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STANDARDIZED CATCH RATES FOR SKIPJACK TUNA CAUGHT BY FRENCH AND SPAIN PURSE SEINE IN THE EAST ATLANTIC BETWEEN 10º N AND 10º S

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SUMMARY

In this study standardized catch rates of skipjack caught by French and Spanish purse-seines were calculated using a delta-lognormal generalized linear model for 1991-2012. Task II catch and effort data by month, 1ºx1º square, fleet and fishing mode (FAD and free school) were used in the analysis. The explanatory variables year, month, area, fleet (French or Spain) and the type of fishery (on free school or on FAD) proved to be important to explain the variability of the catch per unit effort. Months where closures occurred (Nov-Feb) were removed from the entire time series for the final model, though results were not substantively different when these months were included. Overall variability of the standardized index was relatively low. There was a slight decreasing trend until 1997, followed by an increase until 2005, and then a slight decrease in 2012. If we rely in these indices, the conclusion would be that the biomass of skipjack has not shown variability but no long-term trend.

RÉSUMÉ

Dans cette étude, les taux de capture standardisés du listao capturé par les senneurs français et espagnols ont été calculés à l'aide d'un modèle linéaire généralisé delta-lognormal pour la période 1991-2012. Des données de prise et d'effort de la tâche II par mois, carré de 1ºx1º, flottille et mode de pêche (DCP et bancs libres) ont été utilisées dans l'analyse. Les variables explicatives année, mois, zone, flottille (française ou espagnole) et le type de pêcherie (sur bancs libres ou sous DCP) se sont avérées importantes pour expliquer la variabilité de la capture par unité d'effort. Les mois où des fermetures sont survenues (nov.-fév.) ont été supprimés de toute la série temporelle pour le modèle final, même si les résultats n'ont pas considérablement différé lorsque ces mois ont été inclus. La variabilité globale de l'indice standardisé était relativement faible. Une légère tendance décroissante s'est dégagée jusqu'en 1997, suivie d'une augmentation jusqu'en 2005, puis d'une légère diminution en 2012. Si nous nous fions à ces indices, la conclusion à en tirer serait que la biomasse du listao n'a pas dégagé de variabilité ni de tendance à long terme.

RESUMEN

En este estudio se calcularon las tasas de captura estandarizadas de listado capturado por los cerqueros franceses y españoles utilizando un modelo lineal generalizado delta-lognormal para 1991-2012. En este análisis se utilizaron los datos de captura y esfuerzo de Tarea II por mes, cuadrículas de 1ºx1º, flota y modo de pesca (DCP y banco libre). Las variables explicativas año, mes, zona, flota (francesa o española) y el tipo de pesquería (en bancos libres o en DCP) demostraron ser importantes para explicar la variabilidad de la captura por unidad de esfuerzo. Los meses en los que había vedas (noviembre-febrero) se eliminaron de toda la serie temporal para el modelo final, aunque los resultados no fueron sustancialmente diferentes cuando estos meses se incluyeron. La variabilidad general del índice estandarizado fue relativamente pequeña. Se observó una tendencia ligeramente decreciente hasta 1997, seguida de un incremento hasta 2005 y luego un ligero descenso hasta 2012. Si confiamos en estos índices, la conclusión sería que la biomasa del listado no ha mostrado variabilidad ni una tendencia a largo plazo.

KEYWORDS

Catch/effort, Purse seine, Skipjack tuna, Fish aggregating devices

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1. Introduction

Standardized catch rates are often used as relative abundance indices in stock assessment models. In most of the papers the relationship between catch rates (catch in weight or number /fishing effort) (I) and biomass (B) is assumed to be linear across time (t) $[I_t = qB_t]$ (Hilborn and Walters, 1992) where q is the catchability or fraction of the population captured by a unit of fishing effort.. The above equation is useful if the coefficient of catchability (q) is constant. However in the case of the European and associated purse seine fleets and, in particular, in the case of skipjack, this assumption is highly unlikely due to the characteristics of this species and of this fishery with different factors affecting q (*e.g.* changing fishing area, season, increasing capture efficiency, changing fishing practices, etc). To account for the effect of various factors altering q, catch rates have often been treated through a process of statistical standardization Hence calculations are necessary to estimate a modified catch rate index (I_t^*) that reflect B_t only.

To obtain I_t^* many approaches have been used. One alternative is to model I_t as the response of "year" and other explanatory variables (*e.g.* fishing area) using a generalized linear model (GLM) (Maunder and Punt, 2004). Ideally estimations of the parameters concerning "year" reflect the variations of B_t, hence those estimations are the relative abundance indices (I_t^*), which are usually denominated "standardized catch rates". On the other hand, the estimations of parameters for the other explanatory variables concerns the variations of q . This approach works out if all factors changing q across the years are included in the model.

The primary gear, by volume captured, used to capture skipjack is the purse seine. Particularly for skipjack there is a strong interest in developing CPUE indices from the primary capture fisheries. Historically purse seine fishing gear has proven to be a notoriously difficult gear to develop reliable indices of relative abundance. This is due to the complicating factor of search time, the fact that sets generally only occur when sufficient quantities of fish are detected and due to the adoption of technological advances such as sonar, radar, GPS technology more efficient methods of setting and hauling and, notably, increased use of fish aggregating devices (FADs) that increase detection or capture efficiency over time. After the extension of the use of FADs in the 90s more than the 95% of the skipjack catches in the eastern Atlantic are made on FADs. This FAD fishery has been managed since 1997 by different time-area closures.

The characteristics of the purse seine fleets fishing skipjack in the eastern Atlantic make it difficult to isolate the year effect from other effects affecting *q*. The increase in the fishing power of the European and associated fleets has been widely discussed by the SCRS and several approaches to estimate the increase in q for these fleets have been submitted to the SCRS in the past. However, the quick and continuous introduction of new technology in the vessels since the 80s makes it difficult to identify the single effects of the different technological components. On this issue, the introduction of the fish attractive devices (FADs) in the early 90s and all the technology supporting this fishing mode, together with other components mainly targeted to improve the searching capacity of the vessels as well as the fishing operation, have made fishing days far from being an appropriate effort unit and have made it difficult to find a consistent unit of effort. For these reasons, the nominal Task II catch and effort data have not considered a good approach to obtain relative abundance indices for these fleets. However, considering that the main skipjack catches in the eastern Atlantic come from the purse seine fleets and taking into account that Task II data were the only data available; an attempt was made to standardize purse seine catch rates.

This paper presents an attempt to overcome some of the technical difficulties of purse seine gear to develop standardized indices of skipjack CPUE for the European and associated purse seine flees in the Gulf of Guinea in the Eastern Atlantic Ocean. The key contribution of the paper is that it uses catch and effort partitioned by FAD or free school to account for the shift towards use of FADs. Then this paper uses catch and fishing effort by mode measured in hours fished to develop standardized indices of purse seine CPUE for skipjack tuna.

2. Database and analysis

2.1 Databases

The primary database used in this analysis is the ICCAT task II catch and effort database which documents the catch by fishing mode for purse seine vessels by year, month, flag and 1 x1 degree squares (48,321 records from 1991-2013). The European and associated purse seine Task II catch and effort data, in addition to the ICCAT strata requested for statistics includes the fishing mode, FADs and free school. The second database used was the EU purse seine observer database where onboard observers recorded catch and effort by fishing mode on purse seine vessels.

Catch and effort was assigned to one of six different spatial areas: SENEGAL, NortePICCOLO1, PICCOLO, SurEcuador, CaboLopez, NorEsteEcuador (**Figure 1**) corresponding to the sampling strata used by the European and associated fleets for the catch on FADs. Only FleetCodes identified as EU.ESP-ES-ETRO and EU.FRA-FR-ETRO were used in the analysis as these were the only two fleets that have catch recorded in the database in every year from 1991-2012.

Information on price of skipjack was used as a potential explanatory factor in the statistical standardization. Given the increase in price of skipjack in recent years there may be increased targeting of this species. Price data was obtained from Bangkok market data (ICCAT 2014 b) and was corrected for inflation to 2013 U.S. dollars.

2.2 Defining units of effort

One of the more problematic issues in using purse seine data is to develop a standardized unit of catch and effort. In this paper we use fishing hours (fishing days/24) as the unit of effort as it was assumed to encompass the searching, setting and retrieval process. This is in contrast to the total time at sea which could have been used or some other unit of effort. It remains an unresolved issue which is the best metric of purse seine effort.

2.3 Partitioning effort by mode

Considering that purse seine effort in the ICCAT database is not separated by fishing mode, the method used by the SCRS in a previous analysis was used to partition effort by fishing mode (ICCAT 2014b, Appendix 7). A major challenge to inferring abundance patterns is separating fishing effort between FAD and free school fishing. The criteria used to split the purse seine fishing effort by fishing mode is based on observer data. Two variables were considered in the estimation: a) the proportion of time used to handle FADs vs time spend searching for free schools, b) the proportion of time devoted to making sets including both null sets and sets with catch. Estimation of effort was made by fleet (France and Spain) and fishing mode (Gaertner *et al*., 2000).

The method used to split the searching days by fishing mode was as follows:

1. Squares without catch: When there is no catch in the square, 3% of total effort is assigned to FAD and 97% to free school. These percentages have been obtained from observer data detailing the proportion of fishing by mode. The percentages mean that the boat is continuously searching for schools even when the boat is sailing towards a FAD and only a low percentage of the daily time is spend in FAD operations.

2. Squares with catch: The separation of effort by fishing mode is done applying the proportion of time spent in making the sets under each fishing mode:

   Fishing_effort_FAD = total_fishing_effort* (FAD set duration/(FAD set duration+ Free school set duration)

The use of the duration of the sets instead of other alternative methods such as the catch rate has been decided to take into account both the total amount of catch as well as the time spend in making the null sets.

The duration of the sets by mode obtained as a function of the total catch delineated by mode. Empirical data related to the set duration and the catch used to estimate regressions comes from observer data. Observers record the duration of the set from the beginning (when the “panga”, auxiliary boat to pull the net, is put in the water) to the end (when the “panga” is recovered). For the null sets, the duration is calculated as the median value of the distribution of the duration of the null sets in the observer data. Calculation of the duration of null sets is separated for FAD and Free school. For positive sets (Capture > 0,9 t), the duration is estimated by the following relationship as a function of the total catch delineated by mode. Observers record the duration of the set from the beginning (when the “panga”, auxiliary boat to pull the net, is put in the water) to the end (when the “panga” is recovered).

For the null sets, the duration is calculated as the median value of the distribution of the duration of the null sets in the observer data. Calculation of the duration of null sets is separated for FAD and Free school.

2.4 Statistical standardization of CPUE

Explanatory variables evaluated in the model included the year, area, month and fishing mode and skipjack price.

The six areas used in the model are shown in **Figure 1**. The fishing mode, FAD or Free-school, is delineated in the ICCAT task II database. The dependent variable was the skipjack catch on FADs in kilograms divided by the effort on FADs (FISH.HOUR) in hours fished aggregated to 1 x 1 degree squares by year, mode, month and fleet. Thus this represents the total catch for all vessels in a square for that month by each of these factors and not set by set level information for any single vessel. In the Task II database (t2ceETRO199113_fad_FS_Effort.xls) the catch is identified by mode and effort is summed by hours spent fishing (searching, setting and processing catch). Hours fishing was partitioned by mode based on the proportion of catch by mode, as outlined above.

Months where closures occurred (November-February) were identified in the analysis both pre- and post closure to reduce any potential influence of the area closures on catch rates in these months and the model run on the full dataset and on a reduced dataset with months Nov-Feb removed. For data records where there was no effort associated with a catch (15 records), these cells were removed from modeling. Catch and effort was only modeled for the equatorial area between -10 and 10 degrees of latitude, main fishing area over all the year, and for the EU-purse seine fleets. The selected 1 x 1 cells used in the modeling are shown on **Figure 1** as red dots.

The method used to calculate standardized CPUE of the skipjack was the generalized delta-lognormal linear model (Maunder and Punt, 2004; Ortiz and Arocha, 2004). The assumptions of the delta-lognormal model are that the proportion of positive sets and the catch rate of the positive sets can be modeled as two separate and independent processes. The dependent variable for the lognormal component is the log of the positive catch per day of fishing separated by fishing mode which is assumed to follow a normal distribution with the further expectation $E[\log(CPUE)]$ is related to the explanatory variables following an additive linear formulation and an appropriate transformation (link function). The dichotomous variable concerning the catches equal to zero (“failure”) or positive (“success”) was modeled using a binominal mass probability distribution. Link functions for the logarithm of the positive CPUE, and for the proportion of positive were “identity” and “logit”, respectively.

All the main effects and five first order interactions (Area:Month, Area:Year, Year:Type(FAD or Free School), Flag:Area, Flag:Year) were considered. The selection of the variables to keep in the models was based on Akaike Information Criterion (AIC) (Akaike, 1974) by using a backward algorithm. The approach to assess the effects of the closures was to fit the models to all the data, and to a subset obtained by discarding entries from November to February before fitting the models.

Standard diagnostic plots (e.g. residual x fitted, qqplot) and calculations based on the diagonal of the hat matrix (e.g. Cook’s distances, leverage) (e.g. Venables and Ripley, 2002) were used to assess the fitting of the selected model and the influence of database entries on the calculations. Encapsulated confidence envelope (Cook and Weisberg, 1982) and Shapiro test were used to assess the normality of the residuals. All the analyses were carried out using R software functions.

In order to estimate the standardized indices, the first step was to use the selected model to calculated predictions and standard errors using a design matrix containing one positive indicator variable (dummy) for crossing levels of all factors. In order to obtain an estimation of standardized CPUE for the factors of interest (e.g. year) predictions were then weighted averaged over the effects of the nuisance factors (*e.g.* area). Formulations used are in Andrade (2009). When averaging over the grid of explanatory variables we have found no motivation to consider that a particular level of a given factor (e.g. quarter) is more important than the others. Hence equal weights were assigned to all levels of the each factor. The solutions proposed by Goodman (1960) under the assumption that estimations of models fitted to the proportion of positive catches and to the positive CPUE are independent were used to calculate the variance and the confidence intervals of the standardized indices.

3. Results

3.1 Model selection and deviance tables

All main effects and interactions were selected when using Akaike Information Criterion, which gives weight to the balance between bias and variance of the estimations. The exception was the annual price, which was discarded from both, the models for the positive and for the proportion of positive. Hence almost all the factors considered are important if we rely in AIC. Results of models fitted to all data and to the subset obtained by discarding entries regarding closure months were similar hence only results of the later model are showed to not clutter.

Deviance analyses for the models fitted to the proportion of positive catches and to the positive catch per unit effort are showed in **Table 1**. The proportional reduction of deviance as new explanatory variables are included in the model is closely related to the squared R concept. The proportional reduction of the deviance is calculated by summing up the most right column of **Table 1**, hence proportional reduction were close to 29.5% and close to 21% for the models fitted to the proportion of positive, and to positive datasets respectively. Therefore most of the variations of response variables are not explained by explanatory variables and the interactions included in the models. Nevertheless, it is important to highlight that most of the proportional reduction of deviance was driven by the type of fishery (free or FAD schools), which is clearly the more important factor, especially in the model for the proportion of positive catches.

The initial model tested for the binomial model was as follows:

SKJ_CPUE_SUCCESS~YearC+AREA+Month+METIER+price+Fleet_F_S+AREA*Month+AREA*YearC+
YearC*METIER+Fleet_F_S*AREA+Fleet_F_S*YearC

The final selected model for the binomial model was:

SKJ_CPUE_SUCCESS ~ YearC + AREA + Month + METIER + Fleet_F_S + AREA:Month + YearC:AREA + YearC:METIER + AREA:Fleet_F_S + YearC:Fleet_F_S

The initial model tested for the binomial model was as follows:

log(SKJ_CPUE)~YearC+AREA+Month+METIER+price+Fleet_F_S+AREA*Month+AREA*YearC+
YearC*METIER+Fleet_F_S*AREA+Fleet_F_S*YearC,

The final selected model for the lognormal component was:

log(SKJ_CPUE) ~ YearC + AREA + Month + METIER + Fleet_F_S + AREA:Month + YearC:AREA + YearC:METIER + AREA:Fleet_F_S + YearC:Fleet_F_S

In both models only skipjack price was removed from the final models.

3.2 Residual Diagnostics

Diagnostic residual plots for the model fitted to the positive CPUEs are in **Figure 1**. Cook's distances and leverage calculations were not high hence there are not outstanding outliers or influential observations. Residuals seem to be randomly distributed around zero all over the predictions, which is a desirable. There is not strong violation concerning homoscedasticity. However, the assumption concerning the lognormal distribution seems to be violated. Attempts to calculate envelops were not successful due to singularities preventing calculation of the complete hat matrix. Nevertheless, Shapiro-Wilk tests for all residuals or for small samples of residuals indicated the rejection of the normality hypothesis.

Residuals plots are not very useful to assess the quality of the logistic model fittings. However, the sampling distribution of the residual deviance can be approximated by a $\chi^2_{(n-p)}$ pdf, in which n is the number of observations and k is the number of parameters. Consequently the relatively low difference between the residual deviance and degrees of freedom indicate that bias is not of much concern regarding the model fitted to the proportion of positive catches.

3.3 Estimation of the parameters

Models fitted both proportion of positive and to positive CPUE have 193 parameters but only estimations significantly different of zero ($\alpha < 0.01$) are shown to not clutter (**Tables 2 and 3**). Estimations of main effects of year factor fitted to the proportion of positive catches were positive and significant in 1995 and 1996, and from 2008 to 2011. However all significant interactions between the years and some levels of other factors (e.g. free school type of fishery, area at northeast of equator – "NorEsteEcuador") were all negative. If we rely in the proportional reduction of deviance as criterion, the more important explanatory factor is the main effect of the type of fishery, which is negative for free school in comparison to the FAD fisheries (base level). Hence the proportion of positive catches of skipjack in free school fisheries is lower than in FAD fisheries.

Overall estimations of main effects of year were negative and significant for 1990s for the model fitted to positive CPUEs. However most of the interactions between year levels and other factors (e.g. free school type of fishery) were positive. The type of fishery is again the more explanatory factor if we rely in the proportional reduction of deviance as criterion. The estimation of coefficient for free school type of fisheries is negative, hence the expectation of the skipjack CPUE tends to be lower in free schools fisheries, but there are positive interactions between some years and free school fishery.

3.4 Standardized catch rates

Overall time trends of the standardized indices and of nominal values were similar but showed some notable divergence particularly for the positive observations (**Figure 3b**). Expectations of the proportion of positive sets as calculate using GLM showed a slight decreasing trend from 0.5 to 0.4 until 2007 (**Figure 3a**). However the estimations increase in the end of the time series reaching again values close to 0.5. Standardized estimations of positive CPUE have decreased slightly from 1991 to 1997, then increase until 2005, and decreased again until the end of the time series (**Figure 3b**). Standardized indices as calculated by combining the estimations of the logistic and the lognormal models showed some variability in different years but did not have a strong time trend over the series.

The reduced dataset (removing Nov-Feb) was chosen for the index as it was considered to be the least likely to have been affected by closures. The modeling exercise was also run for the entire time series with no exclusion of the months with closures. While this index was not chosen as the best dataset due to potential impacts of spatial closures, the standardized and nominal catch rates were not much different than the index with the months with closures (Dec-Feb) removed throughout time series (**Figure 4**).

4. Discussion

This paper represents an initial attempt to obtain a standardized index of relative abundance from purse seine data accounting for the mode of fishing and using fishing hours as the unit of effort. Nonetheless some strong assumptions remain, notably that the unit of effort is not getting more efficient over time and that the amount of catch by mode is a reflection of the relative distribution of effort. There is some indication that FADs are getting more efficient with the use of sonar on the FADs. Further this standardization does not take into account other changes in the purse seine fishery in general that have increased search or capture efficiency. Nonetheless the separation of catch and effort by mode substantially improves the capacity to obtain an abundance signal from the purse seine data.

In spite of the high model dimension (193 parameters) the proportional reduction of the deviance was lower than 30% in the analyses of positive and of proportion of positive catches. Therefore the models are lacking variables which are important to explain the variability of the data. Among the explanatory variables considered in the analyses the type of fishery (FAD or free school) was by far the most important factor to explain the variability of the skipjack catch rates of the purse-seine in the east Atlantic. The proportional reduction of deviance due to the inclusion of month and of area factors, reflect the strength of effects of seasonal variation on the CPUE. Hence the results gathered here indicate that seasonal variation of CPUE was not that high in the equatorial east Atlantic. This is in agreement with the distribution of the resources and the strategy of the fleets which are mainly focused in the Equatorial area, but with seasonal movements towards North and South of this area. Nevertheless, it is important to highlight that the proportional reduction of deviance when including the factor “area” in the model depends on the choice concerning the bounds of the subareas, which were at some extent a subjective choice. Hence future sensitivity studies concerning areas are recommended.

A lognormal probability distribution is often used to model positive catch rates because it usually fits well to fishery data (e.g. Ortiz and Arocha, 2004). However this is not the case for the skipjack caught in the east Atlantic. Therefore, data transformation or other probability density distributions (e.g. gamma) might be considered in the future, because lognormal assumption was violated. In opposition, the binomial distribution and the logit link function worked well to model the proportion of positive catches.

The main objective when standardizing CPUE is to estimate relative abundance indices. In order to obtain reliable indices the main factors affecting CPUE should be included in the models. More than five potentially important factors were considered, but the low proportional reduction of deviance indicates that other factors (e.g. technological devices, some indication of the target species) as well as oceanographic factors (e.g. thermocline depth, wind speed, etc.) affecting the purse seine catchability should be considered in the future. Also the search of alternative effort unit more representative of the fishing mortality should be also considered. The estimations might be carefully considered in the light of the available information, but if we rely on the standardized CPUE showed here the conclusion is that skipjack biomass showed some oscillatory variation, but there is no clear time trend.

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Table 1. Analysis of deviance table of models fitted to the proportion of positive catches (Logistic) and for the positive catch per unit effort (Lognormal). Df – Degrees of freedom; Resid. – Residual; Dev. – Deviance; Pr(>Chi) – p.value of χ^2 test; Pr(>Chi) – p.value of F test; Dec. Dev. – Decrease of deviance when the explanatory variable was included in the model; Prop. Dev. – Proportional reduction of the deviance due to the inclusion of the explanatory variable.

				Logistic			
	Df	*Deviance*	*Resid. Df*	*Resid. Dev*	*Pr(>Chi)*	*Prop.Dev.*	*Dec.Dev.*
NULL			31915	44026.7			
Year	21	70.6	31894	43956.1	2.85E-07	0.54	0.16
Area	4	398.3	31890	43557.9	6.62E-85	3.06	0.90
Month	7	65.2	31883	43492.7	1.40E-11	0.50	0.15
Type	1	11062.8	31882	32429.9	0.00E+00	85.06	25.13
Fleet	1	79.8	31881	32350.1	4.12E-19	0.61	0.18
Area:Fleet	28	156.4	31853	32193.7	8.43E-20	1.20	0.36
Year:Area	84	206.0	31769	31987.6	3.03E-12	1.58	0.47
Year:Type	21	837.1	31748	31150.5	1.20E-163	6.44	1.90
Area:Fleet	4	48.5	31744	31101.9	7.26E-10	0.37	0.11
Year:Fleet	21	81.9	31723	31020.1	3.93E-09	0.63	0.19
				Lognormal			
	Df	*Deviance*	*Resid. Df*	*Resid. Dev*	*Pr(>F)*	*Prop.Dev.*	*Dec.Dev.*
NULL			14638	29105.7			
Year	21	1261.7	14617	27843.9	9.00E-150	20.70	4.33
Area	4	536.3	14613	27307.6	8.67E-71	8.80	1.84
Month	7	397.3	14606	26910.3	1.01E-49	6.52	1.37
Type	1	2788.4	14605	24121.9	0.00E+00	45.74	9.58
Fleet	1	206.9	14604	23914.9	5.70E-30	3.39	0.71
Area:Month	28	183.7	14576	23731.2	1.65E-12	3.01	0.63
Year:Area	84	372.8	14492	23358.4	6.40E-16	6.12	1.28
Year:Type	21	184.5	14471	23173.9	4.83E-15	3.03	0.63
Area:Fleet	4	61.7	14467	23112.1	8.01E-08	1.01	0.21
Year:Fleet	21	103.1	14446	23009.0	2.49E-06	1.69	0.35

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				Logistic			
	Df	*Deviance*	*Resid. Df*	*Resid. Dev*	*Pr(>Chi)*	*Prop.Dev.*	*Dec.Dev.*
NULL			31915	44026.7			
Year	21	70.6	31894	43956.1	2.85E-07	0.54	0.16
Area	4	398.3	31890	43557.9	6.62E-85	3.06	0.90
Month	7	65.2	31883	43492.7	1.40E-11	0.50	0.15
Type	1	11062.8	31882	32429.9	0.00E+00	85.06	25.13
Fleet	1	79.8	31881	32350.1	4.12E-19	0.61	0.18
Area:Fleet	28	156.4	31853	32193.7	8.43E-20	1.20	0.36
Year:Area	84	206.0	31769	31987.6	3.03E-12	1.58	0.47
Year:Type	21	837.1	31748	31150.5	1.20E-163	6.44	1.90
Area:Fleet	4	48.5	31744	31101.9	7.26E-10	0.37	0.11
Year:Fleet	21	81.9	31723	31020.1	3.93E-09	0.63	0.19
				Lognormal			
	Df	*Deviance*	*Resid. Df*	*Resid. Dev*	*Pr(>F)*	*Prop.Dev.*	*Dec.Dev.*
NULL			14638	29105.7			
Year	21	1261.7	14617	27843.9	9.00E-150	20.70	4.33
Area	4	536.3	14613	27307.6	8.67E-71	8.80	1.84
Month	7	397.3	14606	26910.3	1.01E-49	6.52	1.37
Type	1	2788.4	14605	24121.9	0.00E+00	45.74	9.58
Fleet	1	206.9	14604	23914.9	5.70E-30	3.39	0.71
Area:Month	28	183.7	14576	23731.2	1.65E-12	3.01	0.63
Year:Area	84	372.8	14492	23358.4	6.40E-16	6.12	1.28
Year:Type	21	184.5	14471	23173.9	4.83E-15	3.03	0.63
Area:Fleet	4	61.7	14467	23112.1	8.01E-08	1.01	0.21
Year:Fleet	21	103.1	14446	23009.0	2.49E-06	1.69	0.35

Table 2. Estimation of the parameters significantly different of zero ($\alpha < 0.01$) for the model fitted to the proportion of positive catches.

Parameter	*Estimate*	*Std. Error*	*z value*	*Pr(>|z|)*
Year1995	1.06	0.30	3.56	3.65E-04
Year1996	0.78	0.26	3.02	2.55E-03
Year2008	0.94	0.27	3.45	5.61E-04
Year2009	1.54	0.30	5.17	2.35E-07
Year2010	2.08	0.31	6.77	1.26E-11
Year2011	1.90	0.30	6.37	1.95E-10
Type_FS	-1.43	0.10	-13.94	3.72E-44
Year1995:AreaNorEsteEcuador	-0.77	0.29	-2.63	8.64E-03
Year1996:AreaNorEsteEcuador	-0.80	0.26	-3.04	2.35E-03
Year2000:AreaNorEsteEcuador	-0.73	0.26	-2.87	4.07E-03
Year2008:AreaNorEsteEcuador	-0.96	0.30	-3.17	1.50E-03
Year2009:AreaNorEsteEcuador	-1.07	0.31	-3.42	6.35E-04
Year2010:AreaNorEsteEcuador	-1.51	0.32	-4.73	2.23E-06
Year2011:AreaNorEsteEcuador	-1.22	0.33	-3.74	1.85E-04
Year1996:AreaPiccolo	-0.85	0.32	-2.63	8.56E-03
Year1992:Type_FS	-0.45	0.15	-3.06	2.20E-03
Year1993:Type_FS	-0.63	0.16	-3.95	7.82E-05
Year1994:Type_FS	-1.13	0.16	-6.92	4.51E-12
Year1995:Type_FS	-1.71	0.17	-9.86	6.05E-23
Year1996:Type_FS	-1.02	0.16	-6.28	3.29E-10
Year1997:Type_FS	-1.14	0.17	-6.65	2.97E-11
Year1998:Type_FS	-1.63	0.18	-9.24	2.44E-20
Year1999:Type_FS	-1.34	0.18	-7.64	2.25E-14
Year2000:Type_FS	-1.01	0.16	-6.22	5.11E-10
Year2001:Type_FS	-0.44	0.16	-2.73	6.30E-03
Year2002:Type_FS	-0.96	0.17	-5.76	8.35E-09
Year2003:Type_FS	-0.79	0.16	-4.84	1.31E-06
Year2004:Type_FS	-1.13	0.17	-6.65	2.88E-11
Year2005:Type_FS	-1.11	0.19	-5.93	2.95E-09
Year2006:Type_FS	-0.89	0.20	-4.48	7.60E-06
Year2007:Type_FS	-1.39	0.20	-7.01	2.45E-12
Year2008:Type_FS	-1.91	0.19	-9.80	1.18E-22
Year2009:Type_FS	-2.20	0.18	-11.96	5.71E-33
Year2010:Type_FS	-2.84	0.19	-14.60	2.93E-48
Year2011:Type_FS	-3.12	0.20	-15.48	4.69E-54
Year2012:Type_FS	-3.65	0.23	-16.20	5.12E-59
AreaNorEsteEcuador:Fleet_FRA	-0.43	0.10	-4.42	9.72E-06
AreaNortePiccolo1:Fleet_FRA	-0.54	0.11	-4.81	1.48E-06
AreaPiccolo:Fleet_FRA	-0.69	0.11	-6.13	8.54E-10
AreaSurEcuador1:Fleet_FRA	-0.66	0.10	-6.44	1.17E-10
Year2007:Fleet_FRA	-0.88	0.21	-4.15	3.33E-05
Year2008:Fleet_FRA	-0.87	0.22	-4.02	5.83E-05
Year2009:Fleet_FRA	-0.53	0.19	-2.76	5.84E-03

Table 3. Estimations of the parameters significantly different of zero ($\alpha < 0.01$) for the model fitted to the positive catches.

Parameter	*Estimate*	*Std. Error*	*t value*	*Pr(>|t|)*
(Intercept)	7.52	0.28	26.55	1.01E-151
Year1992	-0.69	0.18	-3.82	1.36E-04
Year1994	-0.56	0.19	-2.97	3.02E-03
Year1995	-1.03	0.18	-5.59	2.26E-08
Year1996	-0.57	0.17	-3.32	8.96E-04
Year1997	-1.01	0.20	-4.95	7.32E-07
Year1998	-0.63	0.19	-3.26	1.11E-03
Year1999	-0.48	0.18	-2.72	6.63E-03
Year2011	0.48	0.16	3.01	2.64E-03
Month7	-0.82	0.26	-3.12	1.81E-03
Month8	-0.75	0.26	-2.86	4.26E-03
Type_FS	-1.44	0.09	-15.44	2.35E-53
AreaPiccolo:Month10	0.82	0.28	2.90	3.74E-03
Year1995:AreaNorEsteEcuador	0.52	0.20	2.62	8.83E-03
Year2003:AreaNorEsteEcuador	-0.71	0.20	-3.53	4.15E-04
Year2010:AreaNorEsteEcuador	-0.69	0.19	-3.55	3.85E-04
Year2011:AreaNorEsteEcuador	-0.75	0.20	-3.82	1.33E-04
Year1995:AreaNortePiccolo1	0.89	0.26	3.42	6.25E-04
Year1995:AreaPiccolo	0.66	0.25	2.65	8.11E-03
Year1995:AreaSurEcuador1	0.62	0.20	3.02	2.50E-03
Year1996:Type_FS	0.54	0.15	3.63	2.81E-04
Year1998:Type_FS	0.52	0.17	3.14	1.70E-03
Year2003:Type_FS	0.55	0.15	3.62	2.98E-04
Year2004:Type_FS	0.76	0.16	4.75	2.04E-06
Year2005:Type_FS	0.58	0.18	3.34	8.51E-04
Year2007:Type_FS	0.59	0.20	2.98	2.85E-03
Year2008:Type_FS	0.79	0.19	4.09	4.33E-05
Year2009:Type_FS	0.60	0.17	3.45	5.55E-04
Year2010:Type_FS	0.80	0.17	4.71	2.55E-06
Year2012:Type_FS	0.83	0.23	3.65	2.68E-04
AreaNorEsteEcuador:Fleet_FRA	-0.22	0.07	-3.22	1.30E-03
AreaNortePiccolo1:Fleet_FRA	-0.29	0.08	-3.61	3.10E-04
AreaPiccolo:Fleet_FRA	-0.30	0.08	-3.69	2.23E-04
AreaSurEcuador1:Fleet_FRA	-0.48	0.07	-6.43	1.34E-10
Year1992:Fleet_FRA	0.40	0.13	3.00	2.74E-03

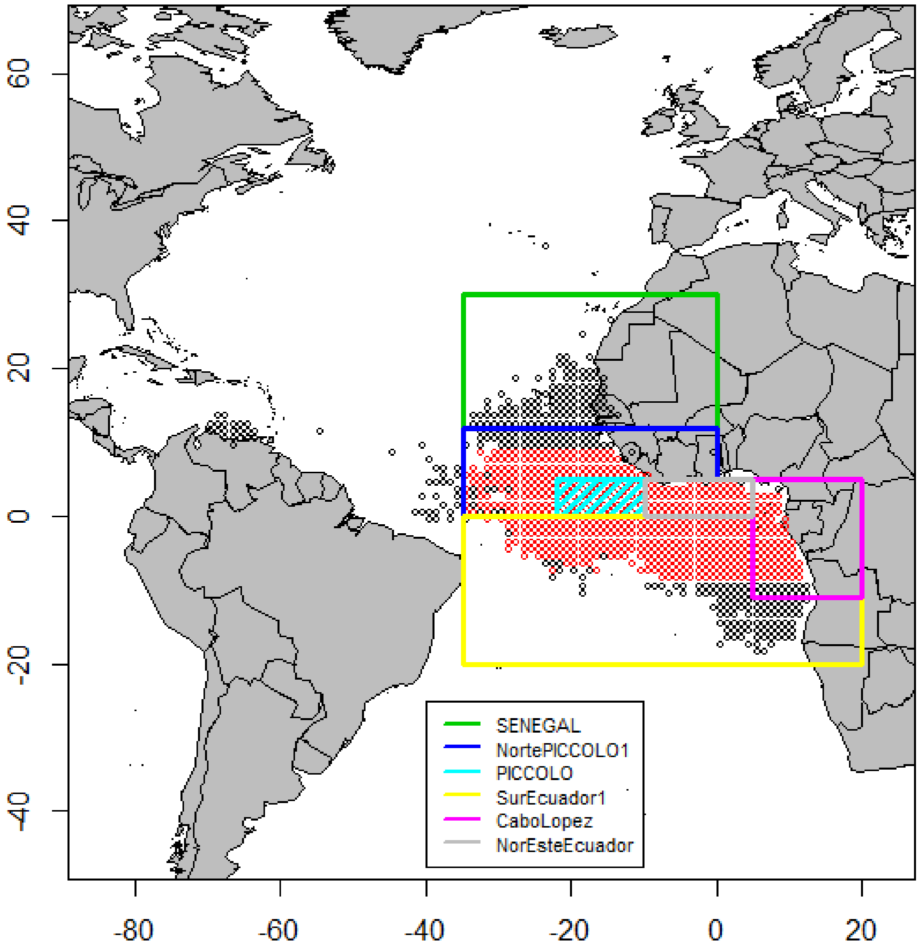

Figure 1. Levels of factor "area" included in the generalized linear models. Points in red are the data, once limited only to the equatorial area and with data exclusions made.

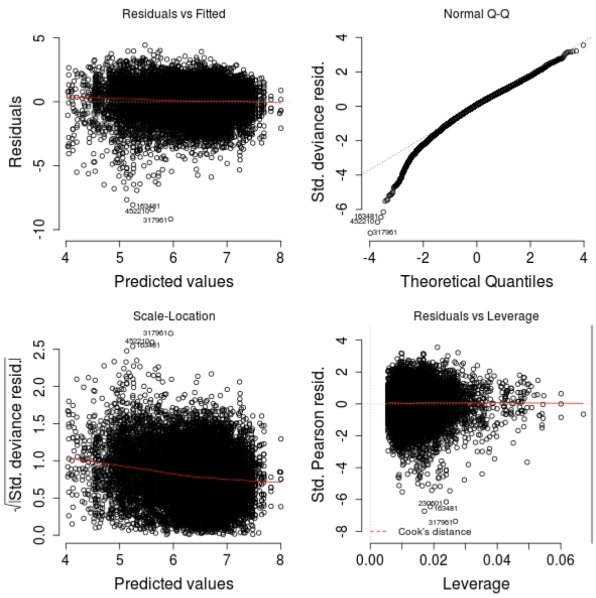

Figure 2. Standard diagnostic plots for the fitting of the lognormal generalized linear model.

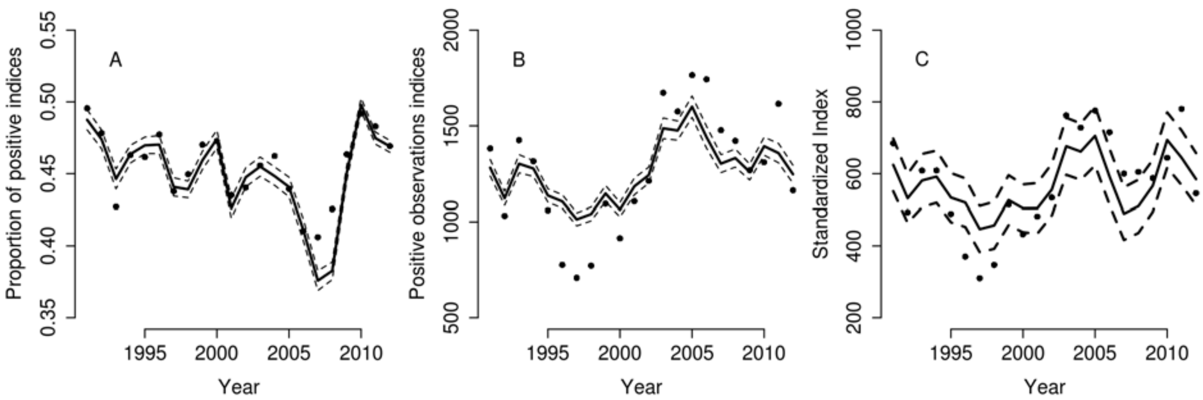

Figure 3. Standardized catch rate (tons/fishing day) by year as calculated using a delta-lognormal model. (A) Logistic model for proportion of positive catches; (B) Lognormal model for positive catch per unit effort (CPUE); and (C) Standardized index as calculated by combining the estimations of logistic and lognormal models. Dots stand for nominal values, while solid and dashed lines stand for the standardized index and the 95% confidence interval respectively.

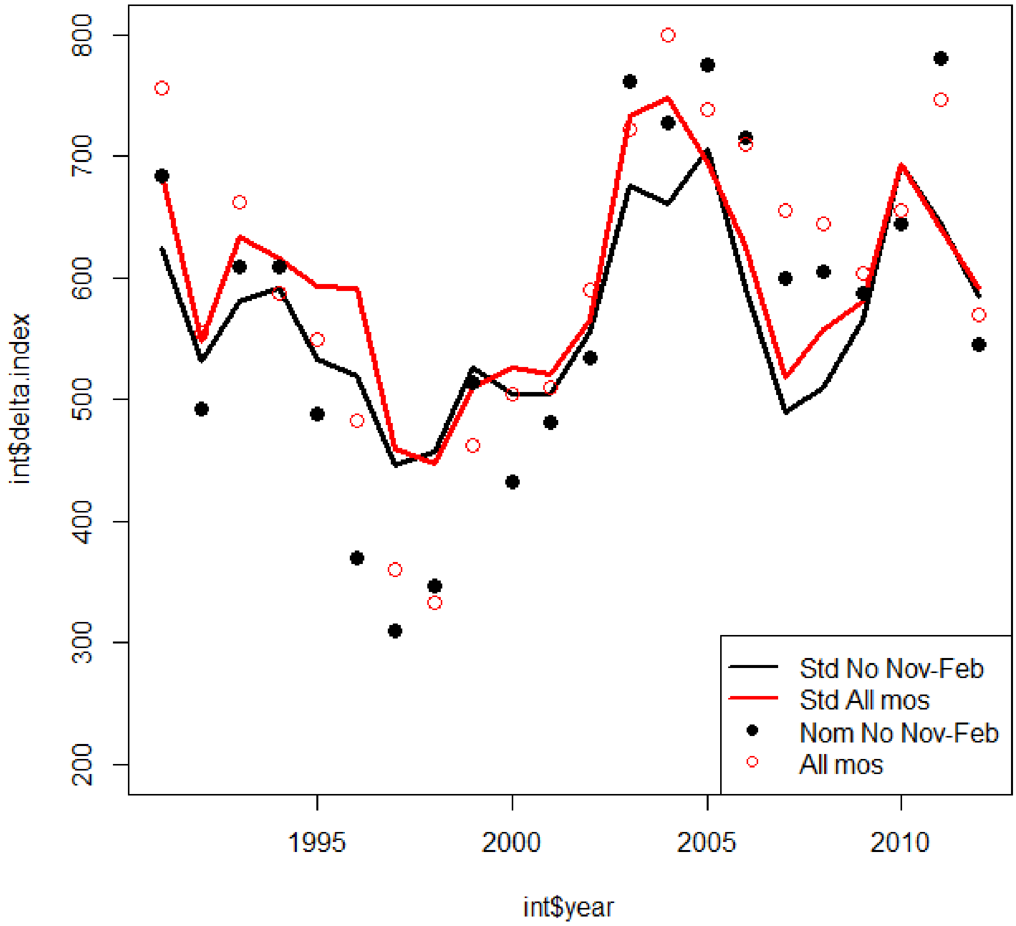

Figure 4. Standardized (black lines) and nominal (black dots) index with months with closures (Dec-Feb) removed throughout time series and standardized ((red lines) and nominal (red dots) CPUE with no exclusions during the months with closures.