across the years (**Figure 1**). For example, if for a given flag (e.g. BRA) there was a period in which HPB was 5 in most of the fishings sets, and a period in which most of the boats used 6 hooks per basket, we have assumed that there were two distinct phases in the fishery, probably with distinct coefficients of catchability. The time series was them split according to the number of phases and different levels of flag factor were assign to the fishing sets of the phases (e.g. BRA 1 and BRA 2). In this approach HPB was not included in the models. Besides year, quarter and area the only factor considered as explanatory variable was:
Flag – factor (qualitative)

- BRA1 – predominance of HPB=5 (1979-1985);
- BRA2 – predominance of HPB=6 (1986-1996);
- BRA3 – predominance of HPB=7 (1997-2004);
- BRA4 – predominance of HPB=5 (2005-2012);
- BRA-ESP1 – predominance of HPB=4 (1997-2002);
- BRA-ESP2 – predominance of HPB=5 (2003-2006);
- BRA-ESP3 – predominance of HPB=6 (2007-2012);
- BRA-PAN1 – predominance of HPB=4 (2000-2003);
- BRA-PAN2 – predominance of HPB=6 (2004-2007;
- BRA-JPN1 – predominance of HPB=5 (1978-2001);
- BRA-JPN2 – predominance of HPB superior a 10 (2011-2012);
- BRA-VCT; BRA-TAI; BRA-BLZ; BRA-HND – only one phase.

Approach 3 – Only the flags with large number of fishing sets (> 2% of the total dataset) were retained for analysis. In addition, ancillary information concerning historical development of Brazilian fleet was considered when selecting the levels of factor flag. Meneses de Lima et al (2000) reported that the type of the longline used by fishermen of the national vessels (BRA) started to change in the end of 1990's because swordfish become a target. As a matter of fact the CPUE of national vessels after 2000 were much higher than in the previous years (**Figure 2**). Hence we have assumed that the catchability has changed. In addition to year, area and quarter, the other explanatory variables were:

HPB – covariate (quantitative)

Flag – factor (qualitative)

BRA1 (1978-2000) – Most of longlines were deployed into the water during the day below the surface layer. They were build with multifilament nylon and fish were the bait;

BRA2 (2001-2012) – Predominance of longlines with monofilament nylon, often deployed surface layer during the beginning of the night with light-sticks and squid as bait;

BRA-JPN; BRA-ESP; BRA-PAN; BRA-VCT; BRA-TAI; BRA-BLZ; BRA-HND – sem modificações.

Approach 4 – Only the flags with large number of fishing sets (> 2% of the total dataset) were retained for analysis. We also considered information concerning government monitoring program. In the very end of 2004 the onboard observer program started. Hence the quality of the data has probably changed. Maybe the catches and CPUEs reported in the two periods (with or without observers) are not comparable. Therefore the time series should be split in two parts, from 1978 to 2004, and from 2005 to 2012. Hence, in addition to year, area and quarter, the other explanatory variables used to model the CPUE of the two parts of the datasets were:

Dataset 1 (1978- 2004)

HPB – covariate (quantitative)

Flag – factor (qualitative) with levels: BRA, BRA-BLZ, BRA-ESP, BRA-HND, BRA-JPN, BRA-PAN, BRA-TAI, BRA-VCT;

Dataset 2 (2005 – 2012)

HPB – covariate (quantitative)

Flag – factor (qualitative) with levels: BRA, BRA-ESP, BRA-HND, BRA-JPN, BRA-PAN, BRA-VCT.

2.3 Models

Generalized linear models (GLM) used in this paper to standardize CPUE in matricial notation are:

(1) $g[E(y)] = X\beta$

in which y is a vector of response realization, $E(.)$ is the expectation, $g[.]$ is the link function, X is the matrix with the realizations of the explanatory variables, and β is the vector of parameters. In order to estimate β a probability distribution of exponential family for y and a link function are selected in advance.

Catch in number of fish was the response variable, while the logarithm of effort was the offset. Catch in weight was not considered due to high proportion of missing values. Because catch (y) is a counting variable (discrete) we selected Poisson (P) and negative binomial (NB) distributions. However, the proportions of catches equal to zero are not low for all levels of the factors. Overal the proportion of zero is approximately 23%. Hence we opted to try also models to account for overdispersion due to the excess of zeros, namely Zero Inflated Poisson (ZIP), Zero Inflated Negative Binomial (ZINB), Hurdle Poisson (HP) and Hurdle Negative Binomial (HNB) models. Because in preliminary analyses we have had convergence problems when fitting mixed models with fixed and random effects (see Oliveira *et al.* 2017), in this paper only fixed effects models were used. In addition, logarithm link function was used for all the models.

In order to select the order the explanatory variables enter in the model we have fitted simple models with only one of explanatory variable at a time, and we calculated the Akaike Information Criterion (AIC) (Akaike 1974) for each each model. The AIC is an index that reflects the trade-off between bias of the models and variance of the estimations (Burnham and Anderson 2002). We have ranked the the explanatory variables based on AIC to select the order they were included in the models. The selection of variables to be kept in the model (or dropped off) was also based on AIC. Although the comparisons of models with such different structures (P, NB, ZIP, ZINB, HP, HNB) may be based in different aspects, we have opted to rely only on AIC for simplicity sake.

Diagnostics of residuals were used to assess the quality of the fittings of the models selected for each approach (1, 2, 3 or 4). Standardized CPUEs time series as calculated in this paper were compared. We also compared estimations calculated in this paper to the standardized CPUE available in the previous swordfish stock assessment meeting in 2013. We also assessed the relationship between each standardized CPUE time series and the total catch of South Atlantic swordfish. Software R 3.3.1 (R Core Team 2016) and package *pscl* were used in the analysis.

4. Results

4.1 Spatial Distribution

Longline Brazilian fleet operations cover a large part of the South Atlantic and equatorial region **(Figure 3**). Overall the catches were high in the core subregions where the effort was also high. There are regions with more than 3 millions of hooks, and catches higher than 10 thousand fishes. In the North are efforts were high over equatorial region, especially in the west of Atlantic Ocean. In the Central area most of longlines were deployed in the mid of Atlantic, while in the South area most of the fishing sets were in the west margin closer to the South America continent. Effort was low in the east of South Atlantic. Most of high CPUE values (> 10 fish/1000 hooks) were in Central area far from the continental land. Overall the CPUEs more close to the continent were low, though the west of equatiorial region is an exception.

4.2 Relationship nominal CPUE and explanatory variables

Relationships between nominal CPUE and explanatory variables are shown in **Figure 4**. Variability of CPUE values across the years were high. Overall the CPUEs have increased from 1978 to 1982, but the values were low from the mid 1980's until the beginning of 2000's. After 2002 the CPUEs estimations increased quickly and remain high, though there was a decreasing trend in the very end of the time series. Variances of CPUE values by quarter were high. Overall CPUEs of the 2nd and 3rd quarter were slightly higher than in other periods of the year. Notice also that CPUEs tend to be higher in Central area. The correlation between CPUE and HPB was negative, hence the larger the HPB the lower the expectation of the catch rate. The CPUEs of the several flags are quite different. Notice the high values of CPUE reported for flags BRA-VUT, BRA-KIT and BRA-UK. Those high values are suspect and we are investigating if there are non-sampling errors. However, the numbers of reports for those three flags were low hence they were discarded in the approaches 2, 3 and 4. In this sense comparisons of results of approach 1 to the results of the other approaches is useful as a sensitivity analysis concerning the inclusion of some of the flags.

4.3 Model Fitting

Frequency distributions of the catches (response variable) as they appear in the datasets retained for calculations are shown in **Figure 5**. Notice that the vector of response variables for approaches 2 and 3 are the same, and that the database was split in two for calculations following approach 4. Overall the distributions of catches were similar for approaches 1, 2, 3 and for the first part of the dataset selected in the approach 4 (period without onboard observers). These distributions showed high quantity of zeros and heavy right tail. On the other hand the proportion of zeros was low and there is not a heavy tail in the distribution of catches as reported in the second part of the dataset used in the approach 4 (period with onboard observer).

Only the simplest Poisson model converges if all the interactions are considered in the calculations. The main problem is the interaction between year and flag, because of the lack of balance. Hence this interaction was not considered in the results showed hereafter. Summary of information criteria, loglikelihood and other indices of the models fitted are shown in **Table 2.** In the approach 1 zero inflated models did not converge. Among the models that converged those with negative binomial outperformed the Poisson models. Because of the structure of the hurdle models, the estimations of the number o zero catches are always equal to the the observed number of zero catches in the dataset, which was 13,465 in the approach 1. If we rely in the difference between the numbers of zeros observed and estimated with the models, the simple Poisson is the more biased model. Overall, the simple negative binomial model outperforms the others in the approach 1 if we rely in the AIC or even in the loglikelihood estimation. All the models converged in the approach 2 and only the ZINB did not converge in the approach 3. Overall results of calculations in the approaches 1, 2 and 3 were similar in the sense Poisson model was biased. In addition, similarly, the simple negative binomial model outperformed the other models in the approaches 2 and 3. In the approach 4 the dataset was split in two parts (1978-2004 – without onboard observers; and 2005-2012 – with onboard observers). If we rely on AIC the simple negative binomial model is selected for first part of the dataset, while the simple Poisson is selected for the second part of the dataset. It is important to highligh that the numbers of parameters of the models are not the same. Hence when we say one model is better than the other is due to the probability distribution but also due to the parameters (main effects and interactions) included in the formulation.

Residual diagnostics of the models fitted following the approaches 1, 2, 3 and 4 were similar (**Figure 6**). Residuals are heterocedastic (panels at left – **Figure 6**), which is an expected result because the response variable is a counting. In addition the variances of Poisson and negative binomial models increase along with the estimation of expectation of the response variable. However, the expectations of the residuals were close to zero for all the models, in this sense all of them are not strongly biased. Distributions of residuals were not approximately normal (central panels – **Figure 6**) because there strong violations in the tails. Catches are strictly positive variables and asymmetrical distributions are common. We did not assume the normal distribution, instead we have used probability distributions (Poisson and negative binomial) for counting data which may be suitable to model such kind asymmetrical response variable. Hence, the non normal data is not of concern. However, it is important to remind that most of inferences in the GLM and GLMM frameworks are based on asymptotical assumption that the data is approximately normal in mild conditions with large sample size (e.g. chi-square and Wald statistics). Hence the inference results may be not as powerful as in the ideal condition of normality. Leverage and Cook's distances are shown in the right panels of **Figure 6**. As a rule of the thomb Cook's distances lower than 0.5 are not of much concern (Dobson 2002). However the leverage was high for several fishing set reports in the approaches 3 and 4. Usually data points with leverage values higher tha 4p/n (p – number of parametes; n – sample size) are highly influential. Further investigation of that influential data points are encouraged if standardized CPUEs of approaches 3 and 4 are selected for stock assessment.

4.4 Standardized CPUE

Scaled standardized CPUEs (x/mean(x)) as calculated following the four approaches are sown in **Table 4** and in F**igure 7** along with nominal CPUE. Overall time trends of nominal and standardized CPUE estimations of approaches 1, and 3 were similar**.** Values of CPUEs decreased from 1978 to 2002, then there was an increase until 2007. The values remain high until 2010, but there decrease in 2011 and 2012. Estimations of standardzed CPUE as calculated following the approach 4 were flat in the two periods (1978-2004 without onboard observer; 2005-2012 with onboard observer).

The intention was to provide alternative standardized CPUE times series to Brazilian fleet, because the previous estimation not useful for stock assessment. We tried out alternative calculations but at the moment we do not have motivation to say that one of the approaches is less biased than the others. Hereafter we show the results in more detail concerning the simplest approach (1), which are similar to the results of approaches 2 and 3. Estimations of parameters of the binomial model selected in the approach 1 are in **Table 3**. Dimension of the model is relatively high and the null hypothesis (parameter equal to zero) was rejected for 162 parameters ($p < 0.05$). All explanatory variables included in the model as main effect or interaction terms proved to be important to understand the variability of the catches.

Brazilian standardized CPUE time series calculated following approach 1 (this paper) and the previous standardized CPUE time series calculated in 2013 (see Hazin *et al.* 2014) are showed together in **Figure 8**. The two time series are conflictive from 1978 until 2005. Overall standardized CPUE calculated in this paper decreased from 1978 until 1998, but increase fast from the end of 1990's until 2005. In opposition standardized CPUE presented in 2013 increased monotously in a constant and moderate rate from 1978 until 2005. After 2005 the two standardized CPUE are not conflictive.

Total catch of South Atlantic swordfish and the relationship between the catch and two standardized CPUE time series (this paper and Hazin *et al.* 2014) are shown in **Figure 9**. Catch time series show two distinct phases. Total cathes increase from 1978 to 1995, and then the catches decreased until 2012 (**Figure 9A**). Correlation between catch and standardized CPUE calculated in this paper (**Figure 9B**) was weak and negative ($r = -0.181$; $p = 0.2973$), while the correlation between the catch and the previous estimation of standardized CPUE (**Figure 9C**) were positive and marginally significative ($r = 0.321$; $p = 0.0598$).

5. Remarks

In the mid of South Atlantic the CPUEs were in general higher than in west close to the South America continent, but the effort was high in the later region. Probably the tradeoff between yield and operational cost are favorable to the regions close to harbors and continental land.

Further investigation is necessary but at first glance the frequency distribution of catches in the period in which the onboard observer program was active (2005-2012) was different than in the previous period. It is expected that the quality of the data with onboard observers is better. To split dataset in two parts is an alternative to cope with the change concerning the quality of the data.

Estimations of standardized CPUEs with HPB as covariate or with categorical variables with levels that reflect the changes in HPB were similar.

In 2013 a "target" explanatory variable was calculated based on a cluster analysis of the catches of the different species. However, in the present paper the explanatory variable HPB was used as a proxy of possible changes concerning the target species. Estimations of standardized CPUE time series calculated in this paper and the one presented in the 2013 are conflictive.

In general if total catch increase it is expected that the biomass of the stock decreases. Hence the correlation between catch and an indice of relative abundance is expected to be negative for a target resource in a traditional developed fishery system. If we rely on this line of reasoning, probably the estimations with HPB as proxy of target are more reliable as relative abundance indices. However, further investigations are encouraged.

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Table 1. Number of fishing set by flag as reported in the available database.

Flag name	*Flag code*	*No. reports*	*(%)*
SPAIN	BRA-ESP	13948	23.73
NATIONAL	BRA	13109	22.30
JAPAN	BRA-JPN	7942	13.51
SAINT VINCENT	BRA-VCT	6887	11.72
PANAMA	BRA-PAN	5799	9.87
CHINESE TAIPEI	BRA-TAI	4024	6.85
BELIZE	BRA-BLZ	1696	2.89
HONDURAS	BRA-HND	1430	2.43
PORTUGAL	BRA-PRT	807	1.37
MAROCCO	BRA-MAR	796	1.35
URUGUAY	BRA-URY	645	1.10
KOREA	BRA-KOR	473	0.80
U.S.A	BRA-USA	426	0.72
GUYANA	BRA-GUY	236	0.40
UNITED KINGDOM	BRA-UK	207	0.35
CANADA	BRA-CAN	146	0.25
ICELAND	BRA-ISL	121	0.21
SAINT KITTS AND NEVIS	BRA-KIT	54	0.09
VANUATU	BRA-VUT	20	0.03
BOLIVIA	BRA-BOL	11	0.02

Table 2. Summary of the models fitted: Poisson (P), Negative Binomial (NB), Zero Inflated Poisson (ZIP), Zero Inflated Negative Binomial (ZINB), Hurdle with Poisson (HP), and Hurdle with Negative Binomial (HNB). In the column at left there are: number of parameters (k), log likelihood (logLik), Akaike Information Criterion (AIC), and number of zero as predicted by using the models.

	Model structure					
	P	NB	ZIP	ZINB	HP	HNB
APPROACH 1						
k	1035	370			346	346
AIC	601442.9	337064.9			598793.0	338906.5
LogLik	-300253.5	-168188.4	-	-	-299050.5	-169106.2
Zero	4792	12708			13465	13465
APPROACH 2						
k	776	300	312	324	108	108
AIC	569243.1	311504.5	535023.2	533567.2	548869.4	313178.0
LogLik	-284265.6	-155465.2	-267199.6	-266459.6	-274326.7	-156480.4
Zero	4577	12252	12851	12851	12851	12851
APPROACH 3						
k	584	312	320		98	98
AIC	561693.5	310930.3	546894.0		571861.5	315879.8
LogLik	-280470.8	-155164.1	-273127.0	-	-285832.7	-157840.9
Zero	4494	12363	12865		12851	12851
APPROACH 4						
(1)						
k	596	175	112		112	90
AIC	435109.7	219134.5	412576.0		412651.2	220242.5
LogLik	-217232.8	-109407.3	-206176.2	-	-206213.6	-110030.3
Zero	3676.0	11531	11182		11200	11200
(2)						
k	137	76	62	40	76	62
AIC	120899.1	89086.69	123671.2	88748.0	122505.6	88178.9
LogLik	-60342.56	-44474.34	-61773.61	-44333.01	-61176.82	-44026.48
Zero	948	1172	1672.00	1757	1651	1651

– algorithm did not converge.

Table 3. Estimations of parameters for the model fitted in approach 1. Only the significant estimations ($\alpha > 0.05$) are showed.

	Estimate	Std. Error	t value	Pr(>|t|)
(Intercept)	-6,00856	0,274392	-21,8977	7,29E-106
flagBRA-BLZ	-1,3013	0,136689	-9,52015	1,79E-21
flagBRA-CAN	-0,76341	0,184485	-4,13804	3,51E-05
flagBRA-ESP	0,128932	0,053808	2,396137	0,016572
flagBRA-GUY	-3,76455	0,718416	-5,24008	1,61E-07
flagBRA-HND	-0,55397	0,088271	-6,27578	3,50E-10
flagBRA-JPN	-1,25165	0,088071	-14,2119	9,21E-46
flagBRA-PAN	-1,93355	0,08284	-23,3407	6,08E-120
flagBRA-PRT	-0,62073	0,149109	-4,16293	3,15E-05
flagBRA-TAI	-1,2669	0,076958	-16,4622	9,40E-61
flagBRA-VCT	-1,82941	0,065384	-27,9796	3,90E-171
year1982	3,036865	0,573283	5,297319	1,18E-07
year1984	1,635494	0,598069	2,734625	0,006247
year1985	2,195295	0,591932	3,708694	0,000209
year1987	1,138805	0,383916	2,966287	0,003015
year1988	1,360859	0,320063	4,251845	2,12E-05
year1989	0,876515	0,341929	2,563445	0,010366
year1991	3,188596	0,391501	8,144539	3,88E-16
year1994	-0,97022	0,381463	-2,54342	0,01098
year1998	2,180172	0,303598	7,181104	7,00E-13
year2000	0,633151	0,280387	2,258129	0,023941
year2001	1,725334	0,280811	6,144116	8,09E-10
year2004	1,585956	0,315602	5,025175	5,04E-07
year2005	1,401994	0,301164	4,655245	3,24E-06
year2006	1,426046	0,308294	4,625601	3,74E-06
year2009	-1,19127	0,473874	-2,51389	0,011943
year2011	1,506619	0,306078	4,922344	8,57E-07
year2012	2,243325	0,305042	7,354156	1,95E-13
hpb2	0,156096	0,030462	5,124192	3,00E-07
areaC	1,067587	0,485993	2,196713	0,028045
quart2	0,550718	0,262316	2,099446	0,035782
year1981:hpb2	-0,1749	0,060904	-2,87178	0,004083
year1982:hpb2	-0,40233	0,097318	-4,13418	3,57E-05
year1984:hpb2	-0,19417	0,051427	-3,77569	0,00016
year1985:hpb2	-0,16372	0,059027	-2,77367	0,005545
year1986:hpb2	-0,10271	0,03924	-2,61744	0,008862
year1987:hpb2	-0,17911	0,039332	-4,55375	5,28E-06
year1988:hpb2	-0,16176	0,033628	-4,8102	1,51E-06
year1990:hpb2	-0,22333	0,112474	-1,98565	0,047076
year1991:hpb2	-0,34211	0,041118	-8,3202	8,97E-17
year1992:hpb2	-0,16075	0,041057	-3,91522	9,04E-05
year1994:hpb2	-0,07325	0,036056	-2,03161	0,042197
year1995:hpb2	-0,11045	0,0314	-3,51747	0,000436
year1996:hpb2	-0,14404	0,032122	-4,48415	7,33E-06

year1997:hpb2	-0,11446	0,031152	-3,67421	0,000239
year1998:hpb2	-0,27873	0,031811	-8,76224	1,96E-18
year1999:hpb2	-0,08291	0,030597	-2,70966	0,006737
year2000:hpb2	-0,10344	0,030293	-3,41477	0,000639
year2001:hpb2	-0,29514	0,030445	-9,69421	3,32E-22
year2002:hpb2	-0,14919	0,032099	-4,64793	3,36E-06
year2004:hpb2	-0,29527	0,036188	-8,15928	3,44E-16
year2005:hpb2	-0,30421	0,035355	-8,60462	7,84E-18
year2006:hpb2	-0,11684	0,036473	-3,20336	0,001359
year2007:hpb2	0,182095	0,064649	2,816663	0,004854
year2009:hpb2	0,271092	0,076376	3,549453	0,000386
year2011:hpb2	-0,20582	0,031531	-6,52764	6,74E-11
year2012:hpb2	-0,26401	0,032468	-8,13154	4,32E-16
year1996:areaC	-2,11184	0,547363	-3,8582	0,000114
year1998:areaC	-2,35439	0,533483	-4,41325	1,02E-05
year2001:areaC	-1,1424	0,493571	-2,31457	0,02064
year2002:areaC	-1,07751	0,508462	-2,11915	0,034082
year2007:areaC	-1,35103	0,505486	-2,67273	0,007526
year1989:areaS	-1,26971	0,29498	-4,30437	1,68E-05
year1993:areaS	-2,91706	0,776219	-3,75804	0,000171
year1994:areaS	-1,74694	0,306276	-5,70379	1,18E-08
year1995:areaS	-0,73951	0,292865	-2,52508	0,01157
year2001:areaS	-1,42059	0,281301	-5,05008	4,43E-07
year2005:areaS	0,556247	0,281716	1,974493	0,04833
year2006:areaS	-0,85516	0,284125	-3,00981	0,002615
year2011:areaS	-1,39804	0,314108	-4,45084	8,57E-06
year1981:quart2	1,76197	0,421666	4,178595	2,94E-05
year1988:quart2	-0,88369	0,280219	-3,15359	0,001614
year1989:quart2	-0,59918	0,28732	-2,0854	0,037037
year1990:quart2	-1,21192	0,426476	-2,84172	0,004489
year1991:quart2	-0,91605	0,318715	-2,87419	0,004052
year1994:quart2	1,642607	0,319817	5,136081	2,81E-07
year1999:quart2	-0,77545	0,270582	-2,86587	0,00416
year2000:quart2	-0,83146	0,266873	-3,11556	0,001837
year2001:quart2	-0,53221	0,267309	-1,99098	0,046487
year1979:quart3	1,053057	0,346736	3,037052	0,00239
year1981:quart3	1,939298	0,419303	4,625053	3,75E-06
year1985:quart3	-0,90327	0,358151	-2,52204	0,01167
year1986:quart3	0,698259	0,297075	2,350448	0,018754
year1992:quart3	1,359655	0,348064	3,906332	9,38E-05
year1994:quart3	2,723077	0,339142	8,029304	9,98E-16
year1995:quart3	0,630802	0,305609	2,064077	0,039015
year1996:quart3	1,227632	0,336867	3,644259	0,000268
year1997:quart3	1,393304	0,306744	4,542236	5,58E-06
year2002:quart3	0,844491	0,303241	2,78488	0,005356
year2004:quart3	0,705092	0,303983	2,319513	0,020371
year2005:quart3	0,819563	0,28614	2,864207	0,004182

year2006:quart3	0,927531	0,290491	3,19298	0,001409
year2009:quart3	0,785828	0,296012	2,654717	0,00794
year2011:quart3	1,254901	0,302073	4,154294	3,27E-05
year1979:quart4	0,916021	0,371399	2,466405	0,013651
year1981:quart4	1,714719	0,43527	3,939436	8,18E-05
year1983:quart4	0,762891	0,356887	2,137626	0,032551
year1984:quart4	1,050614	0,358456	2,930945	0,003381
year1986:quart4	1,337518	0,316347	4,228011	2,36E-05
year1990:quart4	0,845293	0,41167	2,053325	0,040046
year1992:quart4	1,172663	0,327147	3,584512	0,000338
year1993:quart4	1,683531	0,648291	2,596874	0,00941
year1994:quart4	2,309443	0,332543	6,944792	3,83E-12
year1995:quart4	0,769561	0,316721	2,429774	0,015111
year1996:quart4	1,175368	0,347076	3,386484	0,000708
year1997:quart4	1,42309	0,323689	4,39647	1,10E-05
year1999:quart4	0,77804	0,301347	2,581872	0,009829
year2000:quart4	1,281623	0,299165	4,283995	1,84E-05
year2001:quart4	0,715872	0,299989	2,386328	0,017021
year2002:quart4	0,850723	0,322095	2,641218	0,008263
year2004:quart4	1,392232	0,323148	4,308341	1,65E-05
year2005:quart4	1,646865	0,30565	5,388076	7,15E-08
year2006:quart4	1,24733	0,309064	4,035835	5,45E-05
year2008:quart4	1,008538	0,396832	2,541471	0,011041
year2009:quart4	1,166855	0,326269	3,576363	0,000349
year2010:quart4	0,828962	0,391548	2,117138	0,034252
year2011:quart4	1,140455	0,319953	3,564445	0,000365
hpb2:areaC	-0,05525	0,015182	-3,63927	0,000274
hpb2:areaS	-0,03804	0,010776	-3,52966	0,000416
hpb2:quart2	-0,02928	0,010561	-2,77241	0,005566
hpb2:quart3	-0,02528	0,010532	-2,40056	0,016373
hpb2:quart4	-0,05976	0,009442	-6,32916	2,48E-10
areaC:quart2	-0,26361	0,062226	-4,23641	2,27E-05
areaC:quart3	-0,47987	0,077244	-6,21248	5,25E-10
areaS:quart3	0,328385	0,073599	4,461829	8,14E-06
flagBRA-ESP:areaC	0,313416	0,083498	3,753573	0,000175
flagBRA-KOR:areaC	2,005492	0,65688	3,053058	0,002266
flagBRA-PAN:areaC	2,257999	0,151191	14,93474	2,43E-50
flagBRA-PRT:areaC	0,659531	0,149562	4,409753	1,04E-05
flagBRA-USA:areaC	1,771357	0,225685	7,84879	4,27E-15
flagBRA-BLZ:areaS	1,193845	0,183456	6,507526	7,70E-11
flagBRA-HND:areaS	0,636322	0,130216	4,886677	1,03E-06
flagBRA-JPN:areaS	1,281439	0,091293	14,0366	1,10E-44
flagBRA-KOR:areaS	3,282957	0,301224	10,89873	1,24E-27
flagBRA-PAN:areaS	2,852812	0,235859	12,09541	1,23E-33
flagBRA-PRT:areaS	0,802147	0,254607	3,150531	0,001631
flagBRA-TAI:areaS	0,413379	0,125301	3,299097	0,000971
flagBRA-USA:areaS	0,939418	0,39379	2,385578	0,017055

flagBRA-JPN:quart2	-0,28253	0,107326	-2,6324	0,008481
flagBRA-KOR:quart2	-2,17838	0,300449	-7,25041	4,21E-13
flagBRA-PAN:quart2	0,578158	0,110638	5,225658	1,74E-07
flagBRA-PRT:quart2	0,718096	0,167042	4,298891	1,72E-05
flagBRA-TAI:quart2	0,313382	0,13939	2,248235	0,024565
flagBRA-URY:quart2	0,609552	0,181056	3,366651	0,000761
flagBRA-USA:quart2	0,514003	0,197044	2,608573	0,009094
flagBRA-BLZ:quart3	-0,42663	0,193717	-2,20234	0,027645
flagBRA-ISL:quart3	-1,0124	0,401217	-2,52334	0,011627
flagBRA-KOR:quart3	-2,00899	0,29578	-6,79215	1,12E-11
flagBRA-PAN:quart3	0,56347	0,106323	5,299587	1,16E-07
flagBRA-PRT:quart3	1,049954	0,176797	5,938748	2,89E-09
flagBRA-TAI:quart3	0,545968	0,124015	4,402436	1,07E-05
flagBRA-VCT:quart3	0,432725	0,12568	3,443063	0,000576
flagBRA-CAN:quart4	-0,86217	0,341398	-2,52541	0,011559
flagBRA-ESP:quart4	-0,41269	0,072404	-5,69983	1,20E-08
flagBRA-HND:quart4	-0,32906	0,131397	-2,50434	0,012271
flagBRA-JPN:quart4	0,330684	0,102457	3,227523	0,001249
flagBRA-KOR:quart4	-1,51352	0,295213	-5,12687	2,96E-07
flagBRA-MAR:quart4	-0,45995	0,178139	-2,58195	0,009827
flagBRA-PAN:quart4	-0,61539	0,112407	-5,47468	4,40E-08
flagBRA-PRT:quart4	0,51956	0,217304	2,390941	0,016808
flagBRA-URY:quart4	-0,47638	0,176166	-2,70417	0,00685
flagBRA-USA:quart4	0,664614	0,239142	2,779159	0,005452

Table 4. Standardized CPUEs estimated for South Atlantic swordfish.

	Approach 1		Approach 2		Approach 3		Approach 4	
Year	Index	Scaled index	Index	Scaled index	Index	Scaled index	Index	Scaled index
1978	11.23	1.01	7.44	0.69	4.54	0.85	2.95	0.73
1979	7.57	0.68	5.96	0.55	3.33	0.63	2.43	0.60
1980	12.29	1.10	12.24	1.13	5.67	1.07	4.04	1.00
1981	15.99	1.43	15.54	1.43	6.90	1.30	5.72	1.41
1982	11.02	0.99	18.47	1.70	4.46	0.84	6.23	1.53
1983	12.70	1.14	10.48	0.97	6.03	1.13	3.62	0.89
1984	5.35	0.48	5.08	0.47	2.71	0.51	2.34	0.58
1985	12.02	1.08	8.68	0.80	4.87	0.91	2.97	0.73
1986	13.46	1.21	9.46	0.87	5.44	1.02	3.70	0.91
1987	10.22	0.91	10.55	0.97	6.05	1.14	6.43	1.58
1988	7.17	0.64	7.28	0.67	3.35	0.63	3.19	0.79
1989	6.62	0.59	3.76	0.35	3.07	0.58	1.91	0.47
1990	10.32	0.92	7.76	0.72	4.25	0.80	4.17	1.03
1991	10.75	0.96	6.46	0.60	5.20	0.98	3.86	0.95
1992	5.41	0.48	4.56	0.42	2.88	0.54	3.81	0.94
1993	8.02	0.72	4.75	0.44	2.89	0.54	1.68	0.41
1994	11.36	1.02	8.31	0.77	6.01	1.13	3.10	0.76
1995	4.37	0.39	4.23	0.39	2.63	0.49	5.28	1.30
1996	4.24	0.38	2.81	0.26	4.13	0.78	6.34	1.56
1997	6.17	0.55	3.01	0.28	3.19	0.60	4.15	1.02
1998	4.79	0.43	2.38	0.22	2.83	0.53	2.67	0.66
1999	5.72	0.51	3.40	0.31	3.14	0.59	3.60	0.89
2000	8.36	0.75	4.33	0.40	4.31	0.81	4.98	1.23
2001	3.09	0.28	2.45	0.23	1.58	0.30	2.19	0.54
2002	5.22	0.47	2.74	0.25	2.87	0.54	4.07	1.00
2003	19.50	1.75	6.18	0.57	6.90	1.30	7.26	1.79
2004	8.13	0.73	6.32	0.58	3.98	0.75	6.97	1.71
2005	10.25	0.92	9.71	0.89	4.97	0.93	9.02	0.82
2006	15.37	1.38	11.68	1.08	8.12	1.52	11.00	1.01
2007	30.12	2.70	36.15	3.33	16.36	3.07	13.20	1.21
2008	21.97	1.97	29.71	2.74	9.96	1.87	10.69	0.98
2009	27.51	2.46	33.03	3.04	13.72	2.58	11.96	1.09
2010	22.37	2.00	49.88	4.60	9.98	1.88	12.12	1.11
2011	10.95	0.98	11.92	1.10	4.83	0.91	9.19	0.84
2012	11.25	1.01	13.20	1.22	5.18	0.97	10.34	0.95

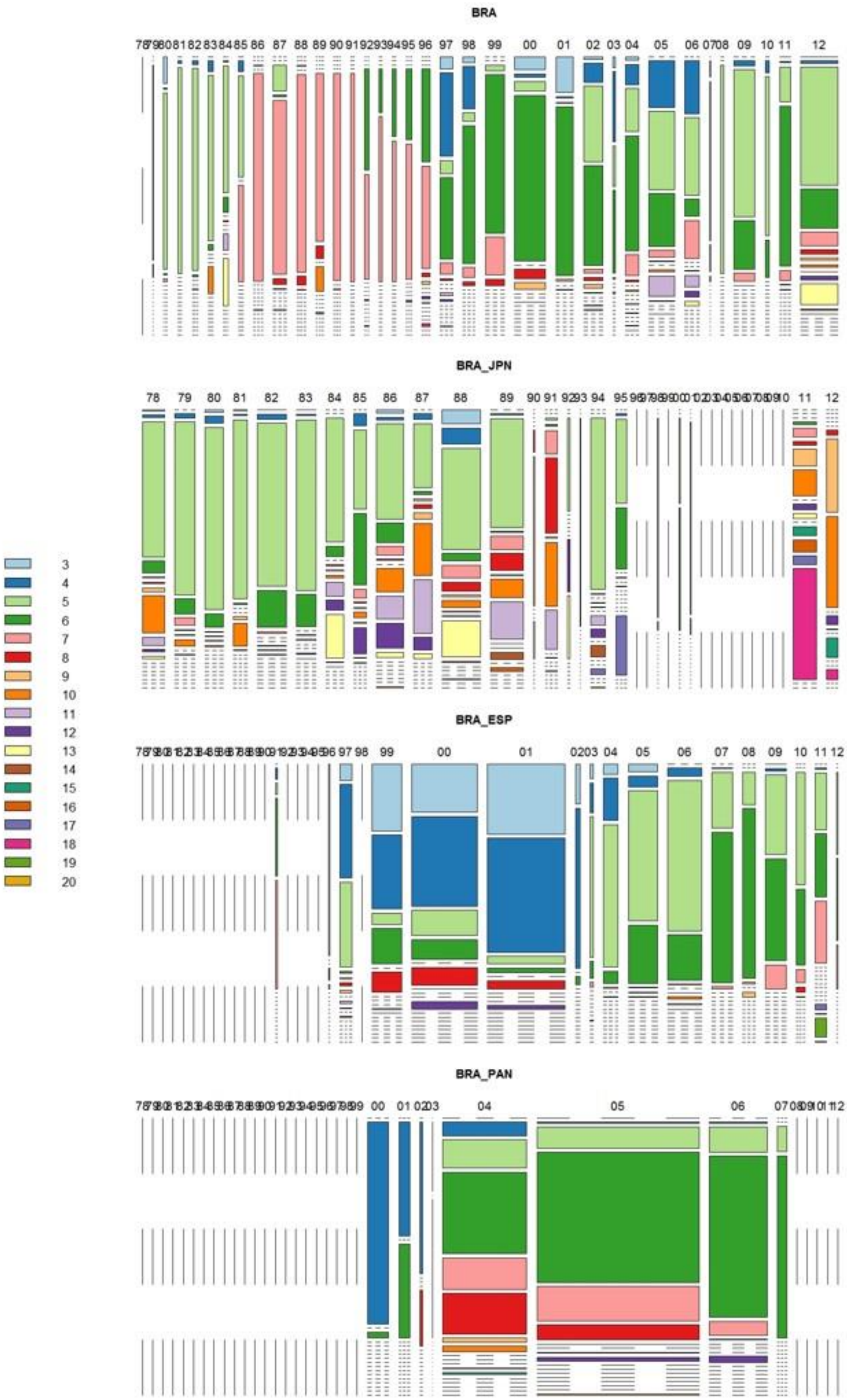

Figure 1. Mosaicplots for year (1978-2012) and number of hooks per basket (HPB). National boats (BRA), boats leased from Japan (BRA_JPN), Spain (BRA_ESP), and Panama (BRA_PAN). Colors stand for the different number of hooks.

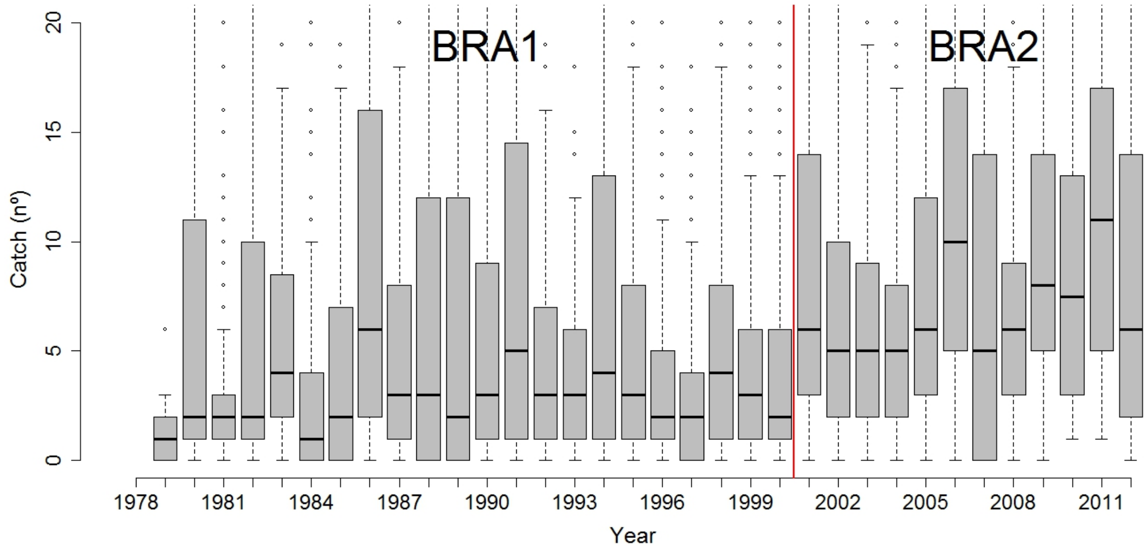

Figure 2. Catch per fishing of national boats. Vertical red line stands for the change of phase concerning fishermen target.

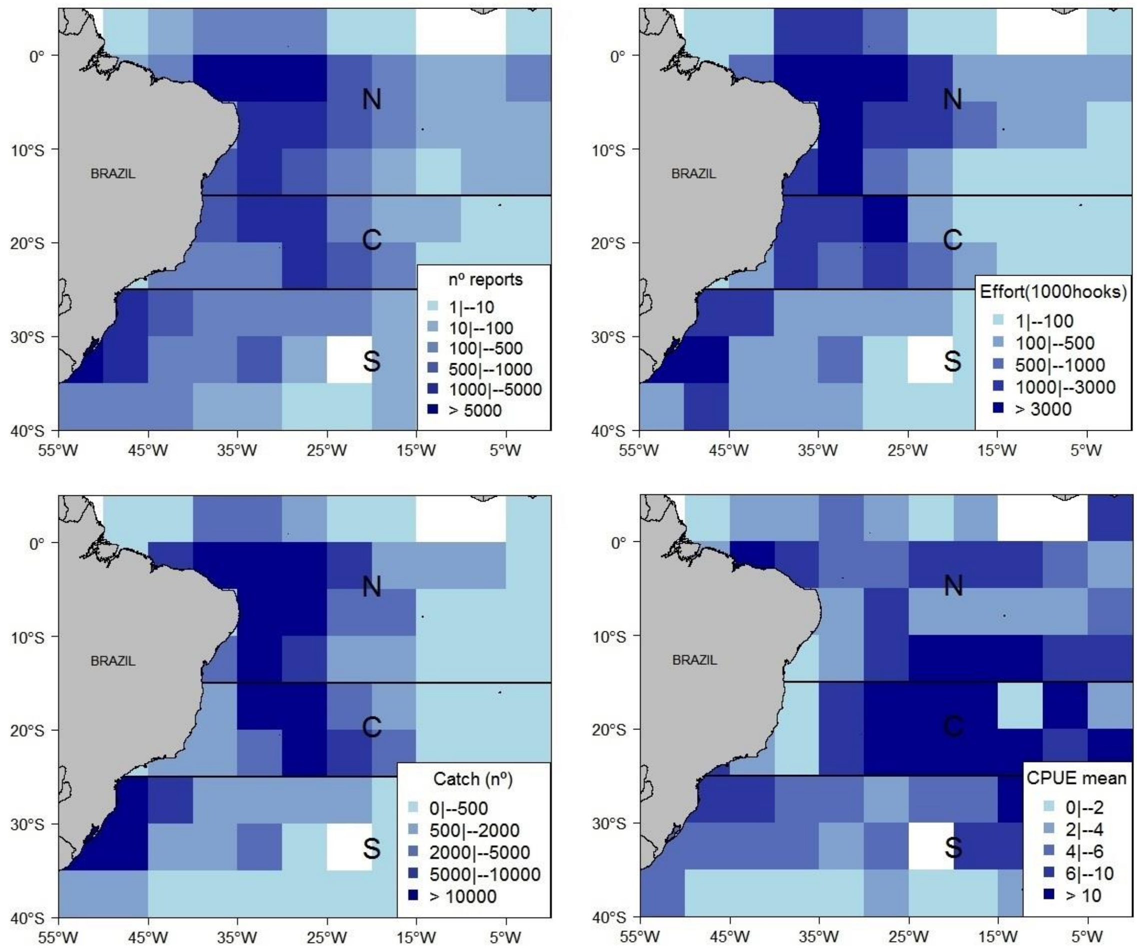

Figure 3. Number of fishing sets, fishing effort, catch of swordfish and the average of catch per unit effort (CPUE) (nº/1000 hooks). All data (1978-2012) were aggregated.

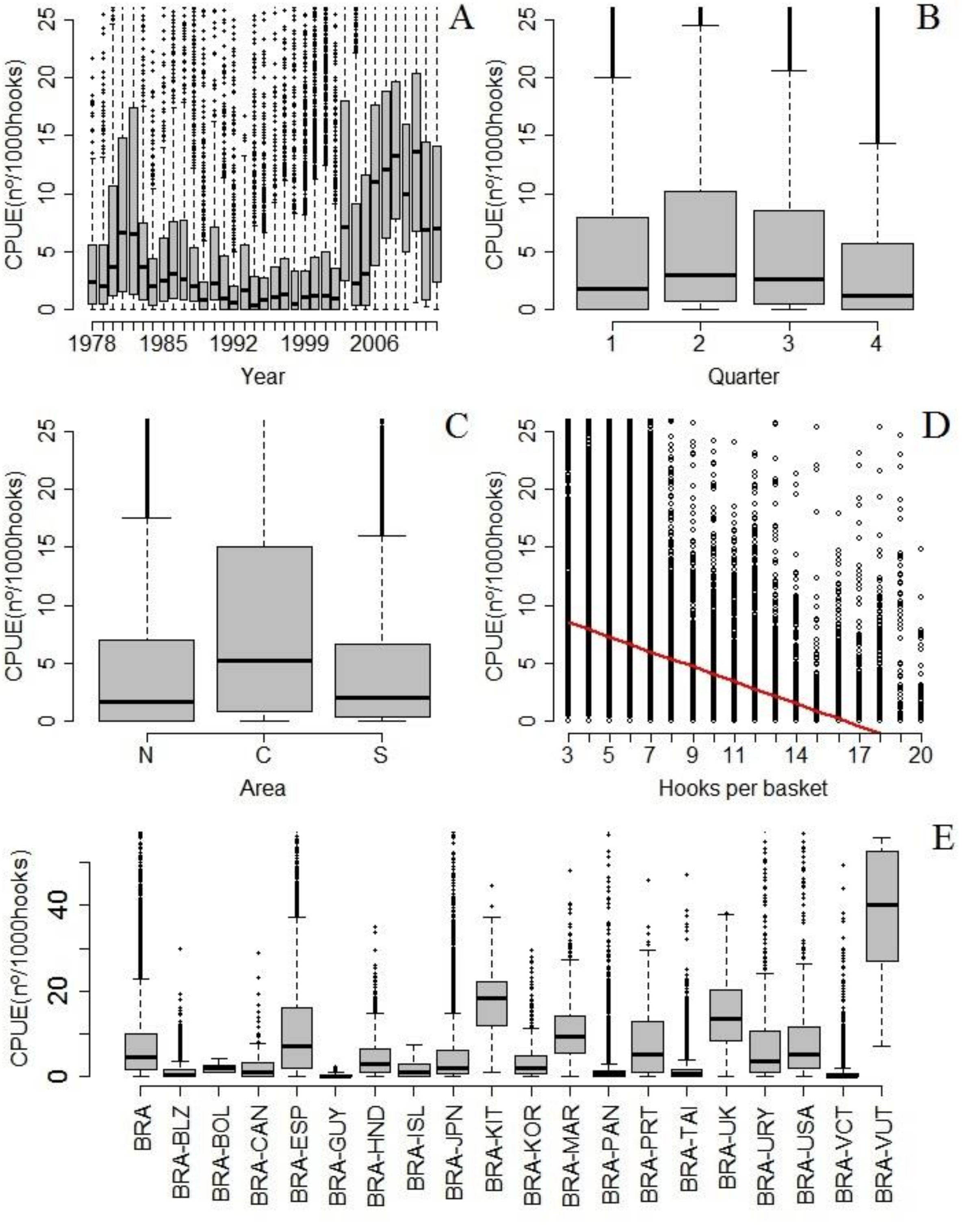

Figure 4. Relationships between catch per unit effort (CPUE) (nº / 1000 hooks) and: Year (A), Quarter (B), Area (C), Hooks per basket (D) and Flag (E).

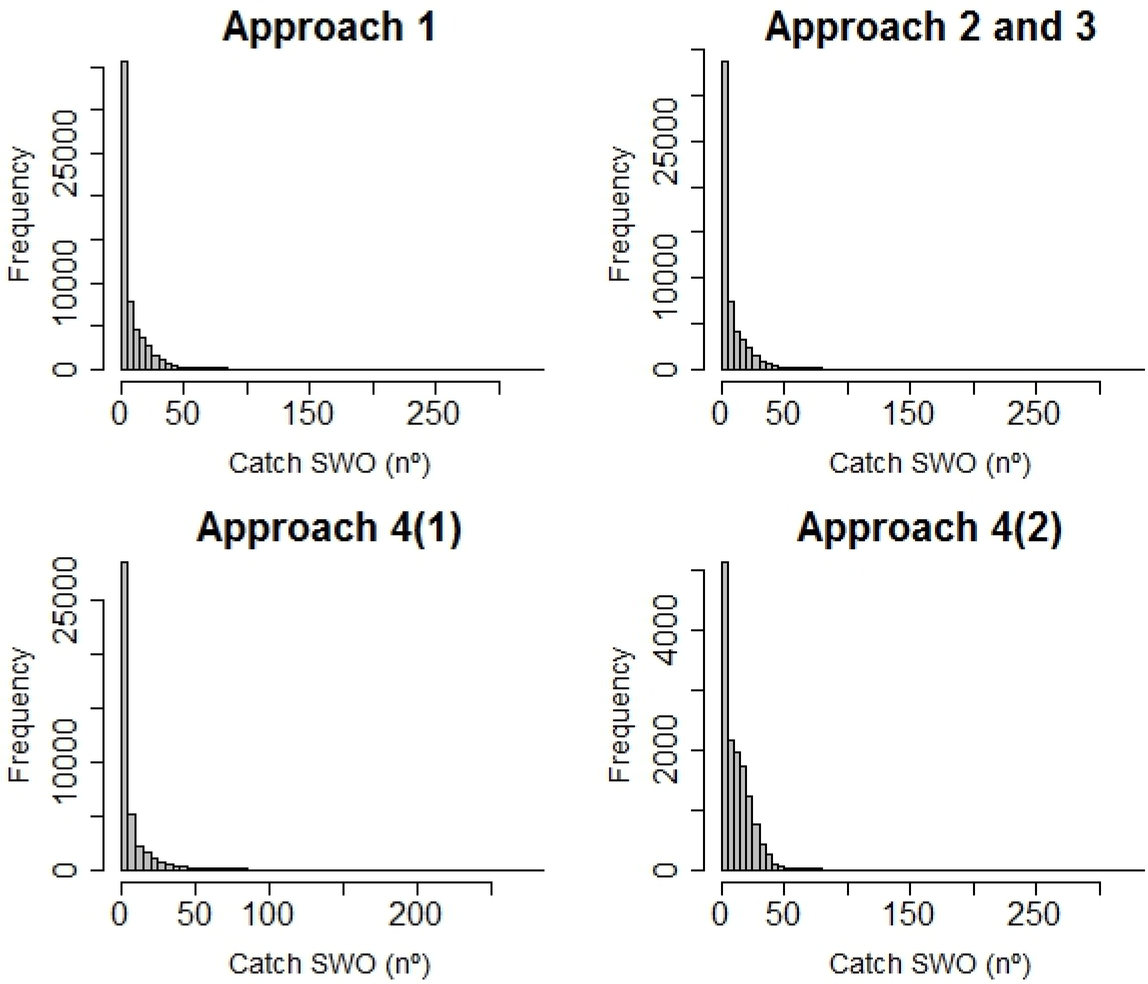

Figure 5. Frequency distributions of catches (number of fish).

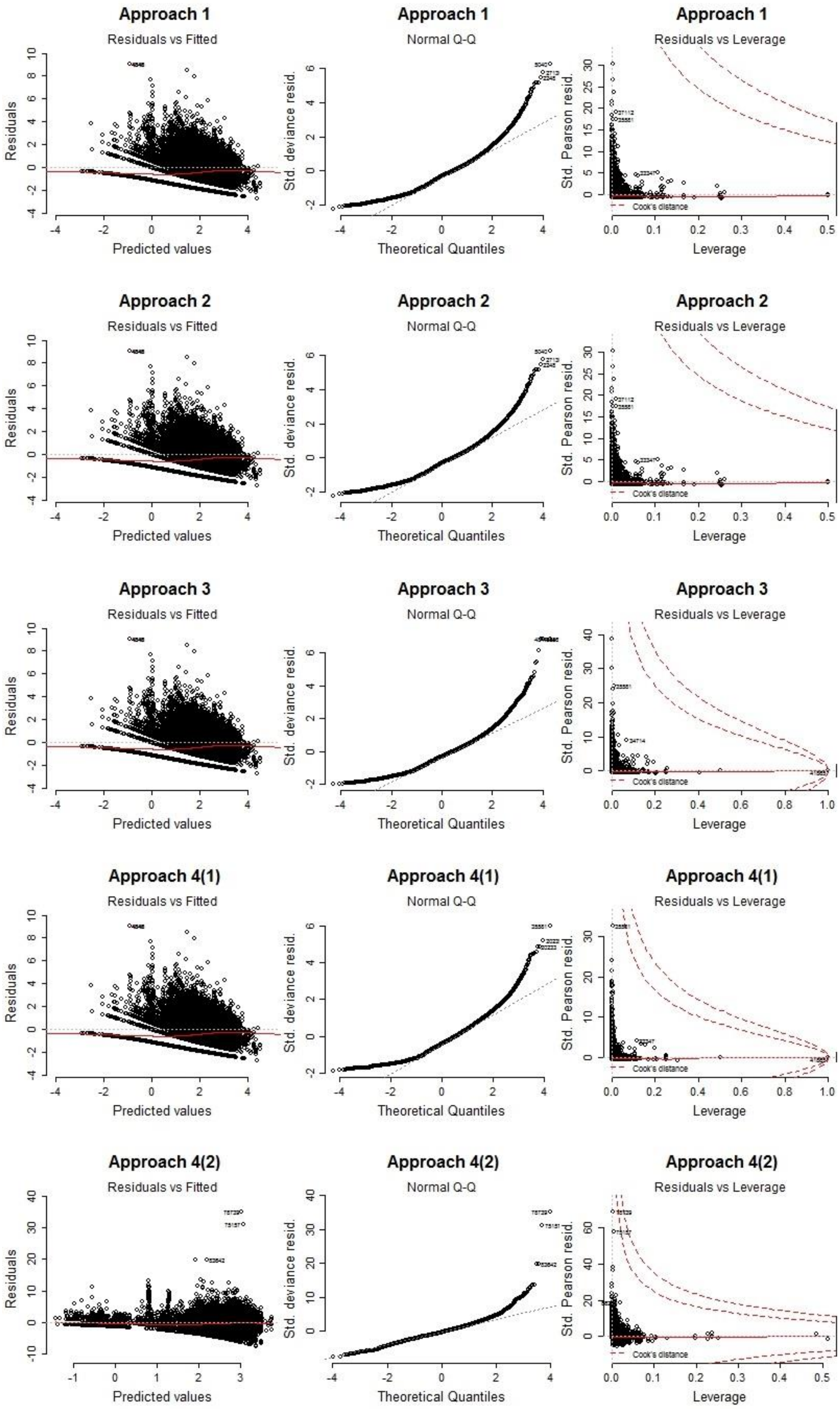

Figure 6. Residual diagnostics of models fitted following the approaches 1, 2, 3 and 4.

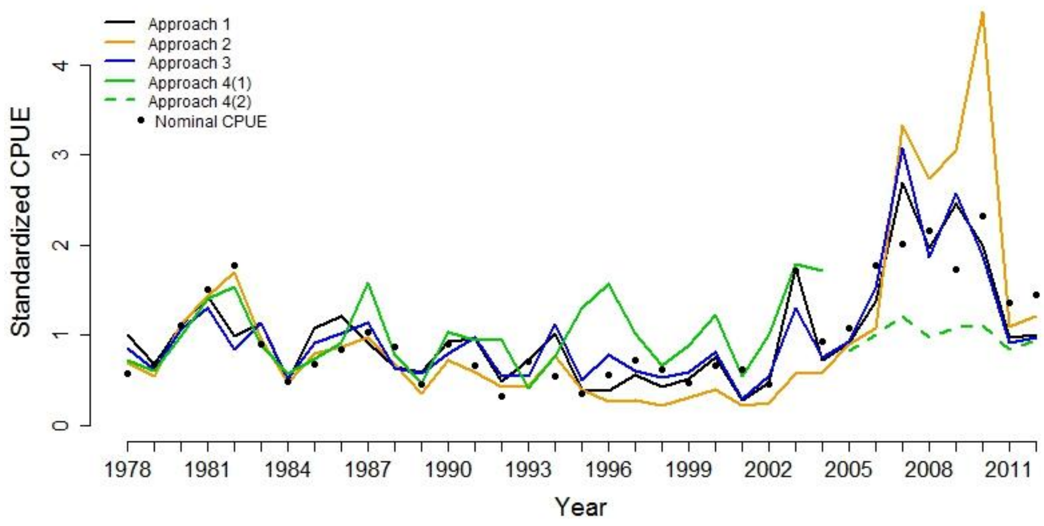

Figure 7. Standardized CPUE as calculated following approaches 1, 2, 3 and 4. Points stand for the nominal CPUE.

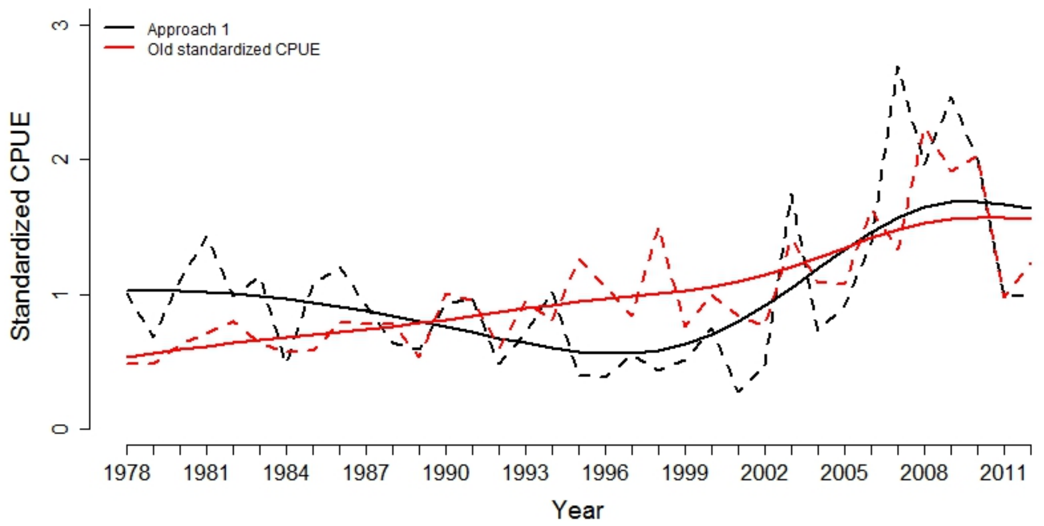

Figura 8. Comparison between the standardized CPUE as calculated in this paper and in 2013.

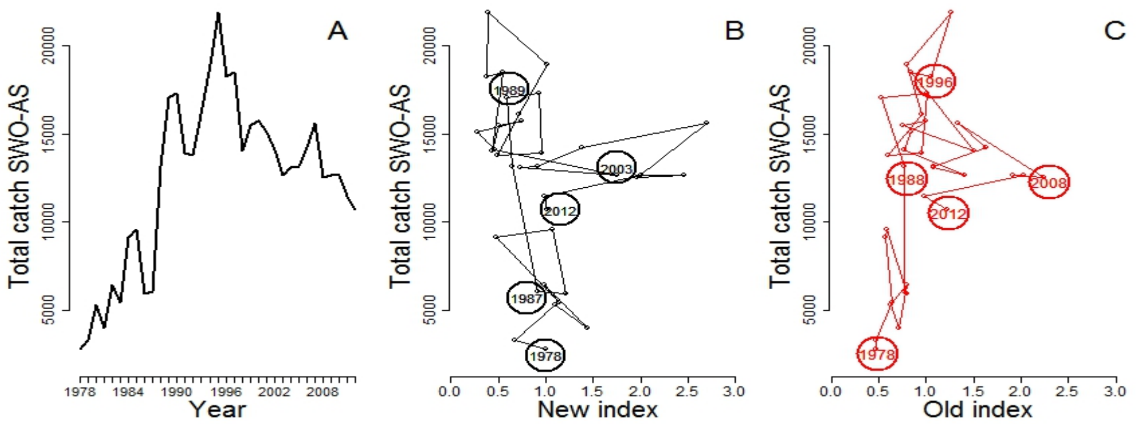

Figure 9. Total catch of South Atlantic swordfish (extracted from Task I ICCAT) (A), and relationships between total catch and standardized CPUEs as calculated in this paper (B) and in 2013 (C).