Standardized CPUE for juvenile yellowfin, skipjack and bigeye tuna from the european purse seine fleet in the Atlantic Ocean from 1991 to 2006

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STANDARDIZED CPUE FOR JUVENILE YELLOWFIN, SKIPJACK AND BIGEYE TUNA FROM THE EUROPEAN PURSE SEINE FLEET IN THE ATLANTIC OCEAN FROM 1991 TO 2006

M. Soto[1], P. Pallarés[1], A. Delgado de Molina[2], D. Gaertner[3]

SUMMARY

In this document three abundance indices are obtained for the juveniles of tropical tunas (yellowfin (≤30Kg.), skipjack and bigeye of European purse seine fishery in the Atlantic Ocean from 1980 to 2006 using generalized linear models (delta-lognormal model). Catch and effort data come from detailed daily logbooks. Catch rates are modelled using the delta lognormal model. The method estimates a combined CPUE of the three species from aggregated catches, and the proportion of catches for each species, so the final individual abundance indices are calculated multiplying both estimators for each species. Explanatory variables used in the analysis are: year, zone, quarter, harvest capacity, country, and starting date of the vessel. Year and zone are the most explanatory factors of variability in CPUEs and vessel characteristics have a minor explanatory effect in observed catch rates.

RÉSUMÉ

Dans le présent document, trois indices d'abondance sont obtenus pour les juvéniles de thonidés tropicaux (albacore ≤30Kg), de listao et de thon obèse de la pêcherie de senneurs européens opérant dans l'océan Atlantique de 1980 à 2006, au moyen de modèles linéaires généralisés (modèle delta-lognormal). Les données de prise et d'effort proviennent des livres de bord journaliers détaillés. Les taux de capture sont modélisés à l'aide du modèle delta-lognormal. La méthode estime une CPUE combinée des trois espèces à partir des prises agrégées, ainsi que la proportion des captures pour chaque espèce, de telle sorte que les indices individuels finaux de l'abondance sont calculés en multipliant les deux estimateurs pour chaque espèce. Les variables explicatives utilisées dans l'analyse sont : année, zone, trimestre, capacité de capture, pays et date du début des opérations du navire. L'année et la zone sont les facteurs les plus explicatifs de la variabilité dans les CPUE et les caractéristiques des navires ont un effet explicatif mineur dans les taux de capture observés.

RESUMEN

En este documento se han calculado tres índices de abundancia para juveniles de túnidos tropicales (≤30Kg- rabil listado y patudo) capturados por la pesquería de cerco europea en el océano Atlántico desde 1980 hasta 2006, utilizando modelos lineales generalizados (modelo delta lognormal). Los datos de captura y esfuerzo proceden de cuadernos de pesca diarios detallados. Las tasas de captura se modelaron con un enfoque delta lognormal. Mediante este método se estimó una CPUE combinada de las tres especies a partir de las capturas agregadas y la proporción de captura de cada especie, de tal modo que los índices de abundancia individuales finales se calculan multiplicando ambos estimadores por cada especie. Como variables explicativas se han considerado año, zona, trimestre, capacidad de captura, país y fecha de comienzo de la actividad del buque. El año y la zona eran los factores que mejor explicaban la variabilidad en las CPUE, y las características de los buques tenían un efecto menos explicativo para las tasas de captura observadas.

KEYWORDS

Tropical tuna, CPUE, standardization, purse seine, generalized linear models, Delta method

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1. Introduction

Since the late 1980s, the increasing use of drifting fishing aggregative devices (FADs) by the purse seine fleets operating in the eastern Atlantic Ocean has changed the length distributions of the tunas in tropical landings. In contrast to non-associated school sets that target large fish (mainly yellowfin, *Thunnus albacares*), FADs fishing operations concern skipjack (*Katsuwonus pelamis*) and juveniles of yellowfin and bigeye tunas (*T. obesus*). Over the past ten years, over 30% of world catches of skipjack, bigeye and yellowfin tuna have been achieved using this fishing method. For the skipjack amounts taken under drifting FADs reached even as high as 72% of all catches.

With this consideration in mind, the aim of this paper is to develop a standardization procedure of CPUEs for FADs fishing operations. Since, purse seine fishermen may target alternatively associated schools and FADs schools, the presence of a high amount of zero-catch per fishing day may be expected in the data set. As explained in the Method section, in such a situation, delta-lognormal method is an appropriate tool for standardizing CPUEs (Lo *et al.*, 1992, Stefansson, 1996).

2. Material and methods

Standardized catch rates of juveniles of yellowfin, skipjack and bigeye were estimated simultaneously for the three species using the generalized linear model assuming a delta-lognormal error distribution. The analysis has been carried out with catch and effort data from logbooks, once the specific composition of catches has been corrected (Anon, 1984, Pallarés y Petit, 1998.) and from detailed fleet data. Catch and effort data are obtained by set, while fleet data contain information about age of vessel, physical characteristics (length, holding capacity, GTR) and vessel history. French, Spanish and NEI fleet data have been analyzed together. In this analysis, the NEI fleet was assumed as part of the Spanish purse seine fleet following results of discriminate analysis (Soto *et al.*, 2002). The period considered goes from 1980 to 2006, years where detailed logbooks are available.

It was considered a minimum threshold of effort by vessel of 120 fishing days per year. This threshold was selected after to analyze the yields as a function of fishing time of vessels and to observe that there was no correlation between both, neither between fleets nor between the whole of the fleets, and also, that the variability, higher for vessels with short fishing periods, was tending to stabilize from this threshold. Later, a selection of vessels operating in the fishery for more than 15 years was done with the intention of analyzing data from vessels that would contribute to obtain trends more representative of real abundance.

Once the selection of representative vessels was done, there were established categories according to the holding capacity, measured in m^3. This variable defines well the vessel capacity as the probability of bias and imprecision are very little. Vessel categories are the following:

Category	*Holding capacity*
1	<550 m^3
2	550 - 749 m^3
3	750 - 949 m^3
4	950 - 1549 m^3
5	> 1550 m^3

Considering the possible interaction of the fleet and the category of the vessels a mixed variable category-country was defined as in Soto *et al*. (2003) and has the following levels:

Level	*Country*	*Harvest capacity*
1	France	<550 m^3
2	France	550 - 749 m^3
3	France	750 - 949 m^3
4	France	950 - 1549 m^3
5	France	> 1550 m^3
6	Spain	<550 m^3
7	Spain	550 - 749 m^3
8	Spain	750 - 949 m^3
9	Spain	950 - 1549 m^3
10	Spain	> 1550 m^3

Data available does not allow assigning effort by set, so catches were aggregated by day.

A combined nominal CPUE was defined as:

$$CPUE = \frac{YFT1 + SKJ + BET1}{fh}$$

where *YFT1* are the catches of juveniles of yellowfin (<30 Kg.), *SKJ* the catches of skipjack and *BET1* catches of juveniles of bigeye (<10 Kg.) in tons and *fh* the nominal effort of the European purse seine fleet measured in fishing hours by day. Specific nominal CPUE for each species was defined as

$$CPUE_{sp} = CPUE \cdot p_{sp}$$

where the specie is $sp=YFT1$, *SKJ, BET*1 and the proportion of catches of each specie over total catches is

$$p_{sp} = \frac{sp}{YFT1 + SKJ + BET1 + other}$$

Data of catches and effort were restricted to those obtained from FADs, aggregated by logs per day, because the catches of juveniles of the purse seine fleet during the period considered are obtained exclusively from logs.

The standardization procedure used was the generalized linear models (GLM) in R. The combined CPUE was estimated assuming that CPUE+k follows a lognormal distribution based on the results of Kolmogorov test, where:

$$k = 0.10 \cdot CPUE$$

The proportion of catches for each species, p_{sp}, was modelled independently from the combined CPUE assumed a binomial error distribution **(Figure 1)**.

The independent variables considered were: (1) year, (2) a combined variable of category of holding capacity and country, (3) operating date of the vessel, (4) area and (5) quarter. The variable age of vessel used in previous studies of CPUE (Soto, 2002) was substituted by the operating date, in order to eliminate the correlation with the year variable and reflect the time effect over the vessels.

Three abundance indices were obtained from GLM analysis. On the one side, a combined positive CPUE was estimated from year average fitted values of the lognormal model. On the other, estimated proportions of catches were estimated for each species from year average fitted values of the binomial model. The specific index for each species was finally calculated as the product of year average fitted values of lognormal model and binomial models. Variance of the indices were calculated using the Delta method (Casella, 2002), based on the Taylor development of the function $g(\mu, p_{sp}) = \mu \cdot p_{sp}$, where μ is the estimator of mixed CPUE from the lognormal model and p_{sp} the estimator of proportion of catches of each species, assuming that both estimators are independent.

Analysis and model formulations for the delta model were done using the R statistical software package. In general, model evaluation and diagnosis was carried out through residual analysis (McCullagh and Nelder, 1989). For the delta models, diagnostic plots are presented for each model component. For the lognormal and binomial components, QQ-plots and Chi-squared residuals against year are presented for each species, respectively.

A stepwise regression procedure was used to determine the set of systematic factors and interactions that significantly explained the observed variability in each model. A Chi-squared test was used to evaluate the statistical significance of an additional factor (McCullagh and Nelder, 1989). Further, the corresponding percentage of deviance explained by each factor relative to the maximum model was estimated to obtain a profile of the most important explanatory factors in the model. A statistically significant variable may, in some instances, be omitted from the model if the amount of variation explained by the variable is small in relation to the complexity that it adds (Stefánsson, 1996). The final models included the Year, Zone and Year:Zone interaction plus a selection of other explanatory factors that explained more the 5% of the deviance percentage in the models.

3. Results

The GLM lognormal and binomial shows that the year and zone are the most significant factors explaining the variability observed. Vessel characteristics are more informative to explain the variability of the combined CPUE than the proportion of catches of each species. The models considered also the starting date of the vessel factor (date) which, although it was statistically significant in the lognormal model and in the binomial model for the proportion of catches of skipjack, it didn't explain enough percentage of the variability in the models. For the proportion of positive YFT1 and BET1, date was not statistically significant. Compared to previous analysis, where the age of the vessel was introduced as a categorical variable (Soto, 2004), the numerical variable date does not improve the results to show evidence that the age of vessel influences the CPUE.

Interaction year: zone was significant in explaining the variability observed except for the proportion of BET1.

Selected model

The results of deviance analysis are shown in **Table 1.** For the lognormal model Year, catpais, zone and interactions year:catpais, year:zone and year:quarter are the main explanatory factors. For the proportion of catches of YFT1, year, zone and the interaction year:zone were the main explanatory factors. For the proportion of catches of skipjack, the explanatory factors were the same as in proportion of YFT1, but the catpais factor was also significant. Only year and zone were significant as explanatory factors of proportion of BET1.

The selected final models for each species included the following explanatory factors: Year, catpais, zone, year:zone, year:catpais and year:quarter.

Observed and standardized scaled CPUE series by specie are shown in **Figure 3.** The three series have similar trends and nominal values are within the confidence intervals of the standardized ones. The lowest CPUE indices for YFT1 and SKJ are for 1998 and 2006 for BET1. The three series shows a decreasing trend for the last year considered, 2006.

The three series have been scaled to their maximum value in order to allow patterns in the series to be more easily seen and compared. **Figure 2** shows the scaled CPUE for the three species together and the corresponding CVs for the nominal and standardized scaled CPUE series for each species. It can be seen than variability of standardized scaled series is sensibly lower than nominal series for all the species. Overall CVs for yellowfin was on average about 45%, 36% for bigeye and 30% for skipjack. Fitting diagnoses are show in **Figure 4** and **5** for lognormal model and **Figure 6** for the binomial models. The residuals follows a relatively linear expected pattern for aggregated catches in the QQ-plot (**Figure 4**) and partial residuals of single factors in the lognormal model shows the variability that can be explained by each single factor in the model (**Figure 5**). The residuals plot for the proportion of catches shows no trend for the three species (**Figure 6**).

Comparing the three series of tropical tunas in the Atlantic Ocean it can be seen that skipjack has been decreasing until 1998 more clearly than yellowfin and bigeye, but it has been recovering in the last years more rapid than the others.

4. Discussion

The delta method has been widely used to construct abundance indices for tuna species. In this study, the delta approach has provided simultaneously three indices for juvenile tropical tunas. The CVs of the indices are similar, showing the yellowfin index the higher variability. No clear trends appear in the series of standardized CPUEs, but it seems that juveniles of skipjack and yellowfin are more similar, with an initial decreasing period form 1991 to 1998 followed of a slight raising period from 1998 to 2005. The three indices decrease in the last year, 2006. For bigeye, the abundance series shows no trend for all the period considered.

The source of variability that comes from the fleet is represented by the factors catpais and date. The factor catpais represents the effect of vessel class and it is more significant to explain the variability of aggregated catch rates than the proportion of individual catches, i.e. there is no evidence of differences between proportions of individual catches between vessel classes. Also, the age of the vessel has been removed from the final model because the proportion of explained variability of global catch rates is very little (3%) and it is not statistically significant for the proportion of individual catches.

The effect of the vessel is independent of the proportions of catches of specie. This factor has been removed from the binomial final models of proportion. Significant differences within catpais appear in the combined catches but not in the proportion of catches of each species. The age of the vessel (date) does not explain the variability of the combine catch rate not the proportion of catches for each species.

In general, the standardization procedure showed that vessel characteristics (country, harvest capacity and age of vessel) have a relative minor explanatory effect on the catch rate of juveniles of tropical tuna in the purse seine fishery.

The goal of the standardization procedure is to eliminate the annual variability in the data that is not attributable to the changes in abundance (Maunder y Punt, 2004). This result is in part achieved as it can be seen in **Figure 3,** where the CVs of nominal CPUEs are higher than the standardized ones.

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Table 1. Deviance table for the lognormal model and the proportion of catches of each species. Catpais= harvest capacity-country, date=starting date of the vessel. Explanatory factors are emboldened.

Model formulation	*d.f.*	*Residual deviance*	*Change in deviance*	*Percentage of total deviance*	*p*
Combined catch rate					
1	1	21006,7			
Factor					
Year	15	20612,7	394	11,9%	<0.001
+date	1	20514	98,8	3,0%	<0.001
+catpais	7	19559,2	954,7	28,9%	<0.001
+zone	5	19124,1	435,1	13,2%	<0.001
+quarter	3	19000,2	123,9	3,7%	<0.001
Inteaction					
+year:date	15	18968,7	31,5	1,0%	0,005
+year:catpais	98	18688,4	280,3	8,5%	<0.001
+year:zone	75	18343,2	345,2	10,4%	<0.001
+year:quarter	45	18113,1	230,1	7,0%	<0.001
+date:catpais	6	18001,2	111,8	3,4%	<0.001
+date:zone	5	17990,4	10,8	0,3%	0,044
+date:quarter	3	17974,9	15,5	0,5%	<0.001
+catpais:zone	35	17876,2	98,7	3,0%	<0.001
+catpais:quarter	21	17829,4	46,9	1,4%	<0.001
+zone:quarter	15	17699,4	130	3,9%	<0.001
Proportion of positive YFT1					
1	1	573,76			
Factor					
Year	15	537,14	36,63	9%	0.001
+date	1	535,95	1,19	0%	0,27
+catpais	7	531,86	4,09	1%	0,77
+zone	5	389,97	141,89	34%	<0.001
+quarter	3	370,2	19,77	5%	<0.001
Inteaction					
+year:date	15	366,08	4,12	1%	1
+year:catpais	98	344,01	22,07	5%	1
+year:zone	75	219,01	125,01	30%	<0.001
+year:quarter	45	185,42	33,59	8%	0,89
+date:catpais	6	182,66	2,76	1%	0,84
+date:zone	5	182,16	0,51	0%	0,99
+date:quarter	3	181,95	0,21	0%	0,98
+catpais:zone	35	178,77	3,18	1%	1
+catpais:quarter	21	176,03	2,73	1%	1
+zone:quarter	15	161,62	14,42	3%	0,49
Proportion of positive SKJ					
1	1	2116,86			
Factor					
Year	15	1896,45	220,41	10%	<0.001
+date	1	1887,94	8,5	0%	<0.001
+catpais	7	1754,39	133,56	6%	<0.001
+zone	5	1419,03	335,35	16%	<0.001
+quarter	3	1351,22	67,82	3%	<0.001
Inteaction					
+year:date	15	1342,46	8,76	0%	0,89
+year:catpais	98	1265,82	76,64	4%	0,95
+year:zone	75	1128,84	136,99	6%	<0.001
+year:quarter	45	1062,39	66,45	3%	0,02
+date:catpais	6	1043,92	18,47	1%	0,01
+date:zone	5	1043,1	0,82	0%	0,98
+date:quarter	3	1041,63	1,47	0%	0,69
+catpais:zone	35	1010,92	30,71	1%	0,68
+catpais:quarter	21	997,63	13,29	1%	0,9
+zone:quarter	15	931,7	65,93	3%	<0.001
Proportion of positive BET1					
1	1	876,66			
Factor					
Year	15	736,95	139,71	16%	<0.001
+date	1	736,11	0,84	0%	0,36
+catpais	7	702,28	33,83	4%	<0.001
+zone	5	440,58	261,7	30%	<0.001
+quarter	3	430,73	9,84	1%	0,02
Inteaction					
+year:date	15	426,64	4,1	0%	1
+year:catpais	98	406,75	19,89	2%	1
+year:zone	75	307,29	99,47	11%	0,03
+year:quarter	45	253,5	53,79	6%	0,17
+date:catpais	6	249,01	4,49	1%	0,61
+date:zone	5	248,51	0,49	0%	0,99
+date:quarter	3	248,46	0,05	0%	1
+catpais:zone	35	243,29	5,17	1%	1
+catpais:quarter	21	240,86	2,43	0%	1
+zone:quarter	15	214,96	25,9	3%	0,04

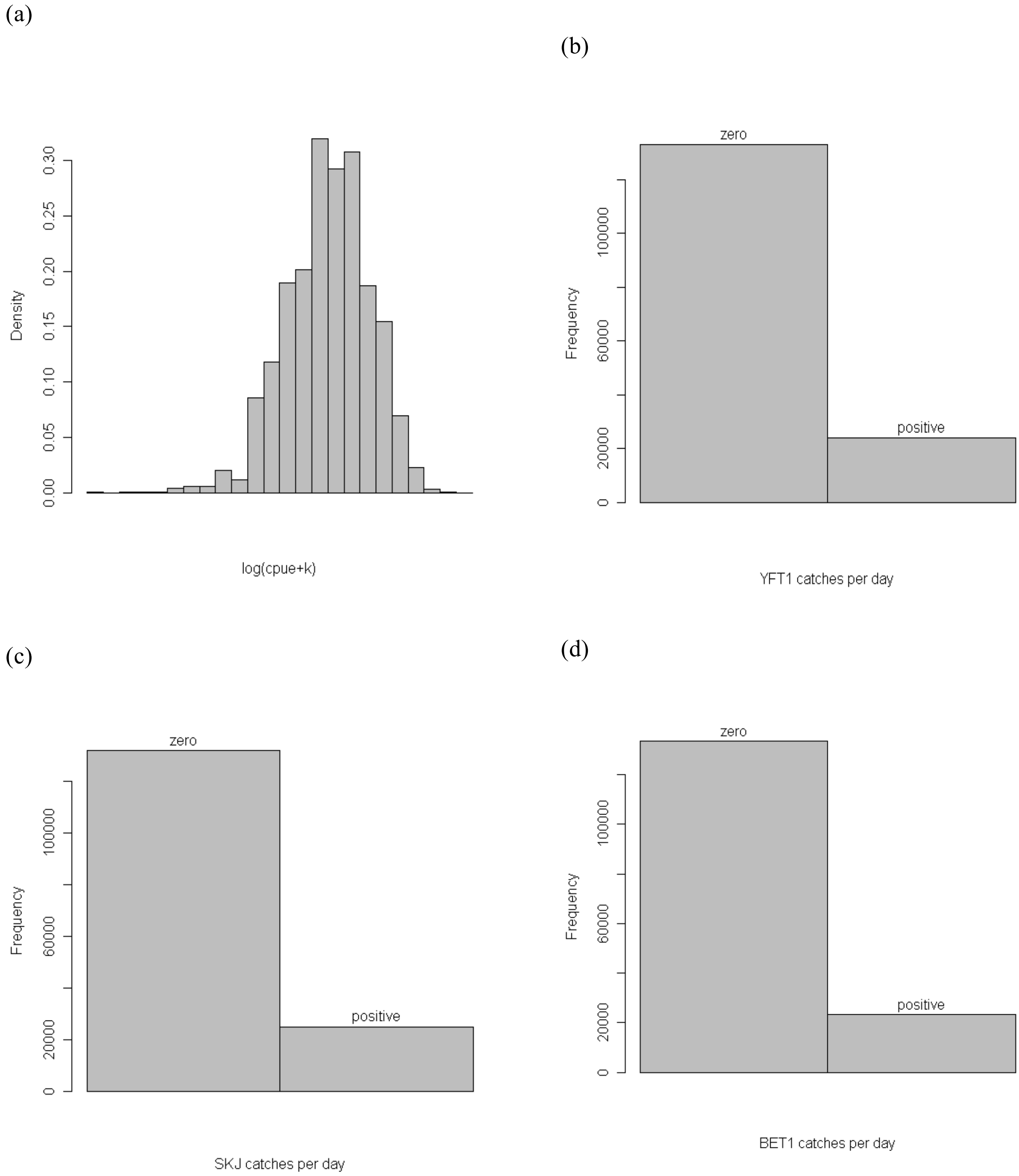

Figure 1. Observed log(cpue+*k*) distribution of all species combined (a) and proportion of zero and positive purse seine catches per day of the three tropical species (b)-(d).

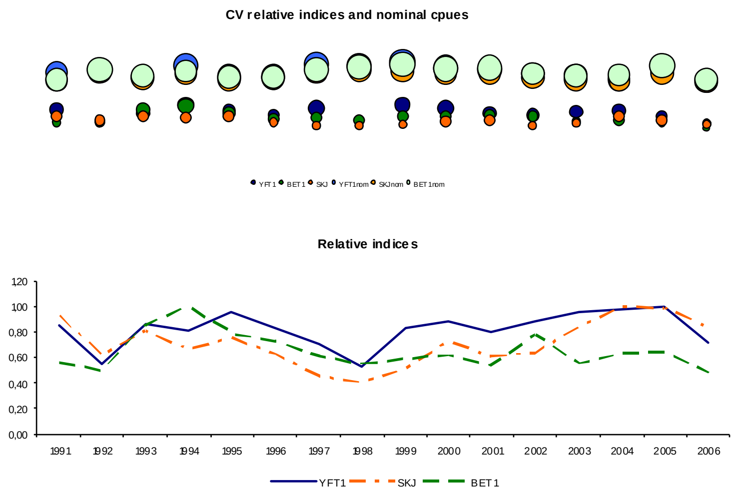

Figure 2. CVs of standardized indices and the corresponding nominal values and standardized scaled CPUE of purse seine for the three tropical species.

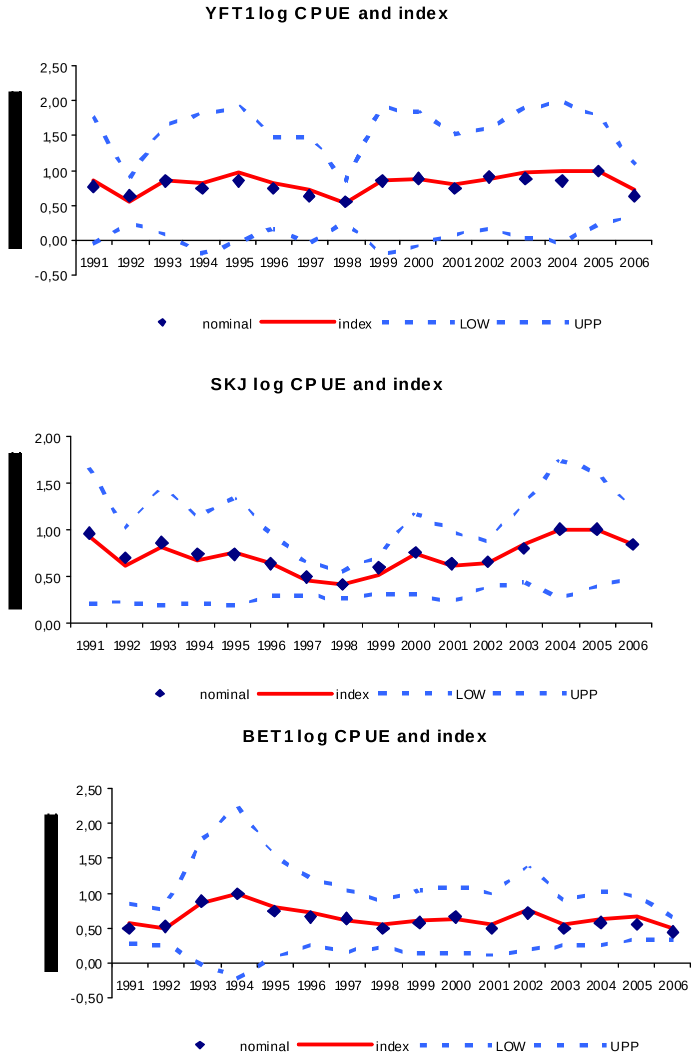

Figure 3. Standardized scaled CPUE of purse seine catches of juveniles of yellowfin, skipjack and juveniles of bigeye. Confidence intervals and nominal values are also plotted for each species.

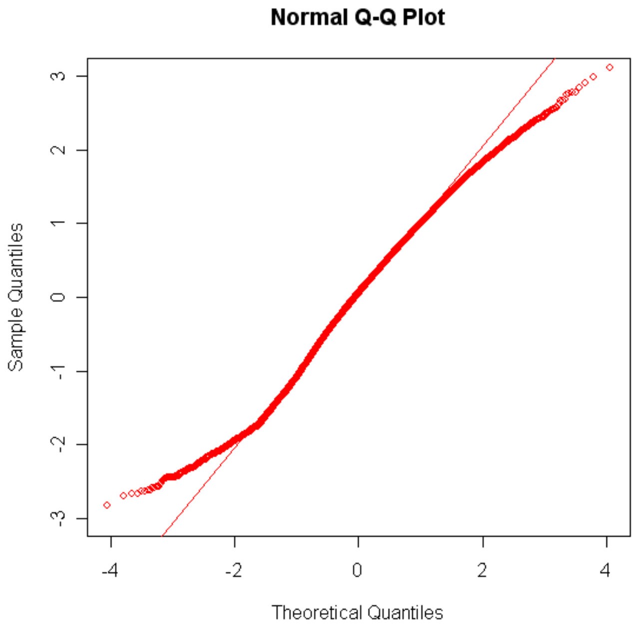

Figure 4. QQ-plot for the final model selected for the combined CPUE.

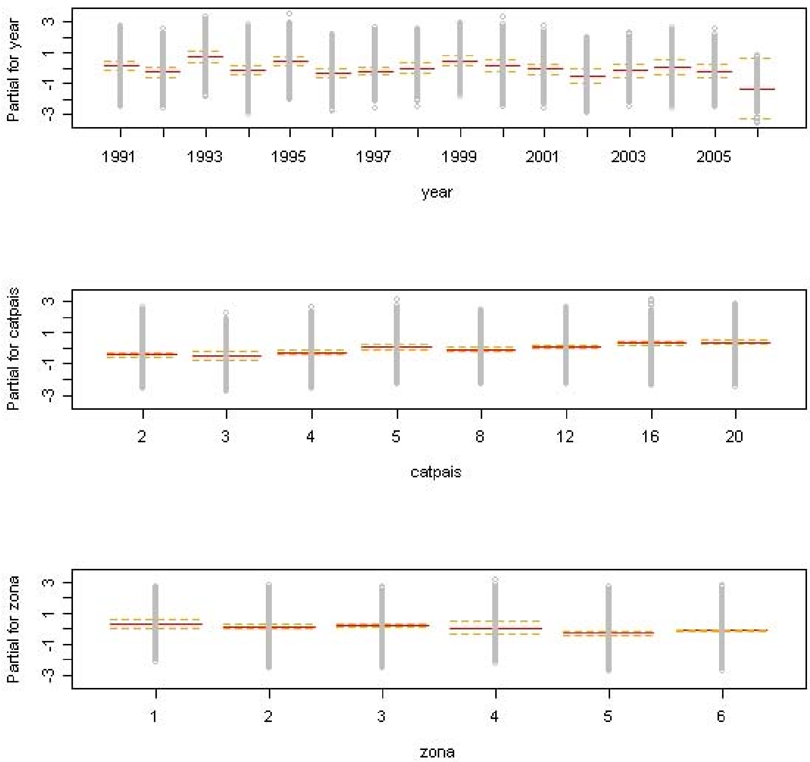

Figure 5. Partial residuals of the Lognormal model for the combined CPUE.

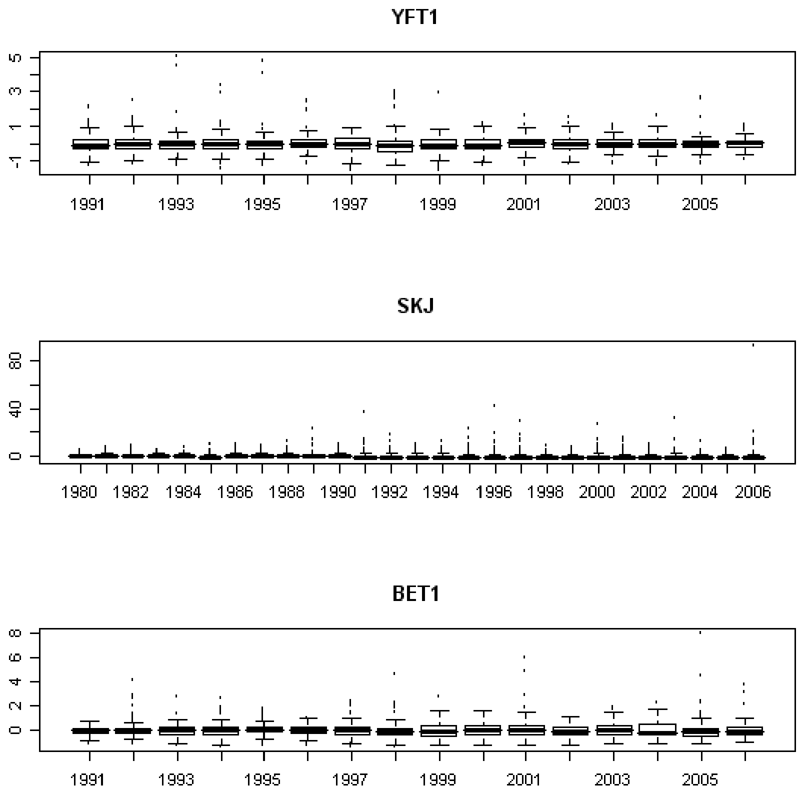

Figure 6. Residuals plot for the final models selected for the proportion of catches of yellowfin, skipjack and bigeye.