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UPDATE OF STANDARDIZED CPUE OF YELLOWFIN TUNA, *THUNNUS ALBACARES*, CAUGHT BY URUGUAYAN LONGLINERS IN THE SOUTHWESTERN ATLANTIC OCEAN (1982-2010)

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SUMMARY

This study presents an update of the standardized catch rate of yellowfin tuna, Thunnus albacares, *caught by the Uruguayan longline fleet in the Southwestern Atlantic using information from logbooks between 1982 and 2010. Three standardizations are presented, one for the whole period and two for shorter periods divided based on vessels and gear characteristics, and target species. Because of the large proportion of zeros catches (45%) 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 first-order interactions were: Year, Quarter, Area, Sea Surface Temperature, Storage and Vessel cluster. A total of 19,057 sets were analyzed. The standardized CPUE series of yellowfin tuna caught by the Uruguayan longline fleet shows a decreasing trend.*

RÉSUMÉ

*La présente étude fournit une actualisation du taux de capture standardisé de l'albacore (*Thunnus albacares*) capturé par la flottille palangrière uruguayenne dans l'Atlantique Sud-Ouest, calculé au moyen d'informations provenant des carnets de pêche couvrant les années 1982 à 2010. Trois standardisations sont présentées: la première concerne la période complète et les deux autres portent sur des périodes plus courtes divisées sur la base des caractéristiques des engins, des navires et des espèces cibles. Compte tenu de la quantité élevée de prises zéros (45%), 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 interactions de premier ordre étaient : année, trimestre, zone, température de la surface de l'eau, stockage et catégorie de navires. Au total, 19.057 opérations ont été analysées. Les séries de CPUE standardisée d'albacore capturé par la flottille palangrière uruguayenne montrent une légère diminution.*

RESUMEN

Este estudio presenta una actualización de la tasa de captura estandarizada del rabil, Thunnus albacares, capturado por la flota de palangre uruguaya en el Atlántico sudoccidental utilizando información de los cuadernos de pesca entre 1982 y 2010. Se presentan tres estandarizaciones, una para todo el periodo y dos para periodos más breves divididos basándose en las características de los buques y los artes y de las especies objetivo. A causa de la elevada proporción de capturas cero (45%), 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, almacenaje y categoría de buque. Se analizaron en total 19.057 lances. La serie de CPUE estandarizada de rabil capturado por la flota de palangre uruguaya muestra una tendencia descendente.

KEYWORDS

Yellowfin tuna, CPUE, Southwestern Atlantic, logbooks, GLMM

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1. Introduction

The Uruguayan tuna fleet began its activities in 1981 mainly targeting bigeye tuna, *Thunnus obesus* and some for albacore *Thunnus alalunga*. The fleet was composed mainly of large-scale freezing vessels operating with Japanese-type longline (Rios *et al*., 1986; Mora, 1988; Pons *et al.*, 2012). 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* and some for blue shark, *Prionace glauca.*

The present study updates the standardized catch rate of yellowfin tuna captured by the Uruguayan longline fleet presented in Pons and Domingo (2009) up to 2010. As in previous standardization for other species, we also used two periods (1982-1991 and 1992-2010) as well as the complete series (1982-2010).

2. Material and methods

2.1 Data reduction and exclusions

We analyzed data from logbooks from the Uruguayan longline fleet operating in the Southwestern Atlantic Ocean between 1981 and 2010. The first year of the fleet was removed from the analysis as it started operating at the end of the year. Sets with no location information and/or no Sea Surface Temperature (SST) data, and spatial cells where the fleet operated occasionally were not considered for the analysis. A total of 682 (3.5%) sets were removed for the analysis. **Figure 1** shows distribution of the effort (sets) and in white dots sets removed.

2.2 Dataset

From each fishing set the following information was used: date, geographical position (latitude and longitude) and SST at the beginning of the set, effort (in thousands of hooks), and weight (in kilograms) of yellowfin tuna caught. Catch per unit of effort (CPUE) was calculated as kilograms of yellowfin tuna caught per 1,000 hooks.

We defined two areas for the analysis according to the distribution of the effort. *Area 1*, 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 (**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).

For the whole period we also use the *Storage* type (fresh-fishing vessel or Freezer vessels) and a *Vessel cluster* prepared by Pons et al. (2012) to account for the variability between different vessels of the Uruguayan tuna fleet by grouping them according to similar characteristic (e.i. length, gross register tonnage, and engine power).

2.3 Standardized methods

Because of a large proportion of zero catches (between 33 and 52% depending on the period of study) 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.

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**.

All the analyses were conducted using the R software (R Development Core Team 2014) with the packages MASS (Venables *et al.* 2002), lme4 (Bates *et al.* 2014), lsmeans (Lenth and Hervé, 2015) and pbkrtest (Halekoh and Højsgaard, 2014).

3. Results and discussion

3.1 1982 – 1991

We analyzed a total of 7,740 sets from 1982 to 1991 with complete information. The percentage of sets that captured yellowfin tuna (positive sets) respect to the total sets was 67% for the entire period, with a maximum of almost 93% in 1982 and a minimum of 50% in 1990 (**Figure 2**).

Frequency distribution of the log-transformed nominal CPUE for positive sets of yellowfin tuna is presented in **Figure 3**. **Figure 4** shows the number of positive sets by factor.

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

Binomial Model: positive/total= Year + Quarter + Area + SST + Quarter:Area + 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 5**).

Final standardized CPUE of yellowfin tuna for the period 1982 – 1991 is shown in **Table 4** and **Figure 6**. The standardized series of yellowfin tuna showed great variability for the period 1982 to 1991.

3.2 1992 – 2010

We analyzed a total of 11,317 sets from 1992 to 2010 with complete information. The percentage of sets that captured yellowfin tuna (positive sets) respect to the total sets was 48% for the entire period, with a maximum of 80% in 1992 and a minimum of 8% in 2009 (**Figure 2**).

Frequency distributions of the log-transformed nominal CPUE for positive sets of yellowfin tuna are presented in **Figure 7**. **Figure 8** shows the number of positive sets by factor.

Deviance table analysis, one for Lognormal and other for the Binomial models, are shown in **Tables 5a** and **5b** respectively. For the mean catch rates given in the positive sets, the factors *Year*, *Quarter, Area, SST,* and the interactions *Year:Quarter, Year:Area* and *Year:SST* were significant (**Table 5a**). In addition, for the proportion of positive/total sets the factors *Year*, *Quarter*, *Area, SST,* and the interactions *Year:Quarter*, *Year:Area* and *Year:SST* were significant (**Table 5b**).

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 6**) the final models selected for the Lognormal and Binomial components were:

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

Binomial Model: positive/total= Year + Quarter + Area + 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 9**).

Final standardized CPUE of yellowfin tuna for the period 1992 – 2010 is shown in **Table 7** and **Figure 10**. The standardized series of yellowfin tuna showed a decreasing trend from 1992 to 2010.

3.3 1982 – 2010

We analyzed a total of 19,057 sets from 1982 to 2010 with complete information. The percentage of sets that captured yellowfin tuna (positive sets) respect to the total sets was 55% for the entire period, with a maximum of almost 93% in 1982 and a minimum of 8% in 2009 (**Figure 2**).

Frequency distributions of the log-transformed nominal CPUE for positive sets of yellowfin tuna are presented in **Figure 11**. **Figure 12** shows the number of positive sets by factor.

Deviance table analysis, one for Lognormal and other for the Binomial models, are shown in **Tables 8a** and **8b** respectively. For the mean catch rates given in the positive sets, the factors *Year*, *Quarter, Area, SST, Storage*, and the interactions *Year:Quarter, Year:Area, Year:SST* and *Quarter:Area* were significant (**Table 8a**). In addition, for the proportion of positive/total sets the factors *Year*, *Quarter*, *Area*, *SST*, and the interaction *Year:Area, Year:Quarter* and *Year:SST* were significant (**Table 8b**).

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 9**) the final models selected for the Lognormal and Binomial components were:

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

Binomial Model: positive/total= Year + Quarter + Area + SST + Quarter:Area + Random (Year:Area) + (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 13**).

Final standardized CPUE of yellowfin tuna for the period 1982 – 2010 is shown in **Table 10** and **Figure 14**. The standardized series of yellowfin tuna showed a decreasing trend from 1982 to 2010.

It is worth mentioning that convergence was problematic in the binomial model (proportion of positive sets) for the three time series used. However, given the reasonable coefficients of variation and the confidence intervals of the parameter estimates, the final model seems to have fitted well.

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

Variable	Type	Observations
Year	Categorical *(10), **(19), ***(29)	Period: 1982-2010
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)	Area 1: < 2000 m depth Area 2: > 2000 m depth
Storage	Categorical ***(2)	C: Fresh-fishing vessels F: Freezer vessels
Vessel cluster (Vcluster)	Categorical ***(3)	See: Pons et al. 2012 (SCRS/2011/114)

* Period 1982-1991
** Period 1992-2010
*** Period 1982-2010

Table 2. Deviance analysis table of positive catch rates (Lognormal) and proportion of positive sets (Binomial) models using CPUE for the period 1982 – 1991. '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	8824		
Year	9	7944	879	40.38
Year + Quarter	3	6950	994	45.66
Year + Quarter + Area	1	6670	281	12.90
Year + Quarter + Area+ SST	2	6647	23	1.05
Year + Quarter + Area+ SST + Year:Quarter	26	6034	613	21.97
Year + Quarter + Area+ SST + Year:Area	9	6552	95	4.16
Year + Quarter + Area+ SST + Year:SST	18	6472	175	7.43
Year + Quarter + Area+ SST + Quarter:SST	6	6597	50	2.24
Year + Quarter + Area+ SST + Quarter:Area	3	6636	10	0.48
Year + Quarter + Area+ SST + Area:SST	2	6642	5	0.23

b) Model factors proportion positives	**d.f.**	**Residual deviance**	**Change in deviance**	**% of total deviance**
NULL	1	3218		
Year	9	2896	323	16.30
Year + Quarter	3	2187	709	35.79
Year + Quarter + Area	1	1550	636	32.14
Year + Quarter + Are a+ SST	2	1238	312	15.78
Year + Quarter + Area + SST + Year:Area	9	1116	122	5.79
Year + Quarter + Area + SST + Year:Quarter	26	910	328	14.21
Year + Quarter + Area + SST + Year:SST	18	1072	166	7.75
Year + Quarter + Area + SST + Quarter:SST	6	1191	47	2.31
Year + Quarter + Area + SST + Quarter:Area	3	1012	226	10.23
Year + Quarter + Area + SST + Area:SST	2	1232	6	0.32

Table 3. Analyses of the delta lognormal mixed model formulations for yellowfin tuna CPUE from the Uruguayan pelagic longline fishery (1982-1991).

GLMM	**Akaike's Information Criterion**	**Bayesian Information Criterion**	**Log Likelihood**	**Likelihood Ratio Test**
Positives catch rates				
Year Quarter Area SST	15971	16089	-7968	
Year Quarter Area SST *Year:SST*	15910	16027	-7937	<0.0001
Year Quarter Area SST *Year:Quarter*	15611	15728	-7787	<0.0001
Year Quarter Area SST *Year:Quarter Year:SST*	15601	15726	-7781	<0.0001
Proportion of positives				
Year Quarter Area SST Quarter:Area	1551	1620	-755	
Year Quarter Area SST Quarter:Area *Year:SST*	1490	1559	-725	<0.0001
Year Quarter Area SST Quarter:Area *Year:Quarter*	1403	1472	-681	<0.0001
Year Quarter Area SST Quarter:Area *Year:Area*	1503	1572	-731	1
Year Quarter Area SST Quarter:Area *Year:Quarter Year:SST*	1353	1426	-656	<0.0001
Year Quarter Area SST Quarter:Area *Year:Area Year:SST*	1443	1516	-701	1
Year Quarter Area SST Quarter:Area *Year:Area Year:Quarter*	1323	1396	-641	<0.0001
Year Quarter Area SST Quarter:Area *Year:Area Year:Quarter Year:SST*	1293	1369	-625	<0.0001

Table 4. Nominal and standardized index of relative abundance (CPUE) of yellowfin tuna in weight (kg) for the Uruguayan pelagic longline fleet (1982-1991). CV=coefficients of variation for the standardized index. SC= Scaled standardized CPUE.

Year	N Observations	Nominal CPUE	Standard CPUE	CV	SC
1982	373	14.16	245.39	0.51	2.44
1983	1266	6.49	68.62	0.57	0.68
1984	2200	3.29	41.02	0.57	0.41
1985	1608	5.84	81.20	0.55	0.81
1986	668	9.35	128.61	0.56	1.28
1987	540	7.38	65.90	0.57	0.66
1988	391	13.96	147.29	0.60	1.47
1989	312	4.13	49.03	0.68	0.49
1990	243	3.72	20.84	0.63	0.21
1991	139	12.60	157.28	0.58	1.56

Table 5. Deviance analysis table of positive catch rates (Lognormal) and proportion of positive sets (Binomial) models using CPUE for the period 1992 – 2010. '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	10588		
Year	18	9701	888	33.02
Year + Quarter	3	9484	217	8.07
Year + Quarter + Area	1	7956	1527	56.82
Year + Quarter + Area+ SST	2	7900	56	2.09
Year + Quarter + Area+ SST + Year:Quarter	53	7520	380	12.38
Year + Quarter + Area+ SST + Year:Area	18	7656	244	8.33
Year + Quarter + Area+ SST + Year:SST	29	7721	179	6.25
Year + Quarter + Area+ SST + Quarter:SST	5	7886	14	0.52
Year + Quarter + Area+ SST + Quarter:Area	3	7888	12	0.46
Year + Quarter + Area+ SST + Area:SST	2	7884	16	0.60

b) Model factors proportion positives	d.f.	Residual deviance	Change in deviance	% of total deviance
NULL	1	4487		
Year	18	3728	759	38.27
Year + Quarter	3	3325	403	20.32
Year + Quarter + Area	1	2610	715	36.06
Year + Quarter + Area+ SST	2	2504	106	5.34
Year + Quarter + Area+ SST + Year:Area	18	2307	196	9.01
Year + Quarter + Area+ SST + Year:Quarter	54	1958	546	21.59
Year + Quarter + Area+ SST + Year:SST	30	2144	360	15.35
Year + Quarter + Area+ SST + Quarter:SST	5	2428	76	3.67
Year + Quarter + Area+ SST + Quarter:Area	3	2433	71	3.45
Year + Quarter + Area+ SST + Area:SST	2	2439	64	3.15

Table 6. Analyses of the delta lognormal mixed model formulations for yellowfin tuna CPUE from the Uruguayan pelagic longline fishery (1992-2010).

GLMM	**Akaike's Information Criterion**	**Bayesian Information Criterion**	**Log Likelihood**	**Likelihood Ratio Test**
Positives catch rates				
Year Quarter Area SST	17453	17631	-8699	
Year Quarter Area SST *Year:SST*	17431	17609	-8688	<0.0001
Year Quarter Area SST *Year:Area*	17372	17550	-8659	<0.0001
Year Quarter Area SST *Year:Quarter*	17371	17549	-8658	<0.0001
Year Quarter Area SST *Year:Area Year:SST*	17338	17522	-8641	<0.0001
Year Quarter Area SST *Year:Quarter Year:SST*	17363	17548	-8653	1.00000
Year Quarter Area SST *Year:Quarter Year:Area*	17273	17458	-8609	<0.0001
Year Quarter Area SST *Year:Quarter Year:Area Year:SST*	17265	17457	-8604	0.001
Proportion of positives				
Year Quarter Area SST	3688	3798	-1818	
Year Quarter Area SST *Year:SST*	3492	3602	-1720	<0.0001
Year Quarter Area SST *Year:Quarter*	3383	3494	-1666	<0.0001
Year Quarter Area SST *Year:Area*	3595	3705	-1771	1
Year Quarter Area SST *Year:Quarter Year:SST*	3263	3378	-1605	<0.0001
Year Quarter Area SST *Year:Area Year:SST*	3398	3513	-1672	1
Year Quarter Area SST *Year:Area Year:Quarter*	3278	3393	-1612	<0.0001
Year Quarter Area SST *Year:Area Year:Quarter Year:SST*	3178	3296	-1561	<0.0001

Table 7. Nominal and standardized index of relative abundance (CPUE) of yellowfin tuna in weight (kg) for the Uruguayan pelagic longline fleet (1992-2010). CV=coefficients of variation for the standardized index. SC= Scaled standardized CPUE.

Year	N Observations	Nominal CPUE	Standard CPUE	CV	SC
1992	198	12.69	191.51	0.63	1.76
1993	147	1.27	34.80	0.76	0.32
1994	227	17.35	217.38	0.67	2.00
1995	545	7.52	139.91	0.67	1.29
1996	627	14.63	228.80	0.67	2.11
1997	493	4.53	146.71	0.69	1.35
1998	563	4.29	196.94	0.66	1.81
1999	538	4.81	118.96	0.68	1.09
2000	465	7.68	138.00	0.68	1.27
2001	553	5.86	102.21	0.67	0.94
2002	683	4.07	45.14	0.64	0.42
2003	1056	3.47	66.60	0.64	0.61
2004	1354	4.68	58.47	0.64	0.54
2005	1423	13.66	126.50	0.65	1.16
2006	816	5.72	101.25	0.68	0.93
2007	527	1.76	56.94	0.68	0.52
2008	516	1.97	30.47	0.66	0.28
2009	444	0.11	3.56	0.68	0.03
2010	142	4.43	60.32	0.74	0.56

Table 8. Deviance analysis table of positive catch rates (Lognormal) and proportion of positive sets (Binomial) models using CPUE for the period 1982 – 2010. '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	19944		
Year	28	17645	2299	42.54
Year + Quarter	3	16710	935	17.31
Year + Quarter + Area	1	14966	1744	32.26
Year + Quarter + Area+ SST	2	14879	87	1.61
Year + Quarter + Area+ SST + Vcluster	2	14815	63	1.17
Year + Quarter + Area+ SST + Vcluster + Storage	1	14539	276	5.10
Year + Quarter + Area+ SST + Vcluster + Storage + Year:Quarter	82	13366	1173	17.84
Year + Quarter + Area+ SST + Vcluster + Storage +Year:Area	28	14216	323	5.64
Year + Quarter + Area+ SST + Vcluster + Storage +Year:SST	49	14097	442	7.57
Year + Quarter + Area+ SST + Vcluster + Storage +Quarter:SST	6	14515	25	0.46
Year + Quarter + Area+ SST + Vcluster + Storage + Quarter:Area	3	14525	14	0.26
Year + Quarter + Area+ SST + Vcluster + Storage + Quarter:Vcluster	6	14357	183	3.27
Year + Quarter + Area+ SST + Vcluster + Storage + Quarter:Storage	3	14350	189	3.39
Year + Quarter + Area+ SST + Vcluster + Storage + Area:SST	2	14500	40	0.73
Year + Quarter + Area+ SST + Vcluster + Storage + Area:Vcluster	2	14496	43	0.79
Year + Quarter + Area+ SST + Vcluster + Storage + Area:Storage	1	14501	38	0.71
Year + Quarter + Area+ SST + Vcluster + Storage + SST:Vcluster	4	14431	108	1.96
Year + Quarter + Area+ SST + Vcluster + Storage + SST:Storage	2	14423	116	2.10

b) Model factors proportion positives	**d.f.**	**Residual deviance**	**Change in deviance**	**% of total deviance**
NULL	1	8369		
Year	28	6623	1746	37.21
Year + Quarter	3	5801	823	17.53
Year + Quarter + Area	1	4354	1447	30.83
Year + Quarter + Area+ SST	2	3977	377	8.03
Year + Quarter + Area+ SST + Vcluster	2	3873	104	2.22
Year + Quarter + Area+ SST + Vcluster + Storage	1	3677	196	4.18
Year + Quarter + Area+ SST + Vcluster + Storage + Year:Area	28	3344	333	6.63
Year + Quarter + Area+ SST + Vcluster + Storage +Year:Quarter	83	2628	1050	18.28
Year + Quarter + Area+ SST + Vcluster + Storage +Year:SST	50	3032	645	12.08
Year + Quarter + Area+ SST + Vcluster + Storage +Quarter:SST	6	3626	52	1.09
Year + Quarter + Area+ SST + Vcluster + Storage +	3	3394	283	5.69

Quarter:Area				
Year + Quarter + Area+ SST + Vcluster + Storage + Quarter:Vcluster	6	3465	212	4.33
Year + Quarter + Area+ SST + Vcluster + Storage + Quarter:Storage	3	3587	90	1.88
Year + Quarter + Area+ SST + Vcluster + Storage + Area:SST	2	3644	34	0.71
Year + Quarter + Area+ SST + Vcluster + Storage + Area:Vcluster	2	3561	117	2.43
Year + Quarter + Area+ SST + Vcluster + Storage + Area:Storage	1	3564	113	2.36
Year + Quarter + Area+ SST + Vcluster + Storage + SST:Vcluster	4	3496	182	3.73
Year + Quarter + Area+ SST + Vcluster + Storage + SST:Storage	2	3601	76	1.60

Table 9. Analyses of the delta lognormal mixed model formulations for yellowfin tuna CPUE from the Uruguayan pelagic longline fishery (1982 – 2010).

GLMM	**Akaike's Information Criterion**	**Bayesian Information Criterion**	**Log Likelihood**	**Likelihood Ratio Test**
Positives catch rates				
Year Quarter Area SST Storage	33437	33713	-16680	
Year Quarter Area SST Storage *Year:SST*	33297	33573	-16611	<0.0001
Year Quarter Area SST Storage *Year:Area*	33332	33608	-16628	1
Year Quarter Area SST Storage *Year:Quarter*	32906	33182	-16415	<0.0001
Year Quarter Area SST Storage *Year:Area Year:SST*	33159	33443	-16541	1
Year Quarter Area SST Storage *Year:Quarter Year:SST*	32887	33170	-16404	<0.0001
Year Quarter Area SST Storage *Year:Quarter Year:Area*	32741	33024	-16331	<0.0001
Year Quarter Area SST Storage *Year:Quarter Year:Area Year>SST*	32721	33012	-16320	<0.0001
Proportion of positives				
Year Quarter Area SST Quarter:Area	5411	5591	-2667	
Year Quarter Area SST Quarter:Area *Year:SST*	5023	5203	-2472	<0.0001
Year Quarter Area SST Quarter:Area *Year:Quarter*	4801	4982	-2362	<0.0001
Year Quarter Area SST Quarter:Area *Year:Area*	5220	5400	-2571	1
Year Quarter Area SST Quarter:Area *Year:Quarter Year:SST*	4603	4787	-2261	<0.0001
Year Quarter Area SST Quarter:Area *Year:Area Year:SST*	4853	5037	-2386	<0.0001
Year Quarter Area SST Quarter:Area *Year:Area Year:Quarter*	4587	4772	-2254	<0.0001
Year Quarter Area SST Quarter:Area *Year:Area Year:Quarter Year:SST*	4431	4621	-2175	<0.0001

Table 10. Nominal and standardized index of relative abundance (CPUE) of yellowfin tuna in weight (kg) for the Uruguayan pelagic longline fleet (1982-2010). CV=coefficients of variation for the standardized index. SC= Scaled standardized CPUE.

Year	N Observations	Nominal CPUE	Standard CPUE	CV	SC
1982	373	14.16	460.42	0.60	4.43
1983	1266	6.49	126.01	0.65	1.21
1984	2200	3.29	70.18	0.65	0.68
1985	1608	5.84	132.24	0.63	1.27
1986	668	9.35	236.90	0.63	2.28
1987	540	7.38	115.07	0.65	1.11
1988	391	13.96	228.44	0.68	2.20
1989	312	4.13	71.19	0.74	0.69
1990	243	3.72	39.95	0.71	0.38
1991	139	12.60	271.27	0.66	2.61
1992	198	12.69	262.20	0.63	2.52
1993	147	1.27	31.90	0.76	0.31
1994	227	17.35	108.56	0.68	1.04
1995	545	7.52	68.87	0.68	0.66
1996	627	14.63	113.13	0.68	1.09
1997	493	4.53	87.71	0.69	0.84
1998	563	4.29	103.27	0.67	0.99
1999	538	4.81	59.66	0.69	0.57
2000	465	7.68	66.41	0.69	0.64
2001	553	5.86	51.50	0.68	0.50
2002	683	4.07	25.00	0.65	0.24
2003	1056	3.47	38.34	0.65	0.37
2004	1354	4.68	35.13	0.65	0.34
2005	1423	13.66	71.39	0.66	0.69
2006	816	5.72	53.80	0.70	0.52
2007	527	1.76	34.17	0.68	0.33
2008	516	1.97	20.59	0.66	0.20
2009	444	0.11	2.19	0.66	0.02
2010	142	4.43	27.79	0.73	0.27

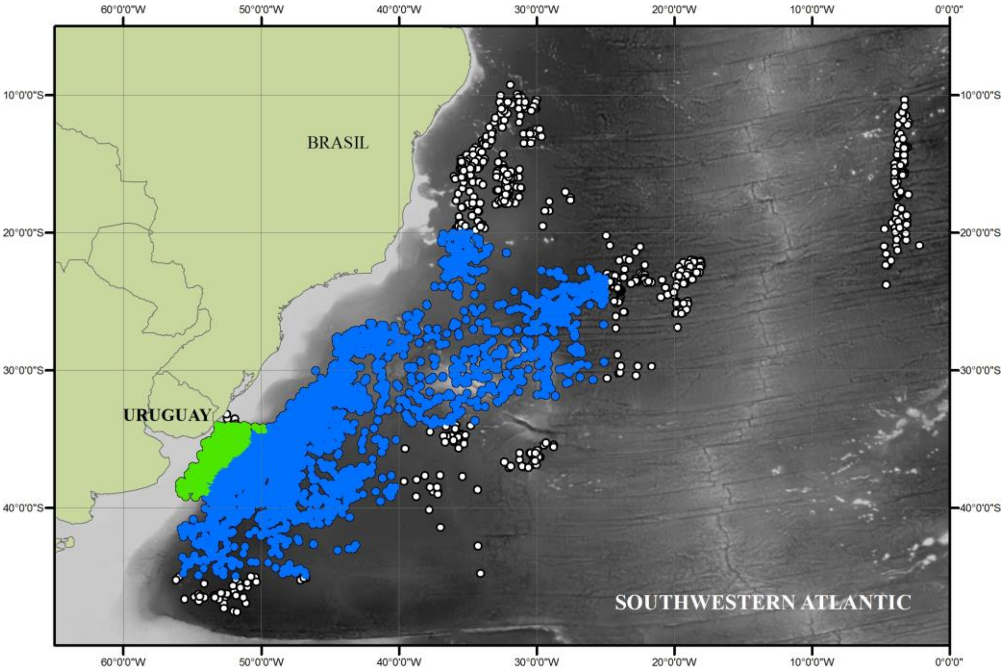

Figure 1. Distribution of longline sets deployed by Uruguayan longline fleet in the Southwestern Atlantic Ocean. Green and blue dots represent the two areas selected for the models: Area 1, below 2000 m depth (red line); and Area 2, above 2000 m depth. White dots were left out of analysis.

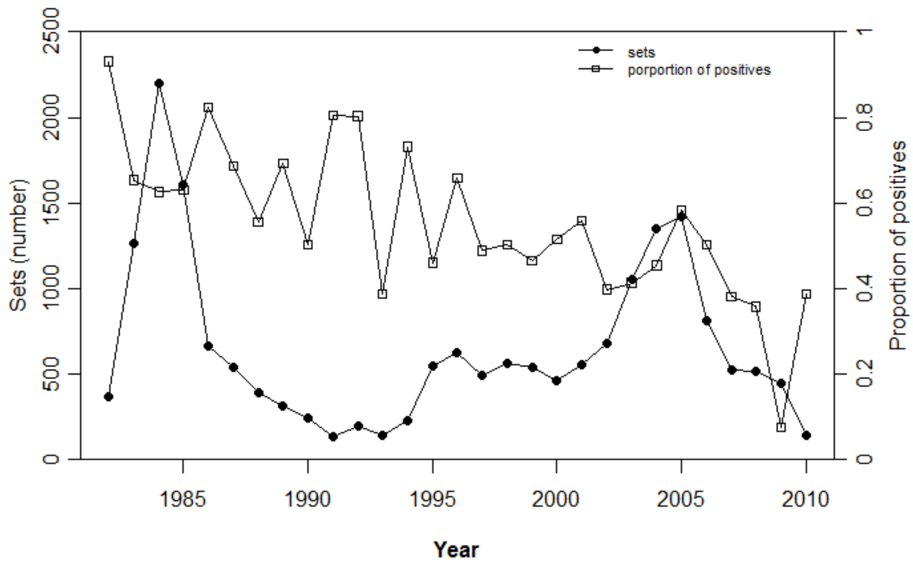

Figure 2. Number of sets and proportion of yellowfin tuna positive sets by year (1982-2010) for the Uruguayan longline fleet.

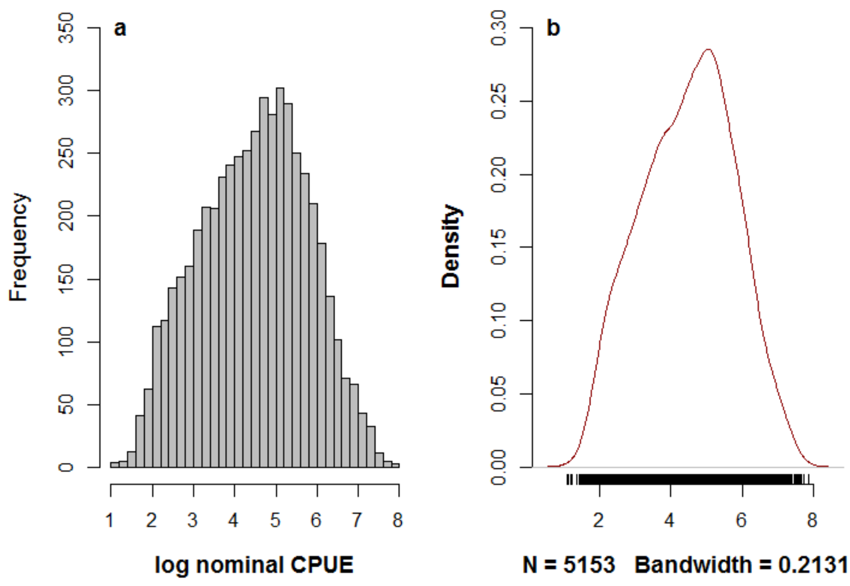

Figure 3. Frequency distribution of Log-tranformed nominal CPUE for positive sets of yellowfin tuna caught by Uruguayan longliners between 1982 and 1991.

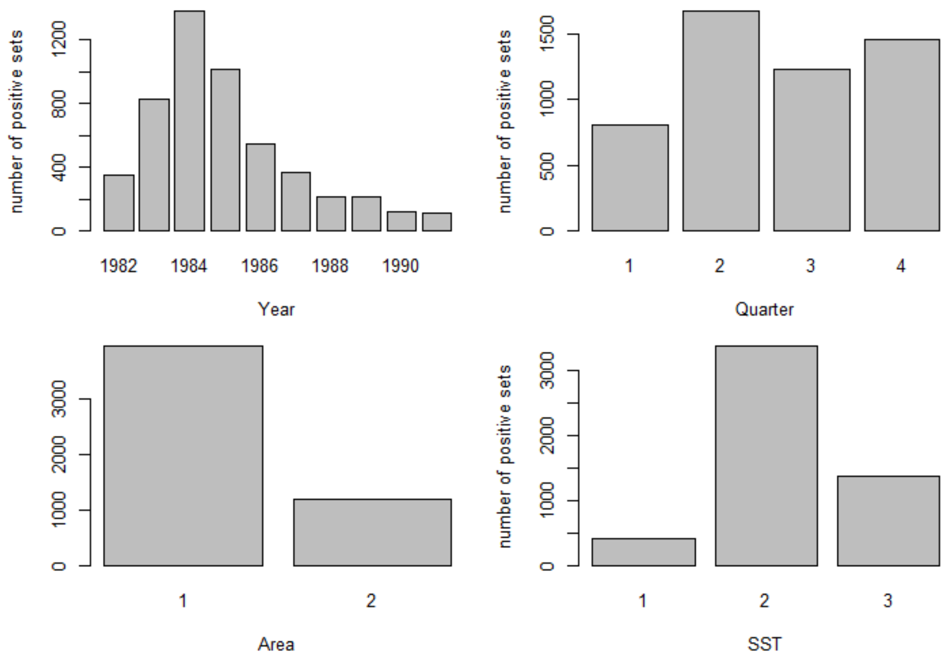

Figure 4. Number of positive sets by factors (Year, Quarter, Area and SST) for the period 1982-1991.

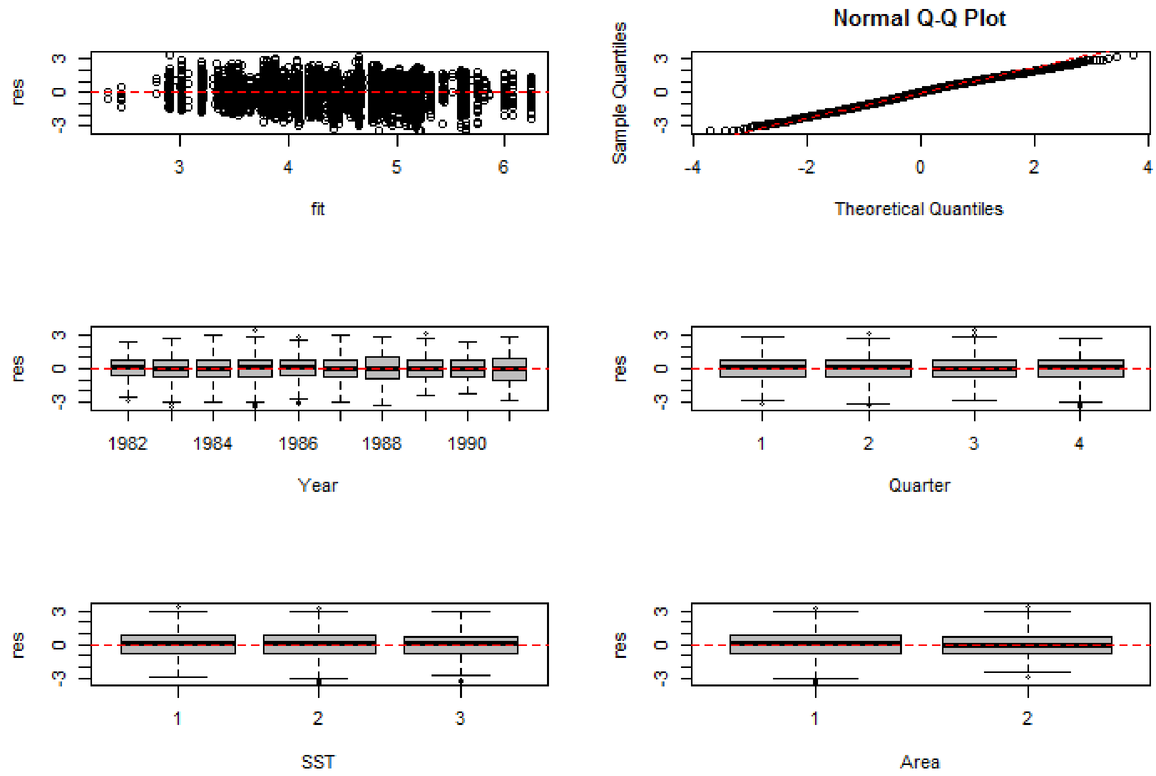

Figure 5. Diagnostic plots for positive yellowfin tuna catch rates (CPUE, Lognormal GLMM) for the period 1982-1991. In all plots the broken line represents the expected pattern of observations.

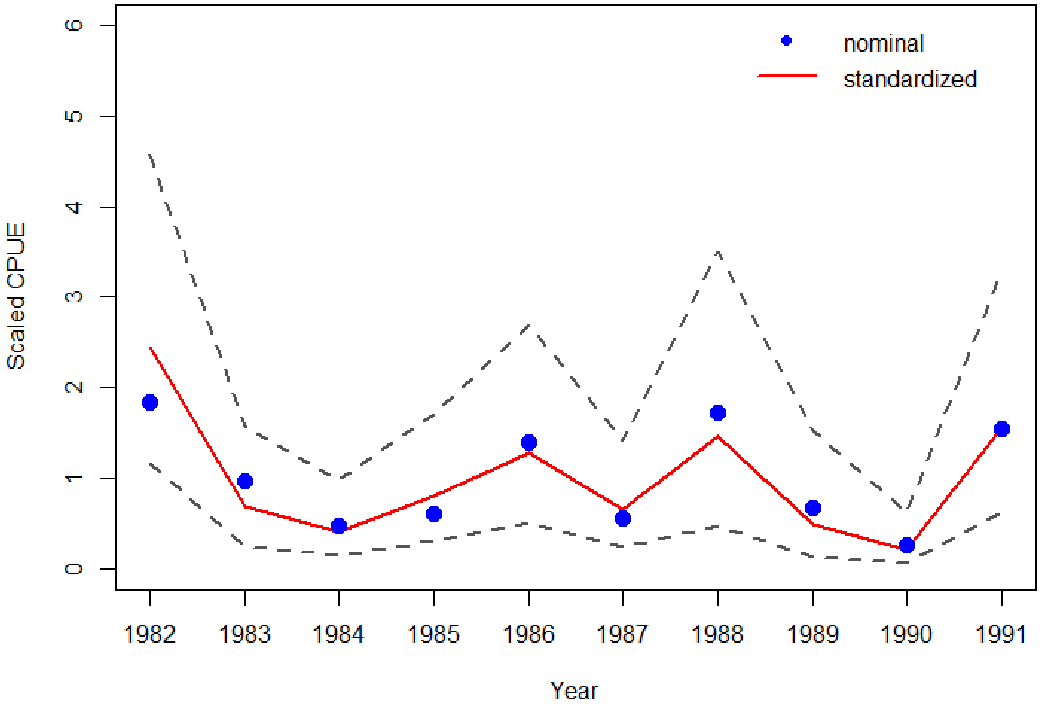

Figure 6. Scaled nominal and standardized index of abundance (CPUE) in biomass for yellowfin tuna caught by Uruguayan pelagic longline fleet in the period 1982-1991. Dotted lines correspond to the 95% confidence interval of the estimated standardized index.

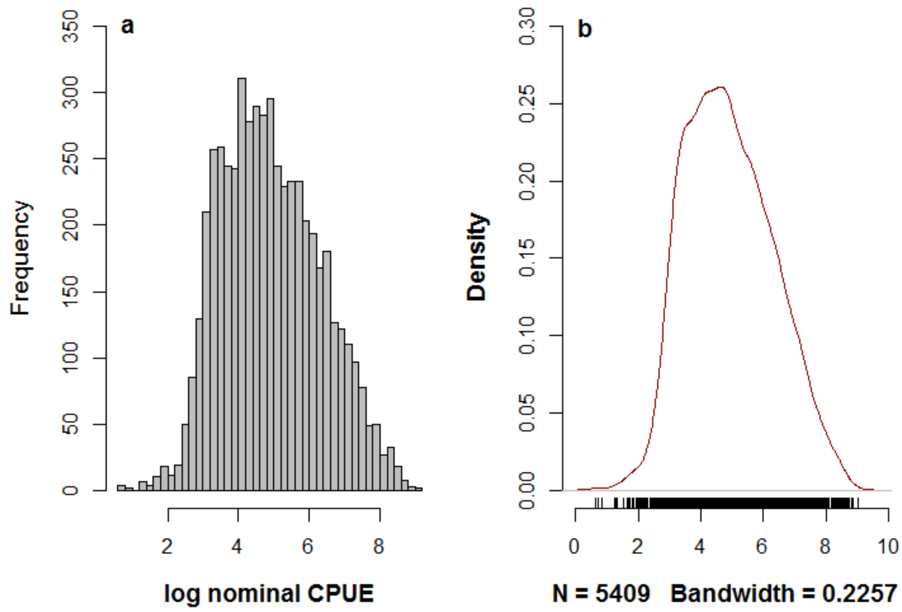

Figure 7. Frequency distribution of Log-tranformed nominal CPUE for positive sets of yellowfin tuna caught by Uruguayan longliners between 1992 and 2010.

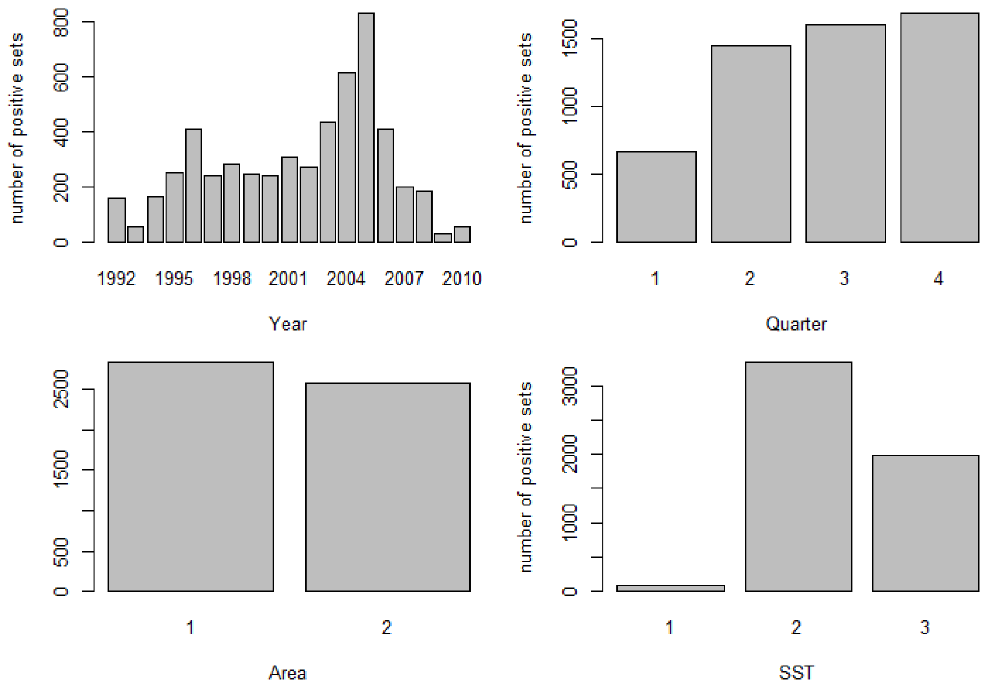

Figure 8. Number of positive sets by factors (Year, Quarter, Area and SST) for the period 1992-2010.

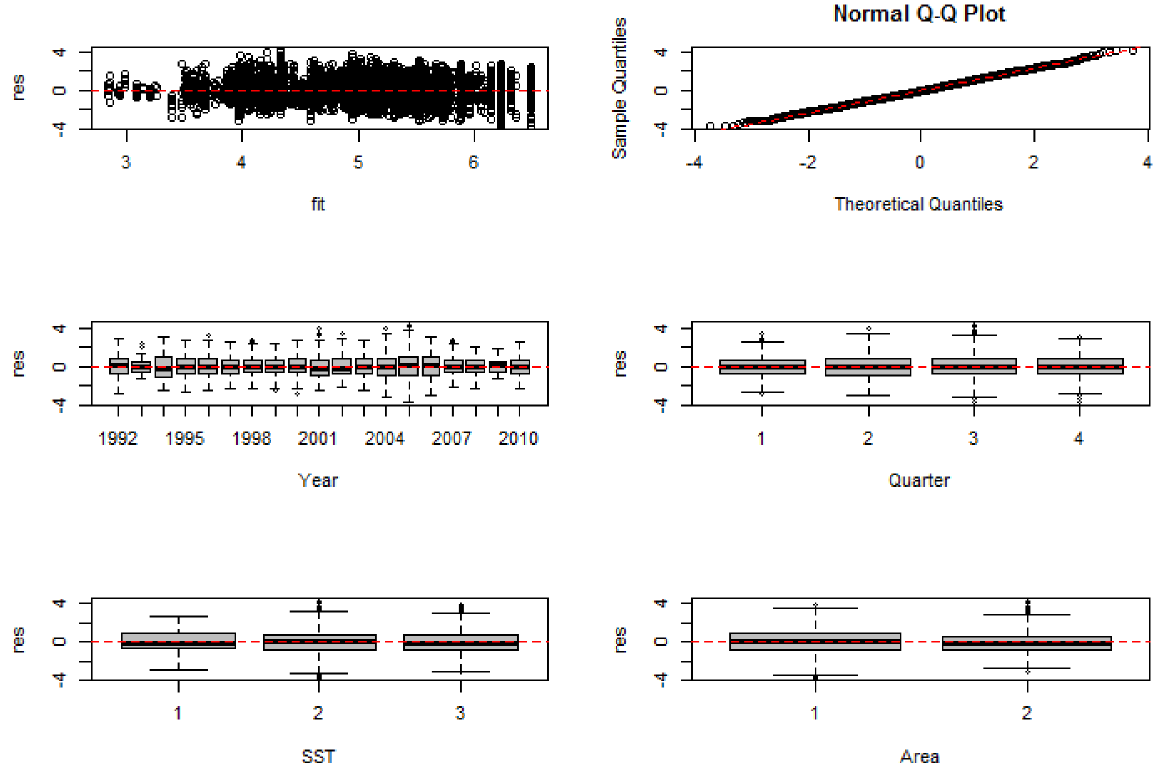

Figure 9. Diagnostic plots for positive yellowfin tuna catch rates (CPUE, Lognormal GLMM) for the period 1992-2010. In all plots the broken line represents the expected pattern of observations.

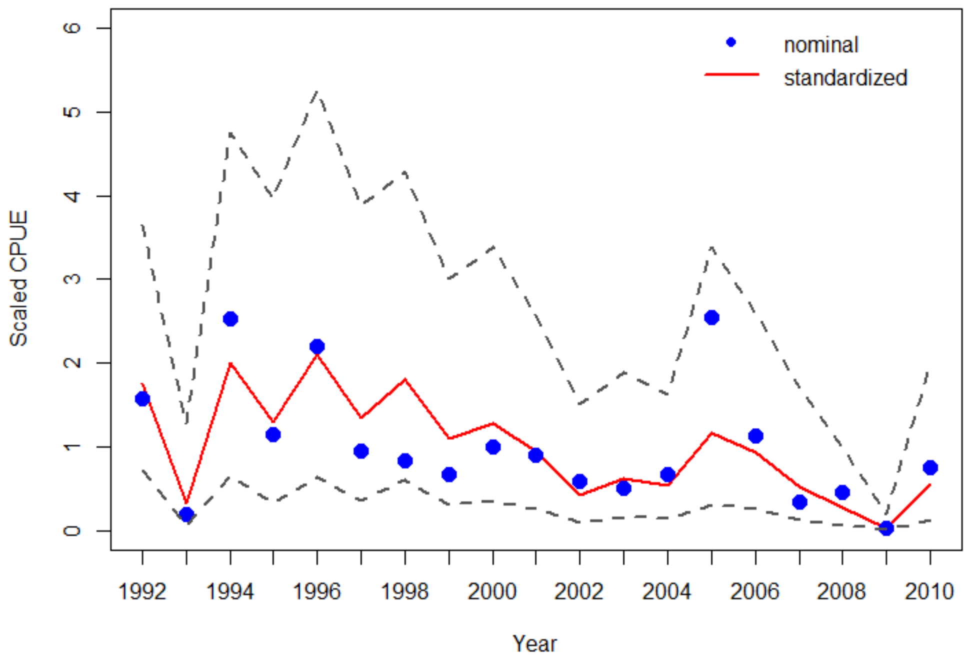

Figure 10. Scaled nominal and standardized index of abundance (CPUE) in biomass for yellowfin tuna caught by Uruguayan pelagic longline fleet in the period 1992-2010. Dotted lines correspond to the 95% confidence interval of the estimated standardized index.

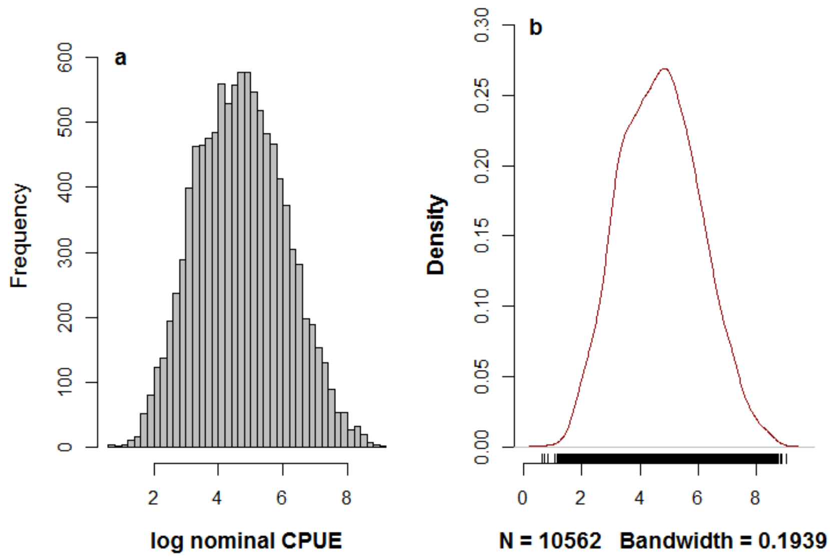

Figure 11. Frequency distribution of Log-tranformed nominal CPUE for positive sets of yellowfin tuna caught by Uruguayan longliners between 1982 and 2010.

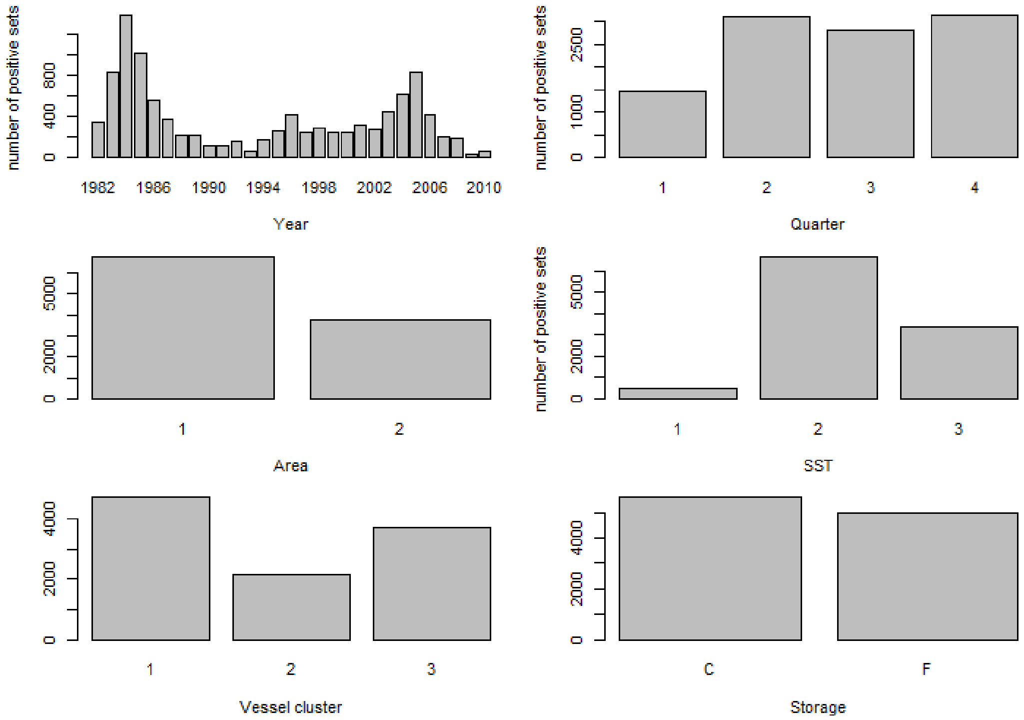

Figure 12. Number of positive sets by factors (Year, Quarter, Area, SST, Vessel cluster and Storage) for the period 1982-2010.

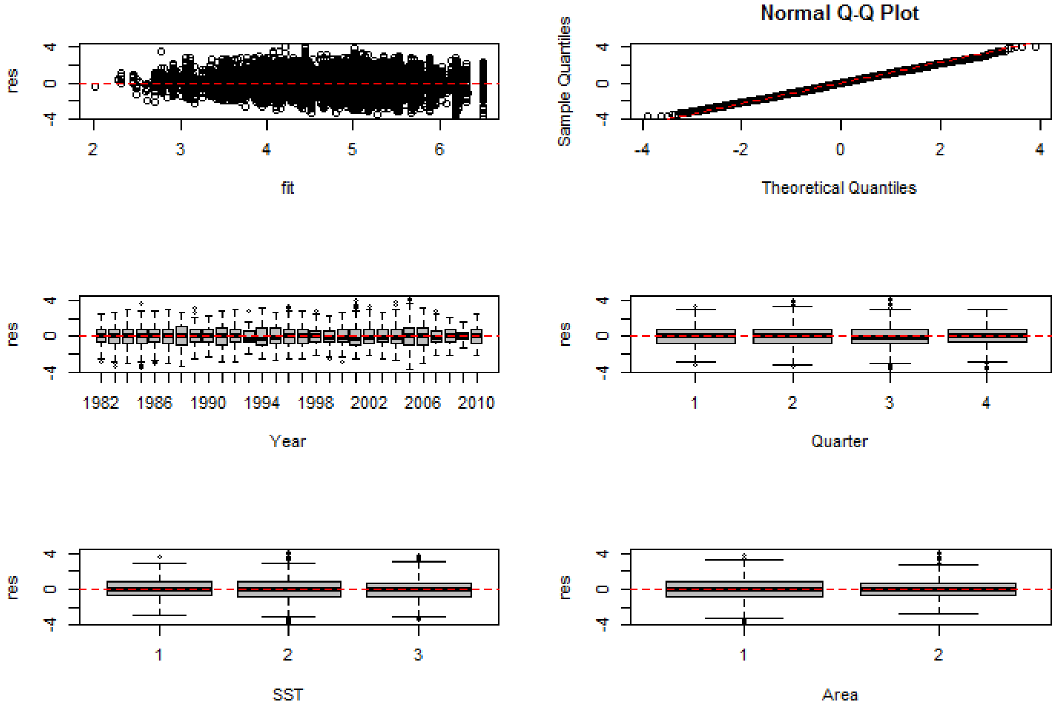

Figure 13. Diagnostic plots for positive yellowfin tuna catch rates (CPUE, Lognormal GLMM) for the period 1982-2010. In all plots the broken line represents the expected pattern of observations.

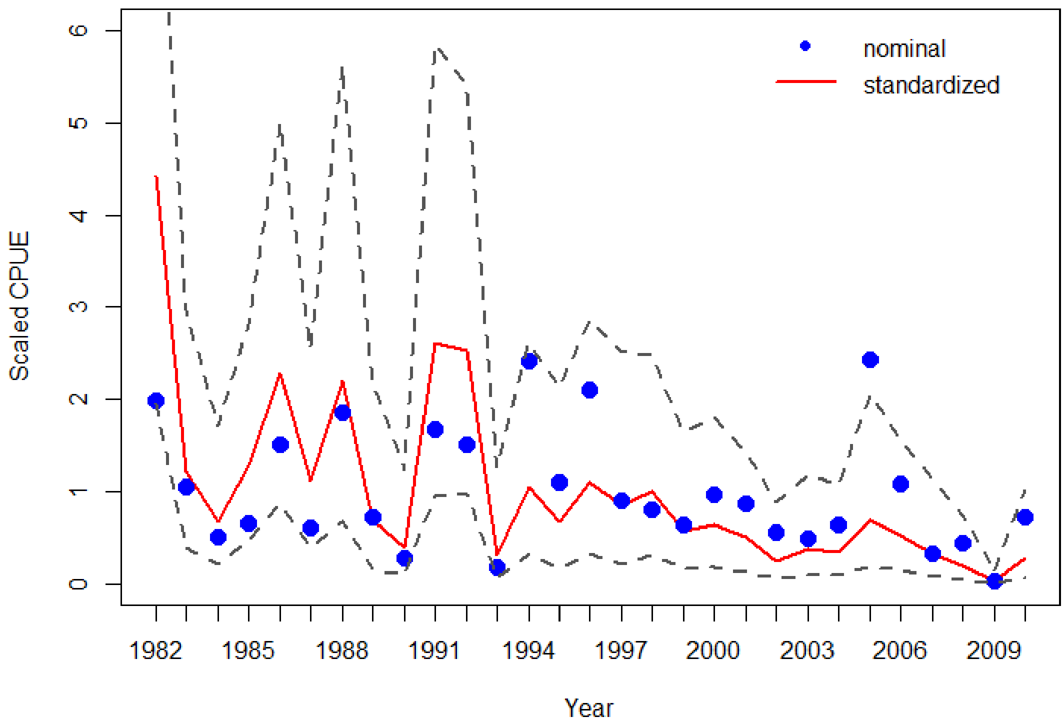

Figure 14. Scaled nominal and standardized index of abundance (CPUE) in biomass for yellowfin tuna caught by Uruguayan pelagic longline fleet in the period 1982-2010. Dotted lines correspond to the 95% confidence interval of the estimated standardized index.