UPDATE OF STANDARDIZED CPUE OF ALBACORE TUNA, *THUNNUS ALALUNGA*, CAUGHT BY URUGUAYAN LONGLINERS IN THE SOUTHWESTERN ATLANTIC OCEAN (1983-2012)

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SUMMARY

This study presents an update of the standardized catch rate of albacore, Thunnus alalunga, *caught by the Uruguayan longline fleet in the Southwestern Atlantic using information from logbooks between 1983 and 2012. Because of the large proportion of zero catches (30%) the CPUE (catch per unit of effort in weight) was standardized by Generalized Linear Mixed Models (GLMMs) using a Delta Lognormal approach. The independent variables included in the models as main factors and also as first-order interactions were: year, quarter, area, sea surface temperature and vessels categories. A total of 18,142 sets were analyzed. The standardized CPUE series of albacore caught by Uruguayan longline fleet showed a slightly decrease in their relative abundance from 1983 to 2005 and became constant in the last seven years.*

RÉSUMÉ

*La présente étude fournit une actualisation du taux de capture standardisé du germon (*Thunnus alalunga*) capturé par la flottille palangrière uruguayenne dans l'Atlantique Sud-Ouest, calculé au moyen d'informations provenant des carnets de pêche couvrant les années 1983 à 2012. Compte tenu de la quantité élevée de prises nulles (30%), la CPUE (capture par unité d'effort en poids) a été standardisée au moyen des modèles mixtes linéaires généralisés (GLMM), en ayant recours à une approche delta log normale. Les variables indépendantes incluses dans les modèles comme facteurs principaux et aussi comme interactions de premier ordre étaient: année, trimestre, zone, température à la surface de la mer et catégorie de navires. Un total de 18.142 opérations a été analysé. Les séries de CPUE standardisée du germon capturé par la flottille palangrière uruguayenne affichent une légère diminution de leur abondance relative de 1983 à 2005 et ont suivi une tendance constante au cours des sept dernières années.*

RESUMEN

Este estudio presenta una actualización de la tasa de captura estandarizada del atún blanco, Thunnus alalunga, *capturado por la flota de palangre uruguaya en el Atlántico sudoccidental utilizando información de los cuadernos de pesca entre 1983 y 2012. A causa de la elevada proporción de capturas cero (30%), la CPUE (captura por unidad de esfuerzo en peso) se estandarizó mediante modelos lineales mixtos generalizados (GLMM) utilizando un enfoque Delta lognormal. Las variables independientes incluidas en los modelos como factores principales e interacciones de primer orden fueron: año, trimestre, área, temperatura de la superficie del mar y categorías de buque. Se analizaron en total 18.142 lances. La serie de CPUE estandarizada de atún blanco capturado por la flota de palangre uruguaya mostró un ligero descenso en su abundancia relativa desde 1983 hasta 2005 y se volvió constante en los últimos siete años.*

KEYWORDS

Albacore, CPUE, Southwestern Atlantic, Logbooks, GLMM, Longline

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1. Introduction

The Uruguayan tuna fleet began its activities in 1981. Until 1991, the pelagic longline fleet consisted mostly of large-scale freezing vessels operating with Japanese-type longline targeting their efforts mainly to bigeye tuna, *Thunnus obesus* (Rios *et al*., 1986; Mora, 1988; Domingo *et al.*, 2008). Since 1992, most of them were replaced by small-scale fresh-fishing vessels operating with American-type longline, except for some freezing units that operate with a Spanish-type. During the latter period these vessels targeted mainly swordfish, *Xiphias gladius*. In any case, albacore, *T. alalunga*, has been incidentally caught by the Uruguayan tuna fleet (Rios *et al*., 1986; Mora and Chiesa, 1991) since 1981, with the exception of five China-Taipei vessels targeting albacore between 1984 and 1986 (Pons *et al*., 2012).

The present study updates the standardized catch rate of albacore tuna captured by the Uruguayan tuna longline fleet presented in Pons *et al.* (2012) up to 2012.

2. Material and methods

2.1 Data reduction and exclusion

We analyzed data from logbooks from the Uruguayan longline fleet between 1981 and 2012. However, in order to improve the database we remove the first two years of the time series because of partial and incomplete data. In addition, spatial cells were the fleet operated occasionally (grey dots in **Figure 1**) were not considered, removing 5% of the total sets. Finally, data from five vessels that operate for a short period of time targeting mainly albacore (see above) were also removed to consider only the sets were albacore was captured as bycatch.

2.2 Data used

We analyzed a total of 18,142 sets from 1983 to 2012 with complete information. The percentage of sets that captured albacore (positive sets) respect to the total sets was 70% for the entire period, with a maximum of 98% in 1990 and a minimum of 32% in 2003 (**Figure 2**).

From each fishing set the following information was used: date, geographical position (latitude and longitude) and Sea Surface Temperature (SST) at the beginning of the set, effort (in thousands of hooks), and weight (in kilograms) of albacore caught. Catch per unit of effort (CPUE) were estimated as kilograms of albacore caught per 1000 hooks by set.

We defined two areas for the analysis according to the distribution of the effort. **Area 1**, south of 34° S and depths less than 2000 m, comprising mainly Uruguayan waters on the continental shelf and slope; and **Area 2**, depths higher than 2000 m in front of Uruguay and Brazil, comprising mainly international waters between 26º-42º S and 38º-55º W (**Figure 1**).

The SST was categorized into three levels according to the presence of different water masses in the region: below 15º C (mainly Sub-Antarctic waters), between 15º and 20º C (frontal zone) and above 20° C (mainly tropical waters). The seasonality was considered in quarters: **1** (January-March), **2** (April-June), **3** (July-September) and **4** (October-December).

Also, to take into account potential differences between vessels in the Uruguayan tuna fleet, we used 'vessels categories' defined by a cluster analysis (see document SCRS/2011/114 for further details). These clusters consider length, gross register tonnage and engine power of each vessel (*Vcluster* in **Table 1**).

2.3 Standardized methods

Because of a large proportion of zero catches (30%) the CPUE was standardized by Generalized Linear Mixed Models (GLMMs) using a Delta Lognormal approach (Lo *et al*. 1992). The Delta method treated separately the positive observations (Lognormal) to the probability that a positive observation occur (Binomial). We used an *identity* link function and a *logit* link function for the Lognormal and Binomial models respectively. **Figure 3** shows the frequency distribution of the log-transformed nominal CPUE for positive sets of albacore.

Deviance tables (for both components of the delta model) were used to select the explanatory factors and interactions that explained most of the variability in the data (Ortiz and Arocha, 2004). The effect of each factor/interaction was evaluated according to: 1) the result of the X^2 test between two nested models (in the case of models with interactions, the X^2 was between a model with and without the interaction); and 2) the percent of deviance explained by the addition of each factor / interaction to the model. Only those factors and interactions whose deviation exceeds 5% of the total deviation explained by the full model were selected as explanatory variables.

Once selected the fixed factors and interactions, all interactions involving the factor year were evaluated as random variables to obtain the estimated index per year, transforming the GLMs in a GLMMs (Generalized Linear Mixed Models) (Cooke, 1997). The significance of the random interactions was evaluated by the Akaike information criterion (AIC), Schwarz's Bayesian criterion (BIC) (Littell *et al.*, 1996) and the likelihood ratio test (Pinheiro and Bates 2000). The models with smaller AIC and BIC values were selected. The indices of abundance were estimated then as the product of the least squares means (LSmeans) of the factor year for the selected Lognormal and Binomial models (Lo *et al*., 1992; Stefánsson, 1996). Also, variance estimation of the standardized index was calculated following Walter and Ortiz (2012) for two-stage CPUE estimators.

The independent variables considered in the standardization model, as main factors and also as first-order interactions, are summarized in **Table 1**. The interaction between year and Vessel category were not included in the analysis because there was not continuity in time of each vessel category, *i.e.* larger vessels operated in the first period of the time series, between 1983 and 1992 (**Figure 4**). Finally, **Figure 5** shows the number of positive observations by factors.

All the analyses were conducted using the R software (R Development Core Team 2012) with the packages MASS (Venables *et al.*, 2002), lme4 (Bates, 2012), lsmeans (Lenth, 2013) and pbkrtest (Højsgaard and Halekoh, 2012).

2.4 Albacore size data

Albacore fork length data presented was taken from the Uruguayan observer program database collected between 1998 and 2012. There are no albacore size data available before 1998, year when the observer program started.

3. Results and discussion

3.1 Standardized index

Deviance table analysis, one for Lognormal and other for the Binomial models, are shown in **Tables 3a** and **3b** respectively. For the mean catch rates given in the positive sets, the factors *year*, *quarter* and *Vcluster*, and the interactions *year: quarter*, *year: area* and *year: SST* were significant (**Table 2a**). In addition, for the proportion of positive/total sets the factors *year* and *area*, and the interactions *year: area*, *year: quarter* and *year: SST* were significant (**Table 2b**).

After fixed factor were selected the interactions with the factor *year* were included as random effects. According to the three criteria evaluated (the likelihood ratio tests and reductions in AIC and BIC values, **Table 3**) the final models selected for the Lognormal and Binomial components were:

Lognormal Model: log (CPUE) = Year + Area + Quarter + SST + Vcluster + Random (Year: Area) + Random (Year: Quarter) + Random (Year: SST)

Binomial Model: positive/total= Year + Area + Quarter + SST + Random (Year: Area) + Random (Year: Quarter) + Random (Year: SST)

Diagnostic plots for the final Lognormal GLMM confirmed model assumptions of homogeneity of variance and lognormal distribution of CPUE (**Figure 6**).

Final standardized index for albacore are shown in **Table 4** and **Figure 7**. The standardized CPUE series of albacore caught by the Uruguayan longline fleet showed a slightly decrease in relative abundance from 1983 to 2005 but remained constant from then to the end of the time series (**Figure 7**).

3.2 Albacore size data

For the period 1998-2012, the Uruguayan tuna fleet captured albacores between 60 and 128 cm fork length, with an overall mean of 94 cm (N=5,908, **Figure 8)**.

References

Bates, D., Maechler, M. and Bolker, B. 2012. lme4: Linear mixed-effects models using S4 classes. R package version 0.999999-0. http://CRAN.R-project.org/package=lme4

Cooke, J. G. 1997. A procedure for using catch-effort indices in bluefin tuna assessments. Collect. Vol. Sci. Pap. ICCAT, 46: 228–232.

Højsgaard, S. and Halekoh, U. 2012. pbkrtest: Parametric bootstrap and Kenward Roger based methods for mixed model comparison. R package version 0.3-4. http://CRAN.R-project.org/package=pbkrtest

Lenth, R. V. 2013. lsmeans: Least-squares means. R package version 1.06-05. http://CRAN.R-project.org/package=lsmeans

Littell, R. C., Milliken, G. A., Stroup, W. W. and Wolfinger, R. D. 1996. SAS® System for Mixed Models. SAS Institute Inc., Cary NC.

Lo, N.C., Jacobson, L. D. and Squire, J. L. 1992. Indices of relative abundance from fish spotter data based on delta-lognormal models. Can. J. Fish. Aquat. Sci. 49, 2515–2526.

Mora, O. 1988. Descripción de pesquería de pez espada. Collect. Vol. Sci. Pap. ICCAT, 27: 283-286.

Mora, O and Chiesa, E. 1991. Evolución y tendencias de las capturas y CPIE de atún blanco obtenidas por la flota uruguaya en el período 1981.89. Collect. Vol. Sci. Pap. ICCAT, 34: 135-140.

Ortiz, M. and Arocha, F. 2004. Alternative error distribution models for standardization of catch rates of non-target species from a pelagic longline fishery: billfish species in the Venezuelan tuna longline fishery. Fish. Res. 70: 275–297.

Pinheiro, J. C. and Bates, D. M. 2000. Mixed-Effects Models in S and S-Plus. Springer-Verlag, New York.

Pons, M., Ortiz, M. and Domingo, A. 2012. Catch rates standardization of albacore tuna, *Thunnus alalunga*, caught by the Uruguayan longline fleet (1983-2010). Collect. Vol. Sci. Pap. ICCAT, 68: 546-557.

R Core Team. 2012. R: A language and environment for statistical computing. R Foundation for Statistical Computing, Vienna, Austria. ISBN 3-900051-07-0. http://www.R-project.org/

Rios, C., R. Leta, O. Mora and Rodríguez, J. 1986. La pesca de atunes y especies afines por parte de la flota de altura palangrera uruguaya. Ier. Simp. Cient. CTMFM, Mar del Plata, Argentina 1984, 1(2):483-544.

Stefánsson, G. 1996. Analysis of grounfish survey abundance data: combining the GLM and Delta approaches. ICES J. Mar. Sci. 53: 577–588.

Venables, W. N. and Ripley, B. D. 2002. Modern Applied Statistics with S. Fourth Edition. Springer, New York.

Walter, J. and Ortiz, M. 2012. Derivation of the delta-lognormal variance estimator and recommendation for approximating variances for two-stage CPUE standardization models. Collect. Vol. Sci. Pap. ICCAT, 68: 365-369.

Table 1. Summary of independent variables used in the GLM and GLMM models. The numbers between parenthesis refer to the number of categories in each variable.

Variable	Type	Observations
Year	Categorical (30)	Period: 1983-2012
Quarter	Categorical (4)	Quarter 1: January-March Quarter 2: April-June Quarter 3: July-September Quarter 4: October-December
Sea surface temperature (*SST*)	Categorical (3)	In Celsius degrees (º C), range: 8º-29º C SST1: < 15º C SST2: between 15º and 20º C SST3: > 20º C
Area	Categorical (2)	Área 1: < 2000 m depth * Área 2: > 2000 m depth *
Vessel cluster (*Vcluster*)	Categorical (3)	1: Mean L 51 m; Mean HP 1256; Mean GRT 322 ** 2: Mean L: 36 m; Mean HP 923; Mean GRT 286 ** 3: Mean L: 21 m; Mean HP 350; Mean GRT 110 **

* See Figure 1.

** L=length, HP= engine power (in horse power), GRT= gross register tonnage, see SCRS/2011/114.

Table 2. Deviance analysis table of positive catch rates (Lognormal) and proportion of positive sets (Binomial) models. 'd.f.' refers to degree of freedom of the added factor; '% of total deviance' to the reduction in percentage of model deviance by adding the factor or interaction to the model.

a) Model factors positive catch rates values	d.f.	Residual deviance	Change in deviance	% of total deviance
NULL	1	17755		
Year	29	16258	1497	37.0
Year + Quarter	3	14054	2204	54.5
Year + Quarter + Area	1	14024	30	0.7
Year + Quarter + Area+ SST	2	13957	67	1.7
Year + Quarter + Area+ SST + Vcluster	2	13714	243	6.0
Year + Quarter + Area+ SST + Vcluster + Year:Quarter	84	12640	1074	21.0
Year + Quarter + Area+ SST + Vcluster + Year:Area	29	13227	487	10.8
Year + Quarter + Area+ SST + Vcluster + Year:SST	50	13275	438	9.8
Year + Quarter + Area+ SST + Vcluster + Quarter:SST	6	13575	138	3.3
Year + Quarter + Area+ SST + Vcluster + Quarter:Area	3	13597	117	2.8
Year + Quarter + Area+ SST + Vcluster + Area:SST	2	13703	11	0.3
Year + Quarter + Area+ SST + Vcluster + Area:Vcluster	2	13537	177	4.2

b) Model factors proportion positives	d.f.	Residual deviance	Change in deviance	% of total deviance
NULL	1	7743		
Year	29	3560	4183	82.6
Year + Quarter	1	3417	143	2.8
Year + Quarter + Area	3	2750	668	13.2
Year + Quarter + Area+ SST	2	2737	13	0.2
Year + Quarter + Area+ SST + Vcluster	2	2681	56	1.1
Year + Quarter + Area+ SST + Vcluster + Year:Area	29	2401	280	5.2
Year + Quarter + Area+ SST + Vcluster + Year:Quarter	84	1804	877	14.8
Year + Quarter + Area+ SST + Vcluster + Year:SST	51	2312	369	6.8
Year + Quarter + Area+ SST + Vcluster + Quarter:Area	3	2587	94	1.8
Year + Quarter + Area+ SST + Vcluster + Quarter:SST	6	2647	34	0.7
Year + Quarter + Area+ SST + Vcluster + Area:SST	2	2646	35	0.7
Year + Quarter + Area+ SST + Vcluster + Area: Vcluster	2	2630	51	1.0

Table 3. Analyses of the delta lognormal mixed model formulations for albacore catch rates from the Uruguayan pelagic longline fishery (1983-2012).

GLMM	Akaike's Information Criterion	Bayesian Information Criterion	Log Likelihood	Likelihood Ratio Test
Positives catch rates				
Year Area Quarter SST Vcluster	36935	37233	-18428	
Year Area Quarter SST Vcluster *Year:Area*	36643	36941	-18282	<0.0001
Year Area Quarter SST Vcluster *Year:Area Year:Quarter*	36032	36337	-17975	<0.0001
Year Area Quarter SST Vcluster *Year:Area Year:Quarter Year:SST*	35978	36291	-17947	<0.0001
Proportion of positives				
Year Area Quarter SST	2811	2980	-1369	
Year Area Quarter SST *Year:Area*	2708	2881	-1316	<0.0001
Year Area Quarter SST *Year:Area Year:Quarter*	2184	2357	-1054	<0.0001
Year Area Quarter SST *Year:Area Year:Quarter Year:SST*	2160	2338	-1041	<0.0001

Table 4. Nominal and standardized index of relative abundance of albacore in weight (kg) for the Uruguayan pelagic longline fleet (1983-2012). CV=coefficients of variation for the standardized index.

Year	N Observations	Nominal CPUE	Standard CPUE	CV
1983	1439	145.9	138.5	0.45
1984	2627	109.9	119.6	0.44
1985	891	125.2	125.1	0.45
1986	630	160.9	123.7	0.48
1987	574	163.4	115.7	0.46
1988	382	151.1	120.3	0.47
1989	313	139.0	143.8	0.50
1990	245	120.6	94.1	0.47
1991	139	128.5	109.3	0.50
1992	218	101.7	72.5	0.53
1993	143	99.3	126.7	0.58
1994	228	83.9	56.6	0.55
1995	529	125.3	90.4	0.55
1996	593	182.2	123.9	0.52
1997	428	124.6	91.0	0.54
1998	564	151.4	125.6	0.53
1999	525	148.2	99.8	0.53
2000	466	110.1	79.5	0.61
2001	553	69.9	46.2	0.62
2002	682	63.8	37.3	0.70
2003	962	38.9	26.0	0.73
2004	1216	24.3	18.8	0.72
2005	1322	17.7	11.9	0.74
2006	746	78.4	46.0	0.56
2007	478	50.0	57.9	0.50
2008	476	53.8	43.5	0.50
2009	404	85.6	55.0	0.56
2010	130	51.9	48.3	0.55
2011	126	24.8	30.4	0.59
2012	113	50.8	40.2	0.59

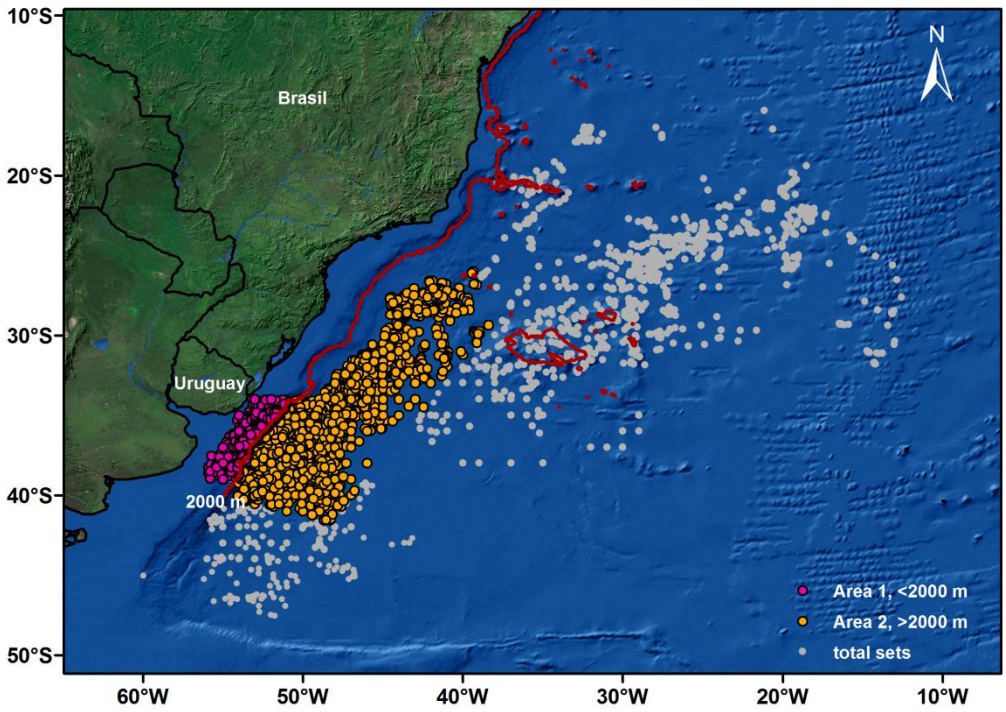

Figure 1. Distribution of longline sets deployed by Uruguayan longline fleet in the Southwestern Atlantic Ocean. Color dots represent the two areas selected for the models: **Area 1**, below 2000 m depth (red line); and **Area 2**, above 2000 m depth. Gray dots were left out of analysis.

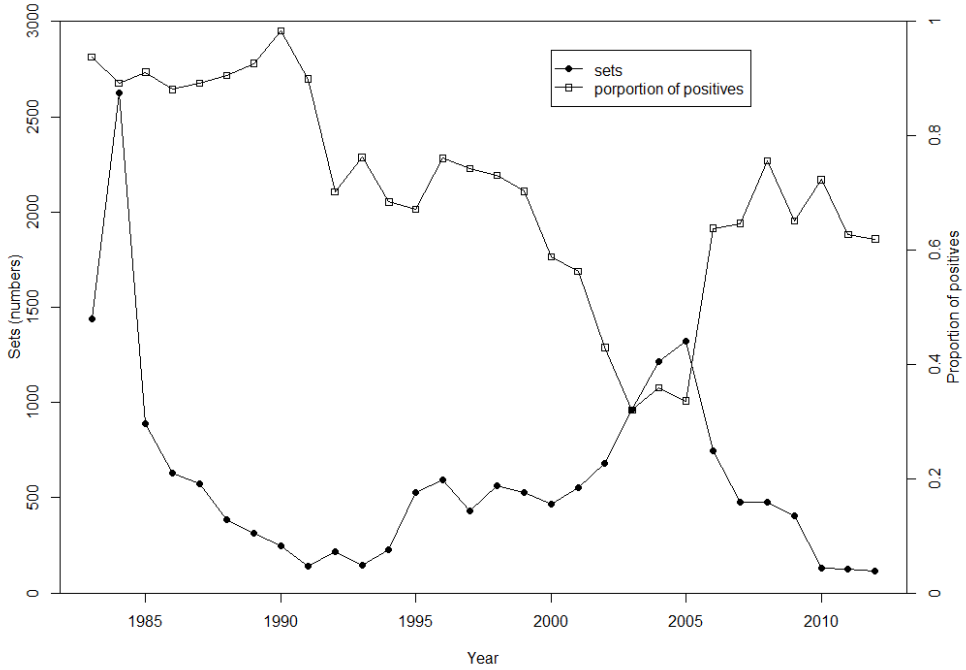

Figure 2. Number of sets and proportion of albacore positive sets by year (1983-2012) for the Uruguayan longline fleet.

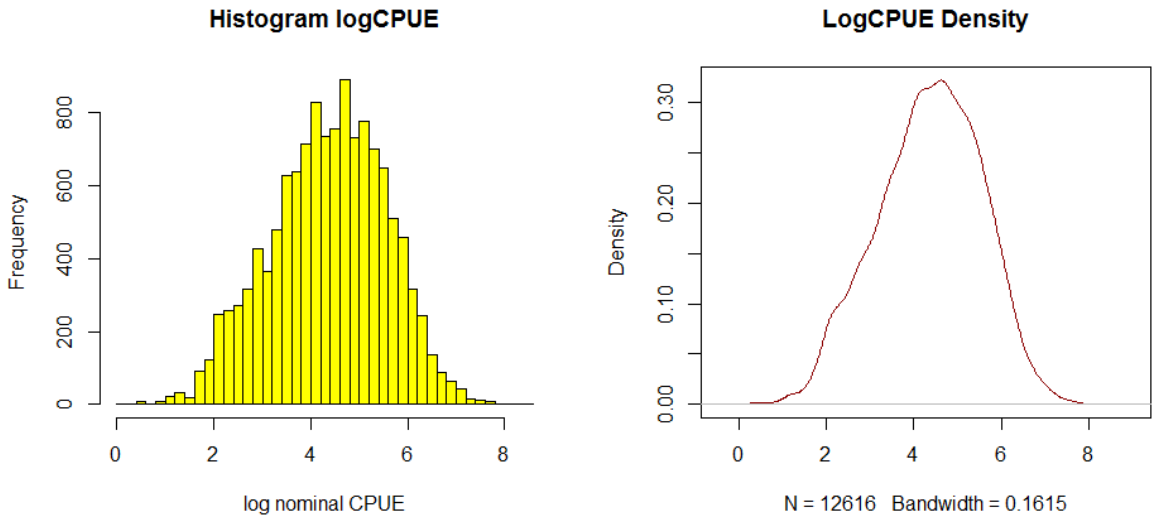

Figure 3. Frequency distribution of Log-tranformed nominal CPUE for positive sets of albacore cauht by Uruguayan longliners between 1983 and 2012.

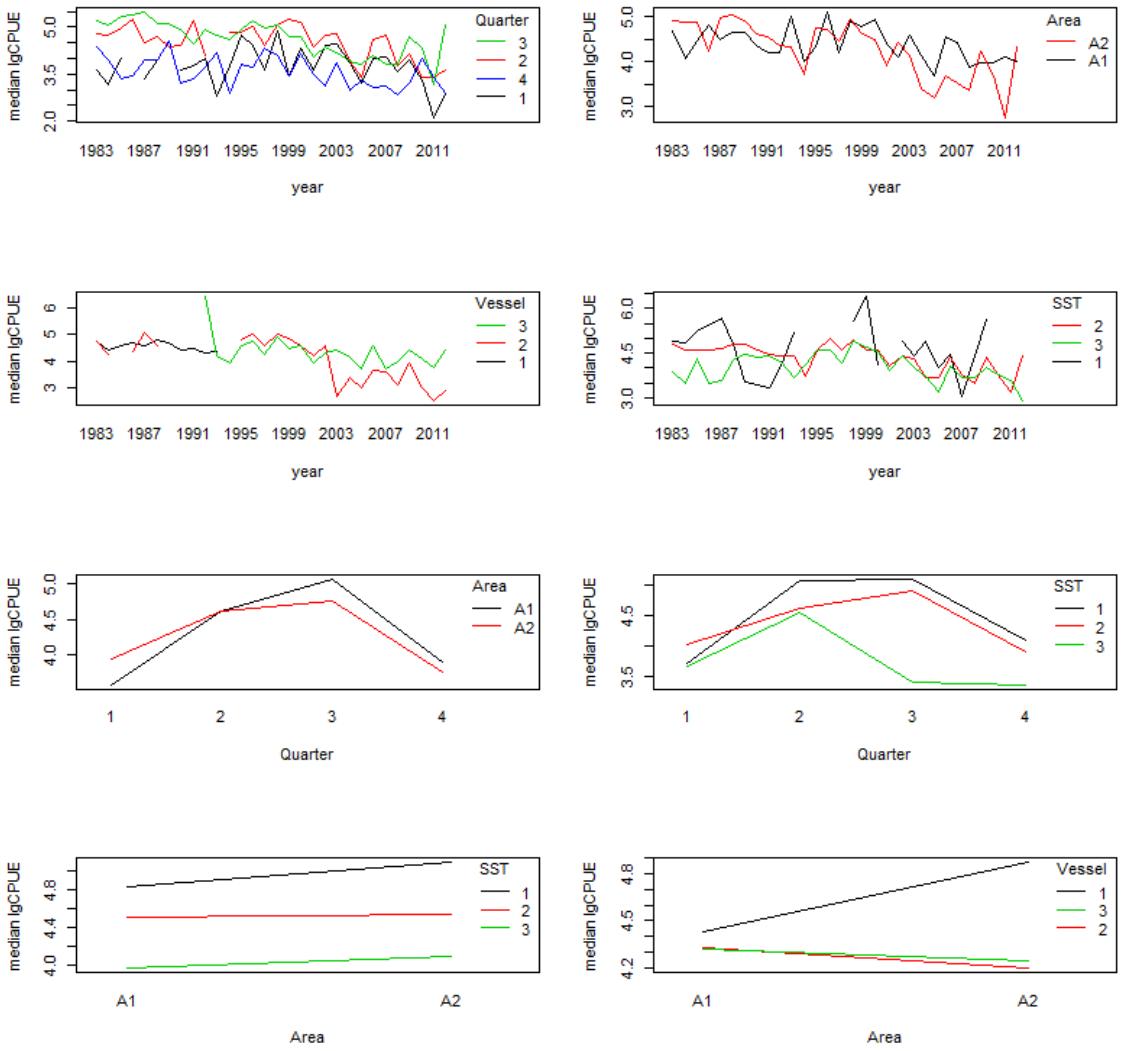

Figure 4. Interaction plots between factors for the logCPUE (Year, SST, Area, Quarter and Vessel cluster).

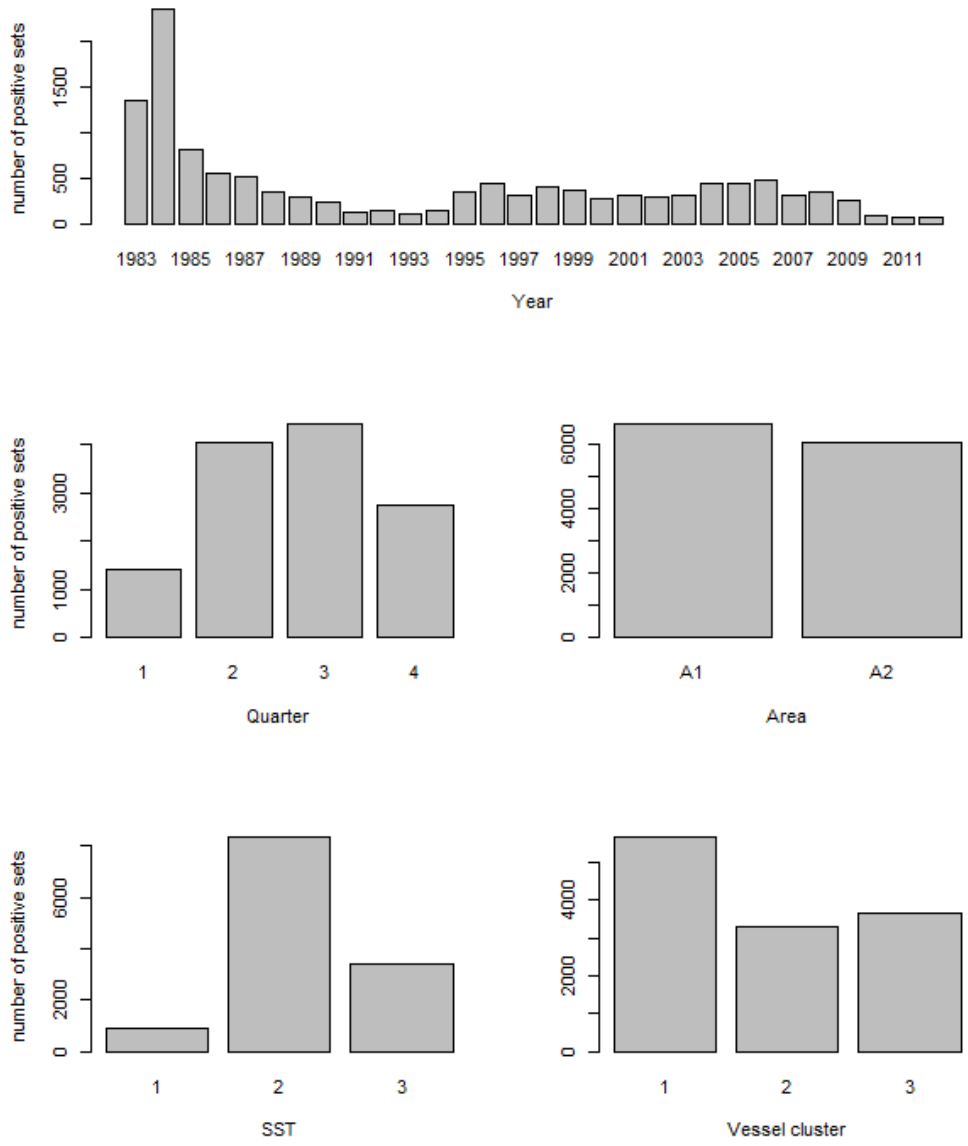

Figure 5. Number of positive sets by factors (Year, SST, Area, Quarter and Vessel cluster).

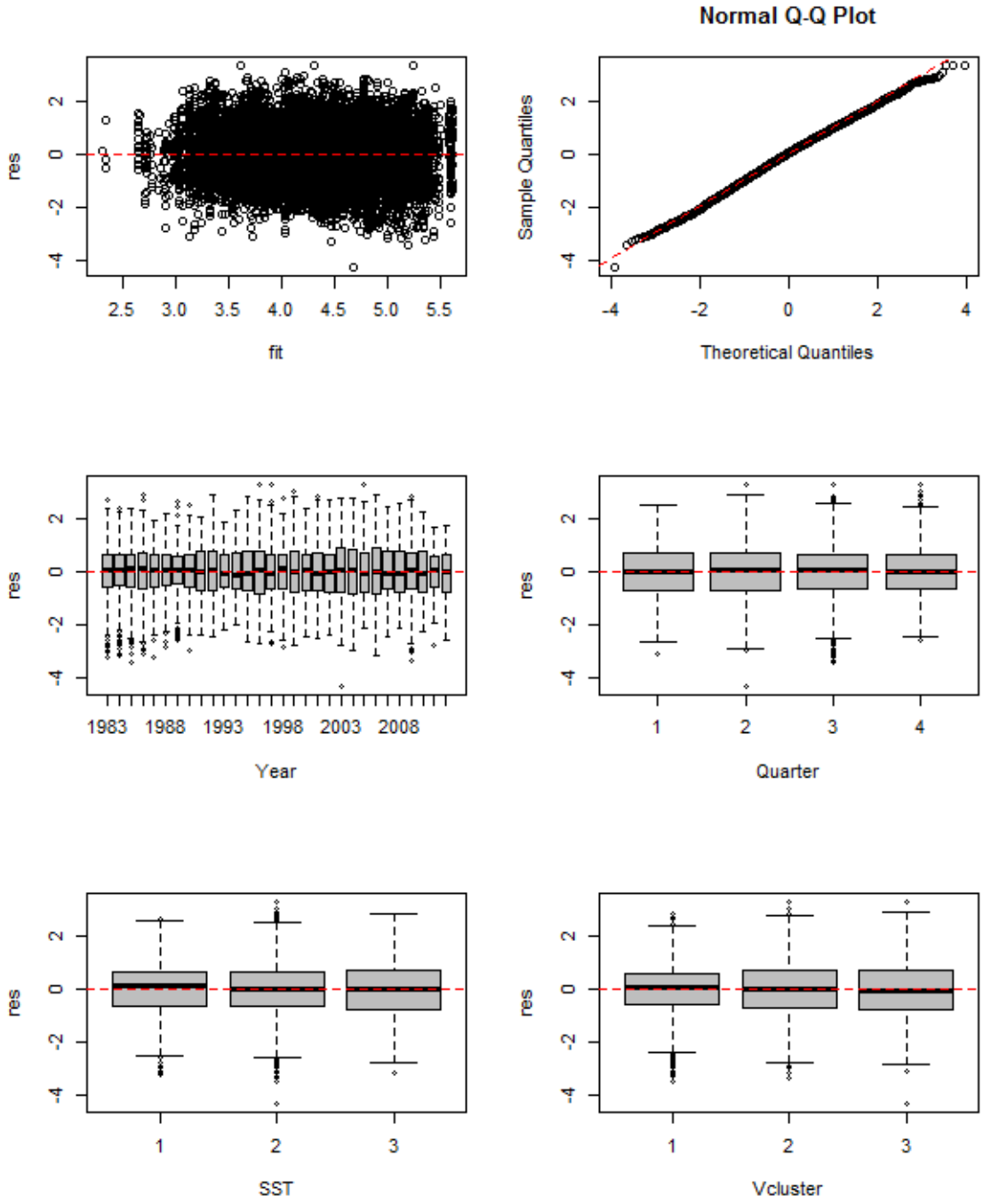

Figure 6. Diagnostic plots for positive albacore catch rates (Lognormal GLMM). In all plots the broken line represents the expected pattern of observations.

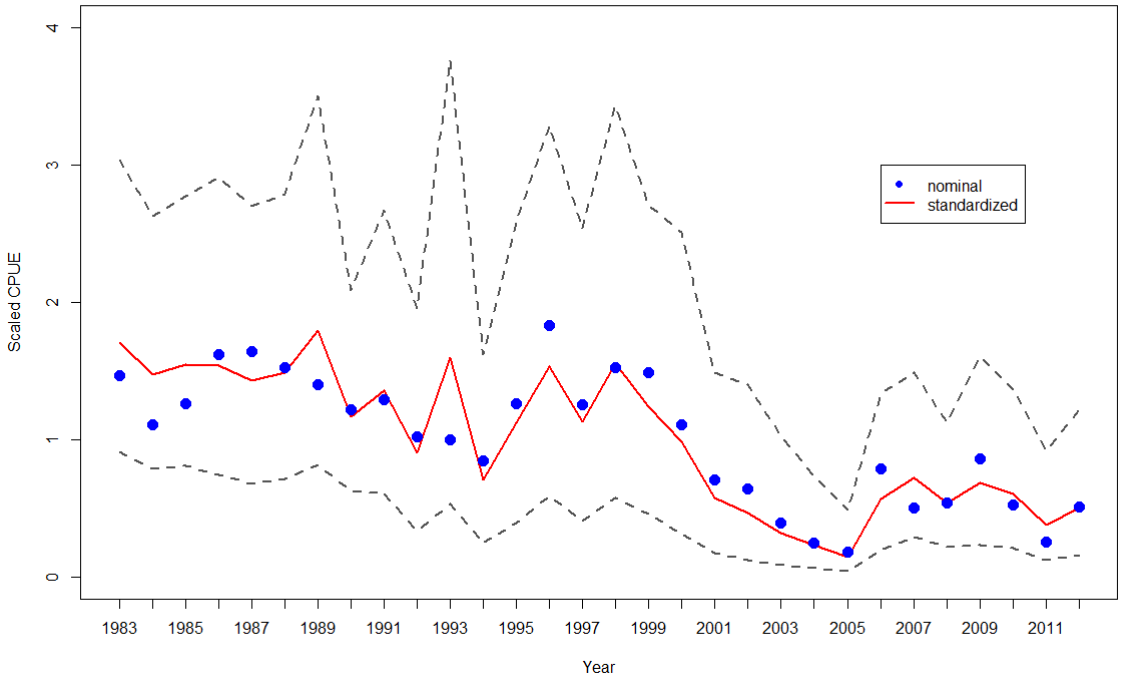

Figure 7. Scaled nominal and standardized indices of abundance in biomass for albacore caught by Uruguayan pelagic longline fleet. Dotted lines correspond to the 95% confidence interval of the estimated standardized index.

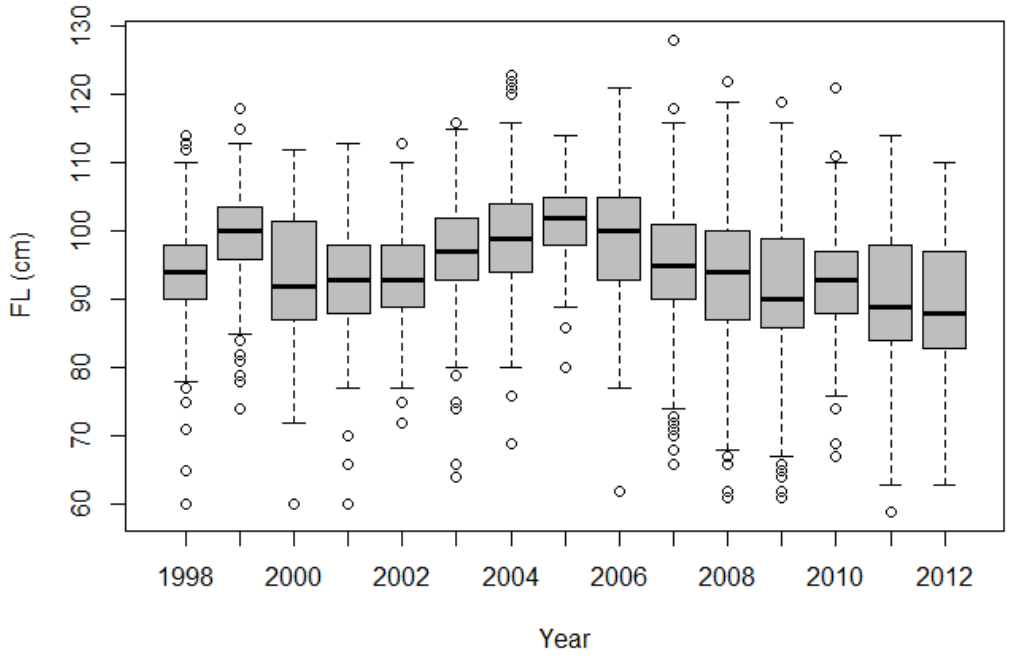

Figure 8. Length frequency (N=5,908) of albacores captured by the Uruguayan tuna fleet (sex combined) per year (1998-2012).