UPDATE OF STANDARDIZED CPUE OF BIGEYE TUNA, *THUNNUS OBESUS*, 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 bigeye tuna, Thunnus obesus*, 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 (40%) 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, Target species and Gear. A total of 19,020 sets were analyzed. The standardized CPUE series of bigeye tuna caught by the Uruguayan longline fleet shows decreasing trend in the three time series presented.*

RÉSUMÉ

*La présente étude fournit une actualisation du taux de capture standardisé du thon obèse (*Thunnus obesus*) 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 nulles (40%), 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, espèce ciblée et engin. Un total de 19.020 opérations a été analysé. La série de CPUE standardisée du thon obèse capturé par la flottille palangrière uruguayenne affiche une tendance décroissante au cours des trois séries temporelles présentées.*

RESUMEN

Este estudio presenta una actualización de la tasa de captura estandarizada del patudo, Thunnus obesus, 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 en las especies objetivo. A causa de la elevada proporción de capturas cero (40%), 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, especie objetivo y arte. Se analizaron en total 19.020 lances. Las series de CPUE estandarizada de patudo capturado por la flota de palangre uruguayo muestra una tendencia decreciente en las tres series temporales presentadas.

KEYWORDS

Bigeye 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 bigeye tuna captured by the Uruguayan longline fleet presented in Pons and Domingo (2011) up to 2010. As in the previous standardization, 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 471 (2.5%) sets were removed for the analysis. **Figure 1** shows distribution of the effort (sets) and in gray 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 bigeye tuna caught. Catch per unit of effort (CPUE) was calculated as kilograms of bigeye 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). Received

For the first and the whole period we also use the *target* species as a categorized variable, with 2 levels for the first period (vessels targeting bigeye tuna and vessels targeting albacore *Thunnus alalunga*), and for the whole period two other categories were added (vessels targeting swordfish, *Xiphias gladius*, and vessels targeting blue shark, *Prionace glauca*). For the second period the type of Gear was used as a categorized variable with 2 levels, monofilament and multifilament longline.

2.3 Standardized methods

Because of a large proportion of zero catches (between 14 and 58% 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 7,979 sets from 1982 to 1991 with complete information. The percentage of sets that captured bigeye tuna (positive sets) respect to the total sets was 86% for the entire period, with a maximum of almost 99% in 1982 and a minimum of 79% in 1990 (**Figure 2**).

Frequency distribution of the log-transformed nominal CPUE for positive sets of bigeye 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*, *Target*, 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*, *Target*, and the interactions *Year:Quarter*, *Year:SST* and *Area: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 + Quarter + Area + SST + Target + Random (Year:Quarter) + Random (Year:SST)

Binomial Model: positive/total= Year + Quarter + Area + SST + Target + Area:SST + 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 bigeye tuna for the period 1982 – 1991 is shown in **Table 4** and **Figure 6**. The standardized series of bigeye tuna showed a constant decreasing trend from 1982 to 1991, with CPUE values eight times lower at the end of the period.

3.2 1992 – 2010

We analyzed a total of 11,041 sets from 1992 to 2010 with complete information. The percentage of sets that captured bigeye tuna (positive sets) respect to the total sets was 42% for the entire period, with a maximum of 80% in 1992 and a minimum of 23% in 2004 (**Figure 2**).

Frequency distributions of the log-transformed nominal CPUE for positive sets of bigeye 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*, *Gear*, and the interactions *Year:Quarter*, *Year:SST* and *Year:Gear* were significant (**Table 5a**). In addition, for the proportion of positive/total sets the factors *Year*, *Quarter*, *Area*, *SST*, *Gear*, and the interactions *Year:Area*, *Year:Quarter*, *Year:SST* and *Year:Gear* 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 + Gear + Random (Year:Quarter) + Random (Year:SST) + Random (Year:Gear)

Binomial Model: positive/total= Year + Quarter + Area + SST + Gear + 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 bigeye tuna for the period 1992 – 2010 is shown in **Table 7** and **Figure 10**. The standardized series of bigeye tuna showed a marked decreasing trend from 1992 to 2010.

3.3 1982 – 2010

We analyzed a total of 19,020 sets from 1982 to 2010 with complete information. The percentage of sets that captured bigeye tuna (positive sets) respect to the total sets was 60% for the entire period, with a maximum of almost 99% in 1982 and a minimum of 23% in 2004 (**Figure 2**).

Frequency distributions of the log-transformed nominal CPUE for positive sets of bigeye 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, Target,* and the interactions *Year:Quarter* and *Year:SST* were significant (**Table 8a**). In addition, for the proportion of positive/total sets the factors *Year*, *Quarter*, *Target*, and the interaction *Year:Quarter* 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 + Target + Random (Year:Quarter) + Random (Year:SST)

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

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 bigeye tuna for the period 1982 – 2010 is shown in **Table 10** and **Figure 14**. The standardized series of bigeye tuna showed a marked decreasing trend from 1982 to 2010 with a low increase between 1992 and 1996.

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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)	Área 1: < 2000 m depth Área 2: > 2000 m depth
Target	Categorical *(2), ***(4)	ALB, BET, BSH, SWO
Gear	Categorical **(2)	1: Monofiament 2: Multifilament

* 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	8898		
Year	9	7970	928	46.6
Year + Quarter	3	7794	175	8.8
Year + Quarter + Area	1	7368	427	21.4
Year + Quarter + Area+ SST	2	7359	9	0.4
Year + Quarter + Area+ SST + Target	1	6904	455	22.8
Year + Quarter + Area+ SST + Target + Year:Quarter	26	6492	412	17.1
Year + Quarter + Area+ SST + Target +Year:Area	9	6876	28	1.4
Year + Quarter + Area+ SST + Target +Year:SST	18	6760	145	6.8
Year + Quarter + Area+ SST + Target +Year:Target	2	6904	0	0.0
Year + Quarter + Area+ SST + Target +Quarter:SST	6	6849	55	2.7
Year + Quarter + Area+ SST + Target + Quarter:Area	3	6829	75	3.6
Year + Quarter + Area+ SST + Target + Quarter:Target	3	6878	26	1.3
Year + Quarter + Area+ SST + Target + Area:SST	2	6853	51	2.5
Year + Quarter + Area+ SST + Target + Area:Target	1	6904	1	0.0
Year + Quarter + Area+ SST + Target + SST:Target	2	6875	29	1.4

b) Model factors proportion positives	d.f.	Residual deviance	Change in deviance	% of total deviance
NULL	1	1635		
Year	9	1469	166	15.4
Year + Quarter	3	1188	280	26.0
Year + Quarter + Area	1	965	223	20.7
Year + Quarter + Area+ SST	2	792	173	16.1
Year + Quarter + Area+ SST + Target	1	556	236	21.8
Year + Quarter + Area+ SST + Target + Year:Area	9	532	24	2.1
Year + Quarter + Area+ SST + Target + Year:Quarter	26	403	153	12.4
Year + Quarter + Area+ SST+ Target + Year:SST	18	419	137	11.3
Year + Quarter + Area+ SST+ Target + Year:Target	2	549	7	0.6
Year + Quarter + Area+ SST + Target + Quarter:Area	3	513	43	3.9
Year + Quarter + Area+ SST + Target + Quarter:SST	6	516	40	3.6
Year + Quarter + Area+ SST + Target + Quarter:Target	3	515	41	3.7
Year + Quarter + Area+ SST + Target + Area:SST	2	489	67	5.8
Year + Quarter + Area+ SST + Target + Target + Area:Target	1	546	10	0.9
Year + Quarter + Area+ SST + Target + Target + SST:Target	2	504	52	4.6

Table 3. Analyses of the delta lognormal mixed model formulations for bigeye 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 Target	19533	19663	-9748	
Year Quarter Area SST Target *Year:Quarter*	19224	19354	-9593	<0.0001
Year Quarter Area SST Target *Year:Quarter Year:SST*	19190	19326	-9575	<0.0001
Proportion of positives				
Year Quarter Area SST.cat Target Area:SST	904	968	-432	
Year Quarter Area SST.cat Target Area:SST *Year:Quarter*	857	921	-408	<0.0001
Year Quarter Area SST.cat Target Area:SST *Year:Quarter Year:SST*	846	914	-402	<0.0001

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

Year	N Observations	Nominal CPUE	Standard CPUE	CV
1982	374	397.4	190.2	0.34
1983	1265	240.5	92.8	0.36
1984	2277	126.2	50.9	0.36
1985	1769	136.5	99.4	0.33
1986	669	123.9	52.5	0.39
1987	546	162.6	74.8	0.39
1988	382	161.3	48.4	0.40
1989	312	74.8	22.8	0.46
1990	245	72.8	23.9	0.43
1991	140	65.8	23.1	0.44

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	5309		
Year	18	4439	871	61.32
Year + Quarter	3	4308	130	9.18
Year + Quarter + Area	1	4021	287	20.25
Year + Quarter + Area+ SST	2	4001	19	1.37
Year + Quarter + Area+ SST + Gear	1	3889	112	7.88
Year + Quarter + Area+ SST + Gear + Year:Quarter	53	3734	156	9.90
Year + Quarter + Area+ SST + Gear +Year:Area	18	3845	45	3.07
Year + Quarter + Area+ SST + Gear +Year:SST	30	3793	96	6.36
Year + Quarter + Area+ SST + Gear +Year:Gear	11	3773	116	7.57
Year + Quarter + Area+ SST + Gear +Quarter:SST	5	3879	10	0.73
Year + Quarter + Area+ SST + Gear + Quarter:Area	3	3859	31	2.13
Year + Quarter + Area+ SST + Gear + Quarter:Gear	3	3877	12	0.85
Year + Quarter + Area+ SST + Gear + Area:SST	2	3889	1	0.04
Year + Quarter + Area+ SST + Gear + Area:Gear	1	3889	0	0.00
Year + Quarter + Area+ SST + Gear + SST:Gear	2	3881	8	0.59

b) Model factors proportion positives	d.f.	Residual deviance	Change in deviance	% of total deviance
NULL	1	3158		
Year	18	2341	817	43.79
Year + Quarter	3	1727	615	32.95
Year + Quarter + Area	1	1595	132	7.08
Year + Quarter + Area+ SST	2	1521	73	3.92
Year + Quarter + Area+ SST + Gear	1	1293	229	12.26
Year + Quarter + Area+ SST + Gear + Year:Area	18	1061	232	11.05
Year + Quarter + Area+ SST + Gear + Year:Quarter	53	876	416	18.25
Year + Quarter + Area+ SST + Gear + Year:SST	30	1108	184	9.00
Year + Quarter + Area+ SST + Gear + Year:Gear	11	1122	171	8.41
Year + Quarter + Area+ SST + Gear + Quarter:Area	3	1218	75	3.87
Year + Quarter + Area+ SST + Gear + Quarter:SST	5	1254	39	2.03
Year + Quarter + Area+ SST + Gear + Quarter:Gear	3	1239	54	2.83
Year + Quarter + Area+ SST + Gear + Area:SST	2	1283	10	0.55
Year + Quarter + Area+ SST + Gear + Target + Area:Gear	1	1291	2	0.11
Year + Quarter + Area+ SST + Gear + Target + SST:Gear	2	1276	17	0.91

Table 6. Analyses of the delta lognormal mixed model formulations for blue shark 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 Gear	12417	12597	-6180	
Year Quarter Area SST Gear *Year:Quarter*	12379	12560	-6162	<0.0001
Year Quarter Area SST Gear *Year:Quarter Year:SST*	12367	12554	-6155	<0.0001
Year Quarter Area SST Gear *Year:Quarter Year:SST Year:Gear*	12309	12503	-6125	<0.0001
Proportion of positives				
Year Quarter Area SST Gear	2295	2400	-1121	
Year Quarter Area SST Gear *Year:Area*	2175	2280	-1060	
Year Quarter Area SST Gear *Year:Area Year:Quarter*	1978	2086	-961	<0.0001
Year Quarter Area SST Gear *Year:Area Year:Quarter Year:SST*	1958	2070	-950	<0.0001
Year Quarter Area SST Gear *Year:Area Year:Quarter Year:SST Year:Gear*	1924	2041	-932	<0.0001

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

Year	N Observations	Nominal CPUE	Standard CPUE	CV
1992	174	83.3	68.5	0.65
1993	123	171.6	166.0	0.64
1994	220	156.9	64.5	0.79
1995	498	209.5	80.9	0.78
1996	569	179.9	68.7	0.78
1997	423	79.8	62.1	0.64
1998	607	54.5	40.1	0.63
1999	567	51.0	24.9	0.74
2000	451	47.4	20.9	0.77
2001	548	51.6	17.1	0.76
2002	643	47.1	11.7	0.72
2003	1042	33.2	8.8	0.59
2004	1281	11.4	3.2	0.58
2005	1435	27.9	4.1	0.60
2006	911	51.3	15.1	0.62
2007	593	15.1	12.6	0.62
2008	482	25.9	15.1	0.62
2009	374	21.0	18.9	0.62
2010	100	31.9	9.6	0.75

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	14370		
Year	28	12408	1961	55.25
Year + Quarter	3	12272	136	3.84
Year + Quarter + Area	1	11507	765	21.55
Year + Quarter + Area+ SST	2	11476	31	0.87
Year + Quarter + Area+ SST + Target	3	10819	657	18.50
Year + Quarter + Area+ SST + Target + Year:Quarter	82	10177	642	15.32
Year + Quarter + Area+ SST + Target +Year:Area	28	10761	58	1.61
Year + Quarter + Area+ SST + Target +Year:SST	50	10583	237	6.25
Year + Quarter + Area+ SST + Target +Year:Target	12	10756	63	1.74
Year + Quarter + Area+ SST + Target +Quarter:SST	6	10769	50	1.39
Year + Quarter + Area+ SST + Target + Quarter:Area	3	10697	123	3.34
Year + Quarter + Area+ SST + Target + Quarter:Target	9	10682	137	3.72
Year + Quarter + Area+ SST + Target + Area:SST	2	10791	29	0.80
Year + Quarter + Area+ SST + Target + Area:Target	3	10816	3	0.09
Year + Quarter + Area+ SST + Target + SST:Target	5	10775	45	1.25

b) Model factors proportion positives	d.f.	Residual deviance	Change in deviance	% of total deviance
NULL	1	8788		
Year	28	3806	4982	72.15
Year + Quarter	3	2929	877	12.70
Year + Quarter + Area	1	2621	308	4.45
Year + Quarter + Area+ SST	2	2448	173	2.50
Year + Quarter + Area+ SST + Target	3	1883	565	8.18
Year + Quarter + Area+ SST + Target + Year:Area	28	1628	255	3.56
Year + Quarter + Area+ SST + Target + Year:Quarter	82	1305	578	7.72
Year + Quarter + Area+ SST+ Target + Year:SST	50	1551	332	4.59
Year + Quarter + Area+ SST+ Target + Year:Target	13	1797	86	1.23
Year + Quarter + Area+ SST + Target + Quarter:Area	3	1773	110	1.56
Year + Quarter + Area+ SST + Target + Quarter:SST	6	1830	53	0.77
Year + Quarter + Area+ SST + Target + Quarter:Target	9	1786	97	1.39
Year + Quarter + Area+ SST + Target + Area:SST	2	1856	27	0.40
Year + Quarter + Area+ SST + Target + Target + Area:Target	3	1865	18	0.26
Year + Quarter + Area+ SST + Target + Target + SST:Target	6	1786	97	1.39

Table 9. Analyses of the delta lognormal mixed model formulations for bigeye 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 Target	32010	32304	-15965	
Year Quarter Area SST Target *Year:Quarter*	31580	31874	-15750	<0.0001
Year Quarter Area SST Target *Year:Quarter Year:SST*	31531	31832	-15724	<0.0001
Proportion of positives				
Year Quarter Target	3437	3593	-1683	
Year Quarter Target *Year:Quarter*	3134	3290	-1531	<0.0001

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

Year	N Observations	Nominal CPUE	Standard CPUE	CV
1982	374	397.4	157.3	0.29
1983	1265	240.5	75.7	0.30
1984	2277	126.2	40.4	0.31
1985	1769	136.5	86.0	0.28
1986	669	123.9	37.9	0.34
1987	546	162.6	62.6	0.33
1988	382	161.3	37.9	0.37
1989	312	74.8	20.1	0.41
1990	245	72.8	19.7	0.40
1991	140	65.8	17.8	0.43
1992	174	83.3	38.7	0.38
1993	123	171.6	67.5	0.48
1994	220	156.9	49.8	0.43
1995	498	209.5	61.9	0.41
1996	569	179.9	57.5	0.41
1997	423	79.8	30.2	0.44
1998	607	54.5	22.3	0.44
1999	567	51.0	18.1	0.44
2000	451	47.4	17.3	0.45
2001	548	51.6	14.7	0.46
2002	643	47.1	11.2	0.48
2003	1042	33.2	13.7	0.45
2004	1281	11.4	4.8	0.48
2005	1435	27.9	8.0	0.47
2006	911	51.3	22.2	0.42
2007	593	15.1	11.7	0.45
2008	482	25.9	15.6	0.44
2009	374	21.0	19.1	0.45
2010	100	31.9	8.3	0.62

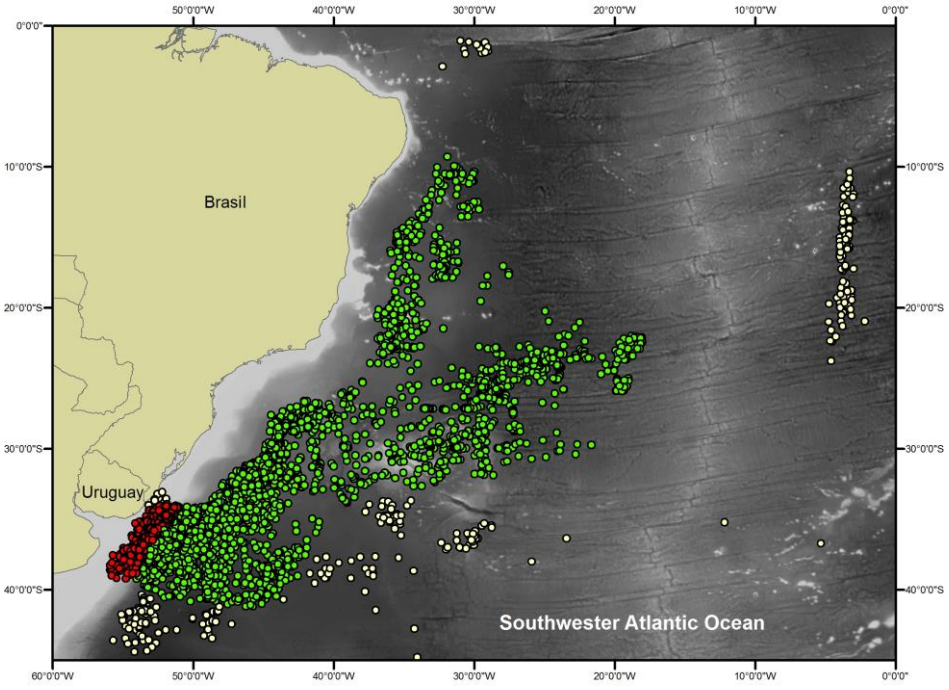

Figure 1. Distribution of longline sets deployed by Uruguayan longline fleet in the Southwestern Atlantic Ocean. Red and green dots represent the two areas selected for the models: Area 1, below 2000 m depth (red line); and Area 2, above 2000 m depth. Gray dots were left out of analysis.

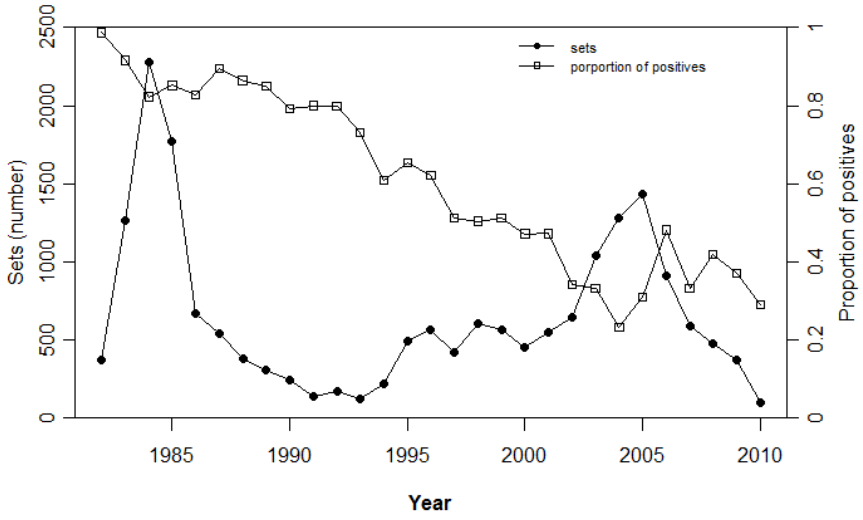

Figure 2. Number of sets and proportion of bigeye tuna positive sets by year (1982-2010) for the Uruguayan longline fleet.

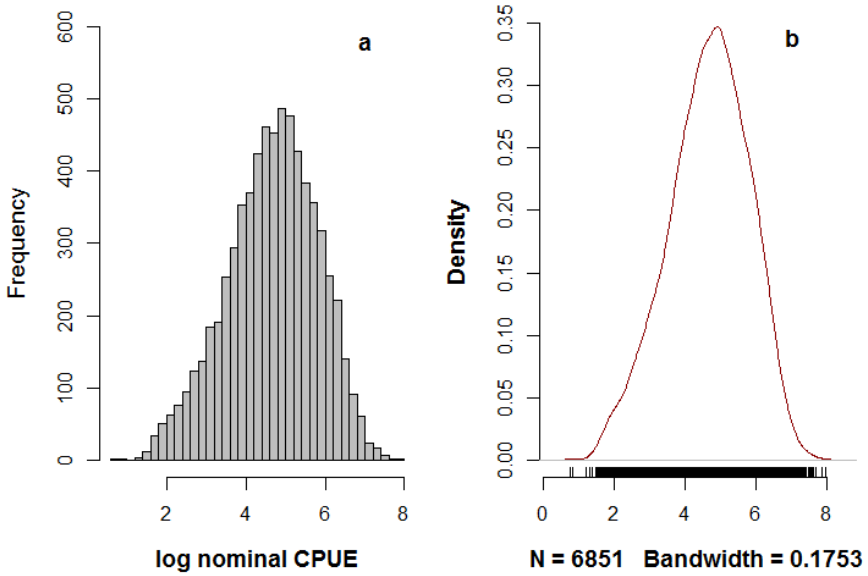

Figure 3. Frequency distribution of Log-tranformed nominal CPUE for positive sets of bigeye tuna caught by Uruguayan longliners between 1982 and 1991.

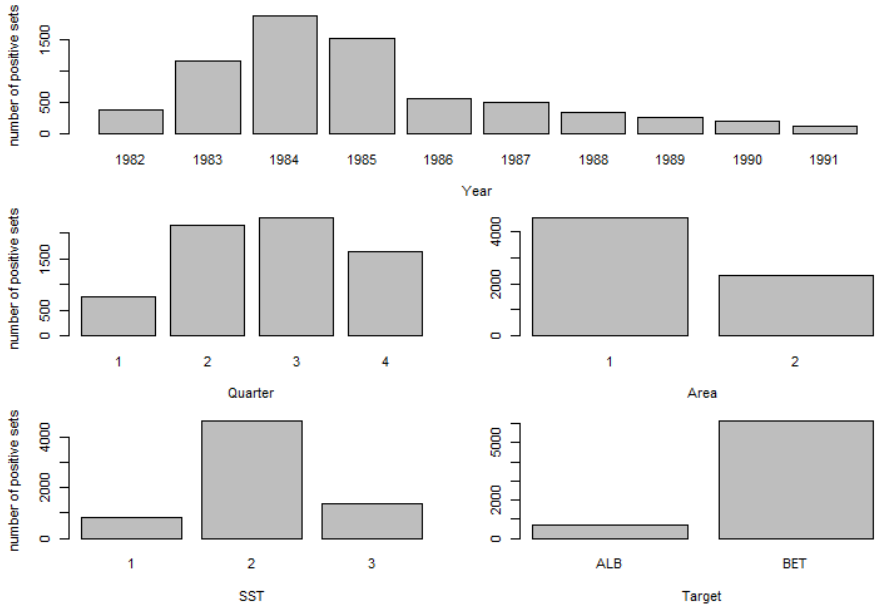

Figure 4. Number of positive sets by factors (Year, Quarter, Area, SST and Target) for the period 1982-1991.

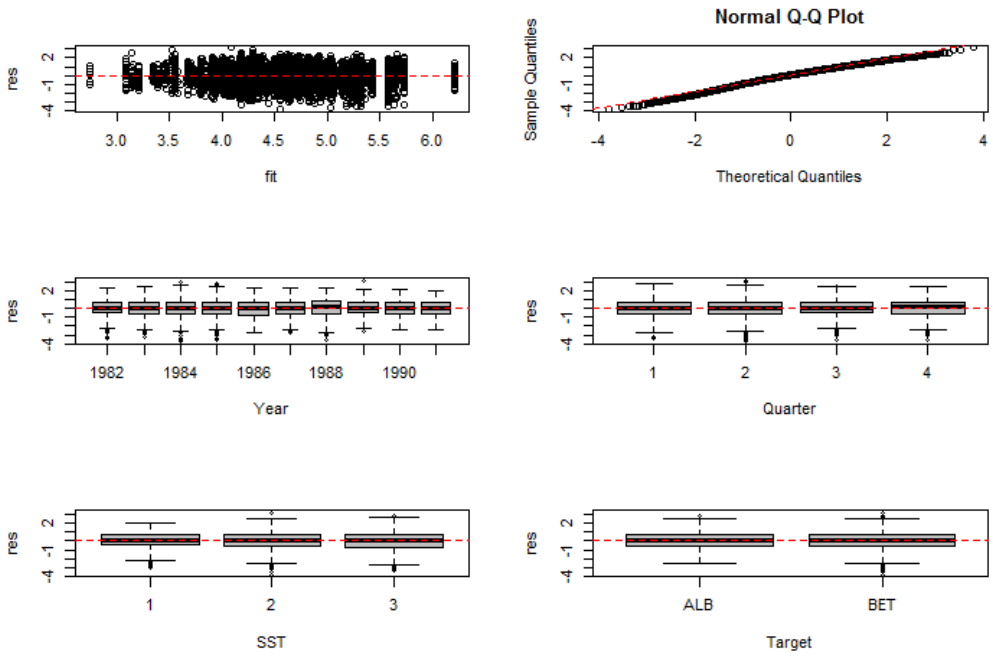

Figure 5. Diagnostic plots for positive bigeye tuna catch rates (CPUE, Lognormal GLMM) for the period 1982-1991. In all plots the broken line represents the expected pattern of observations.

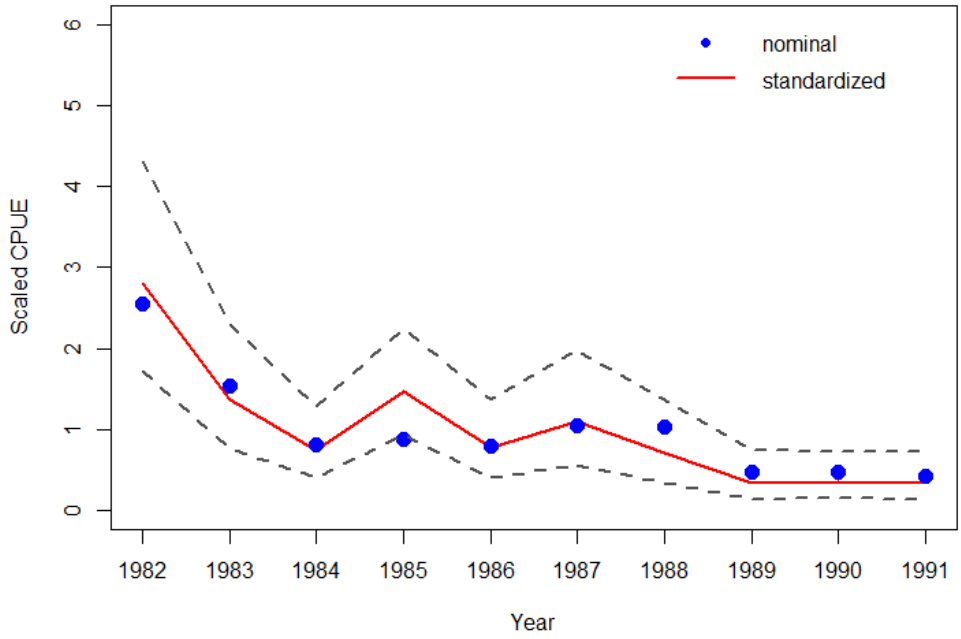

Figure 6. Scaled nominal and standardized index of abundance (CPUE) in biomass for bigeye tuna caught by Uruguayan pelagic longline fleet in the period 1982-1991. Dotted lines correspond to the 95% confidence interval of the estimated standardized index.

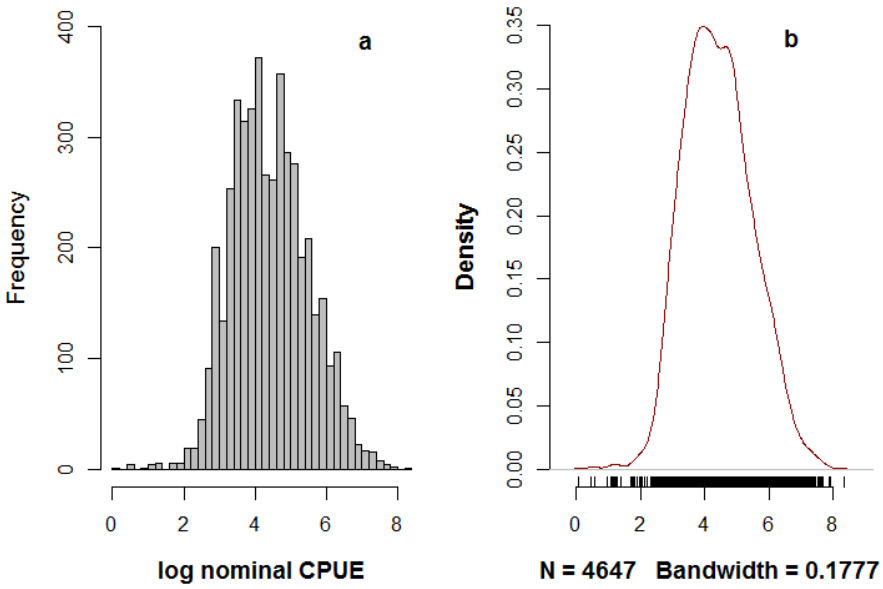

Figure 7. Frequency distribution of Log-tranformed nominal CPUE for positive sets of bigeye tuna caught by Uruguayan longliners between 1992 and 2010.

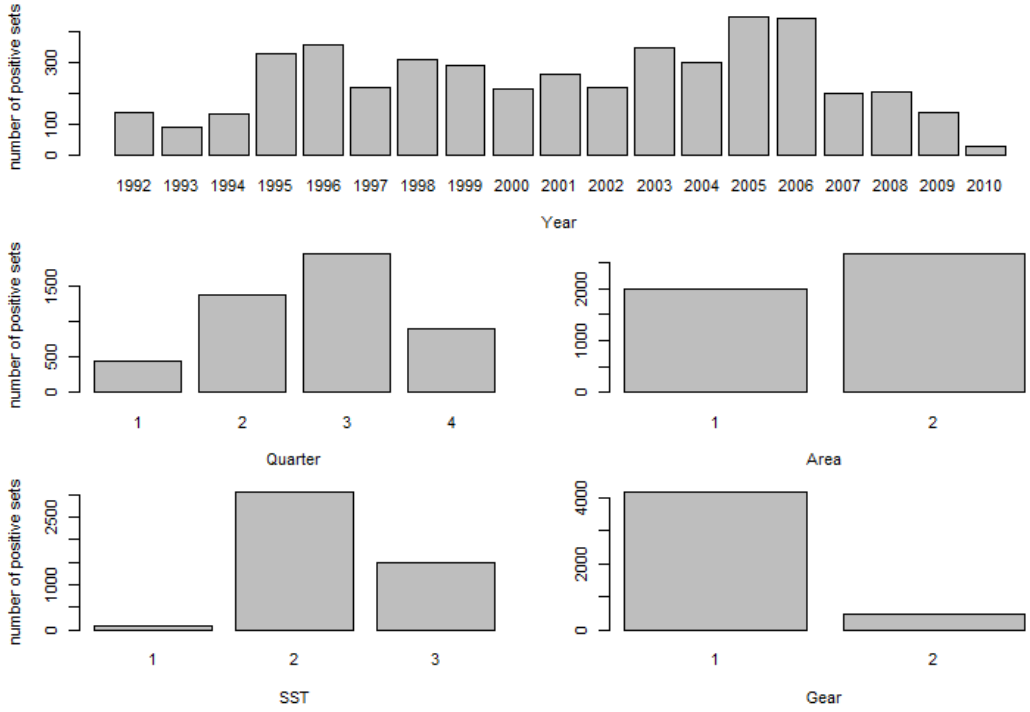

Figure 8. Number of positive sets by factors (Year, Quarter, Area, SST and Gear) for the period 1992-2010.

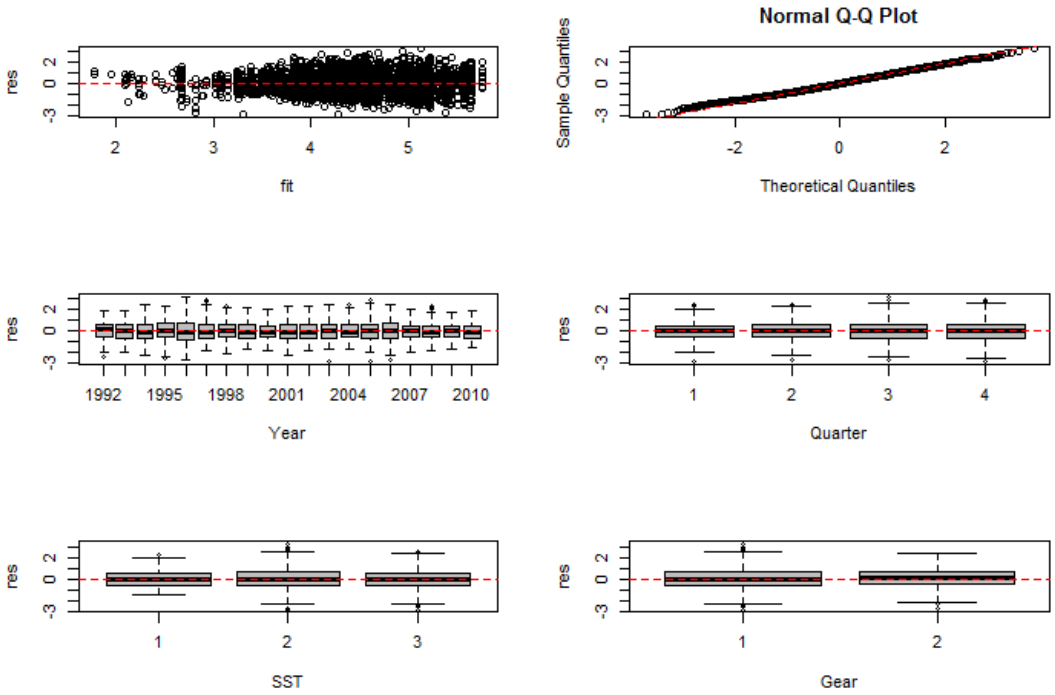

Figure 9. Diagnostic plots for positive bigeye tuna catch rates (CPUE, Lognormal GLMM) for the period 1991-2010. In all plots the broken line represents the expected pattern of observations.

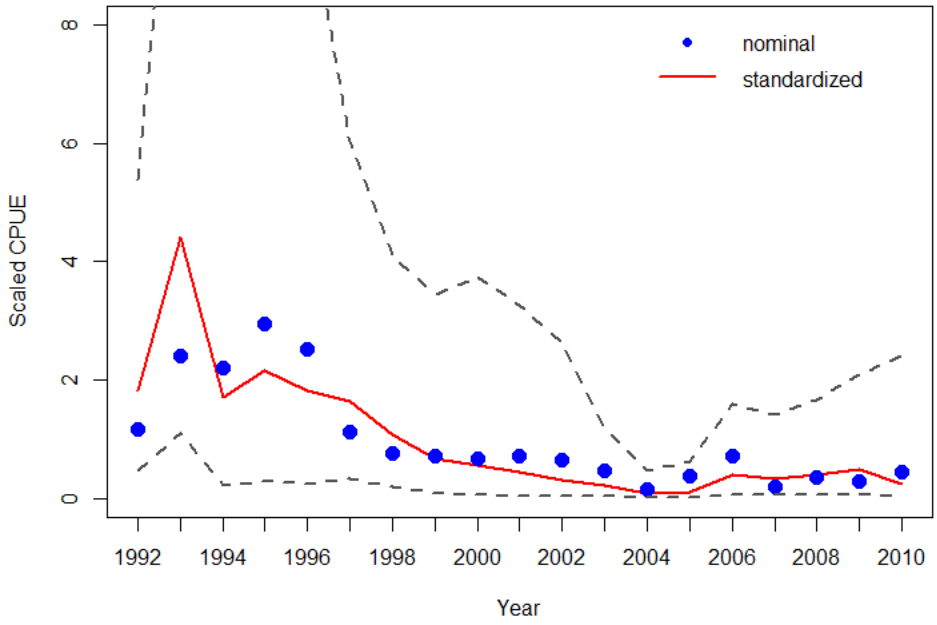

Figure 10. Scaled nominal and standardized index of abundance (CPUE) in biomass for bigeye tuna caught by Uruguayan pelagic longline fleet in the period 1992-2010. Dotted lines correspond to the 95% confidence interval of the estimated standardized index.

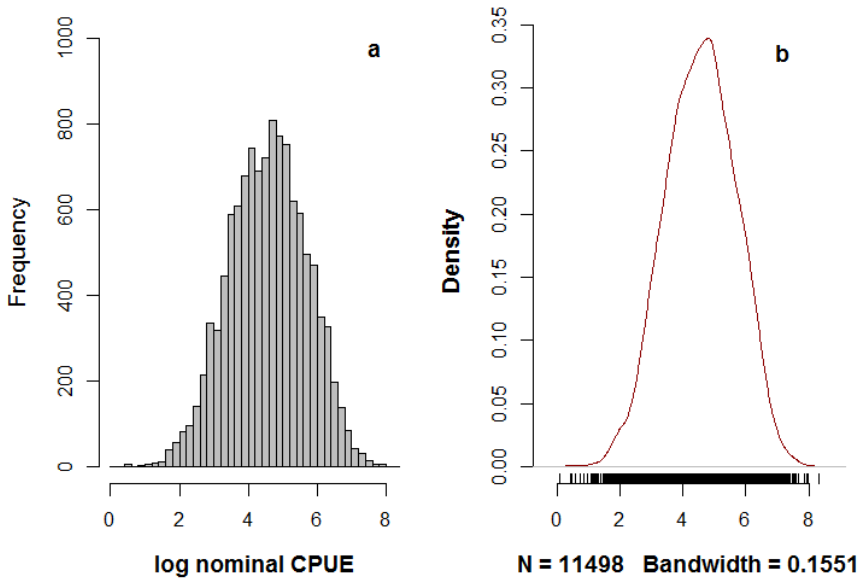

Figure 11. Frequency distribution of Log-tranformed nominal CPUE for positive sets of bigeye tuna caught by Uruguayan longliners between 1982 and 2010.

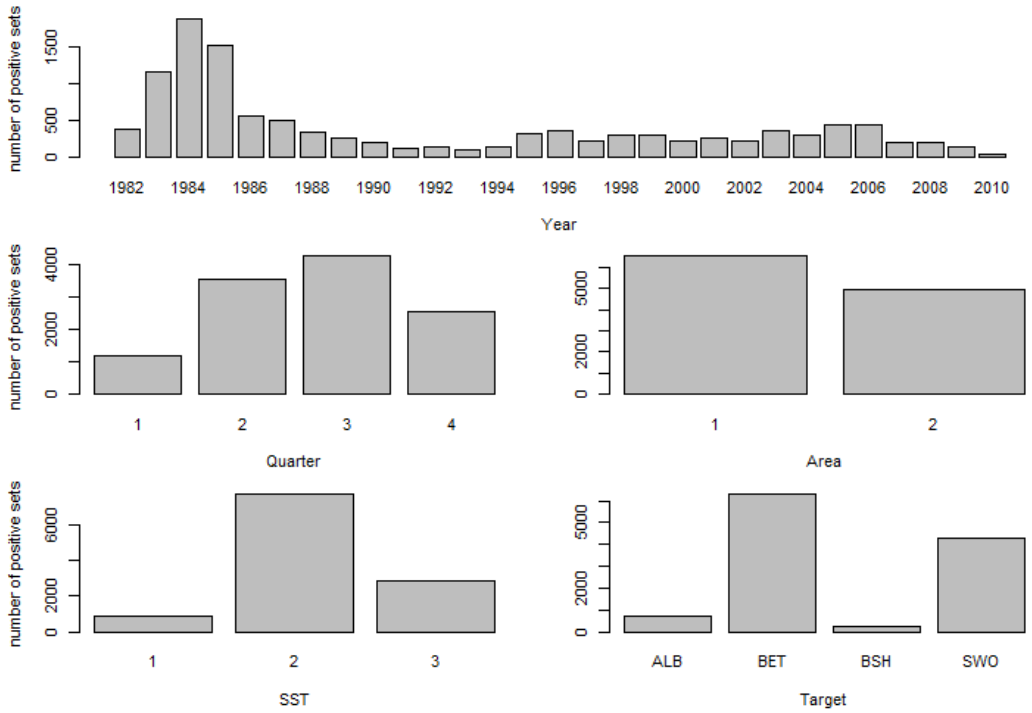

Figure 12. Number of positive sets by factors (Year, Quarter, Area, SST and Target) for the period 1982-2010.

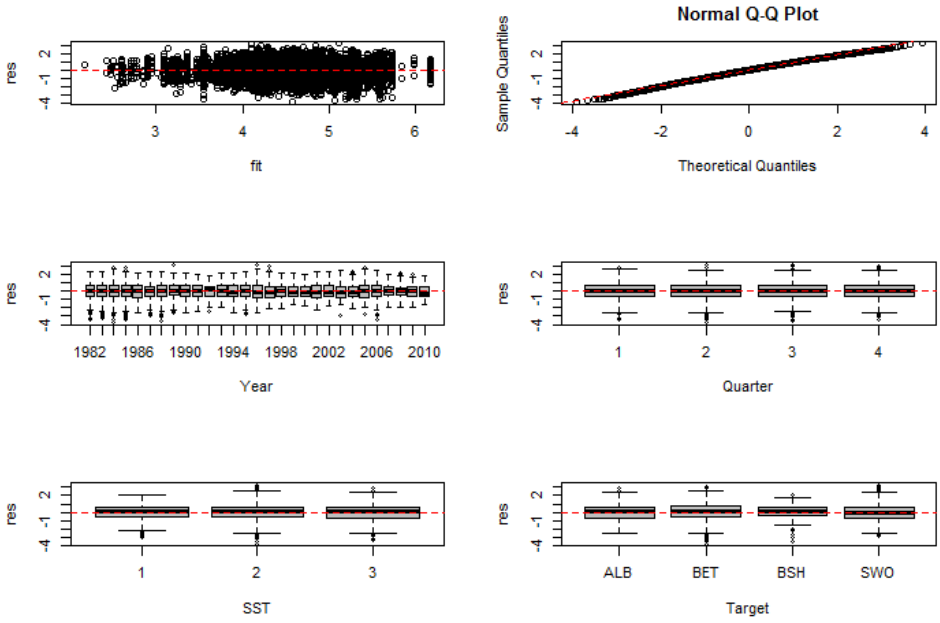

Figure 13. Diagnostic plots for positive bigeye tuna catch rates (CPUE, Lognormal GLMM) for the period 1982-2010. In all plots the broken line represents the expected pattern of observations.

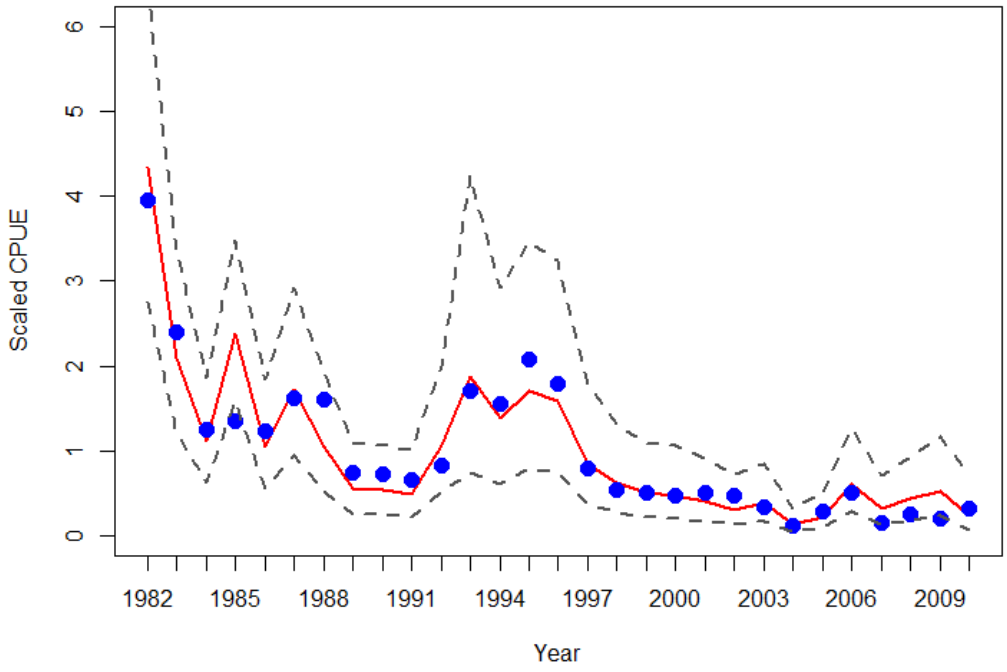

Figure 14. Scaled nominal and standardized index of abundance (CPUE) in biomass for bigeye tuna caught by Uruguayan pelagic longline fleet in the period 1982-2010. Dotted lines correspond to the 95% confidence interval of the estimated standardized index.