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UPDATE OF STANDARDIZED CPUE OF BLUE SHARK, *PRIONACE GLAUCA*, CAUGHT BY URUGUAYAN LONGLINERS IN THE SOUTHWESTERN ATLANTIC OCEAN (1992-2012)

Rodrigo Forselledo[1], Federico Mas[1,2], Maite Pons[2] and Andrés Domingo[1,2]

SUMMARY

This study presents an update of the standardized catch rate of blue shark, Prionace glauca, *caught by the Uruguayan longline fleet in the Southwestern Atlantic using information from logbooks between 1992 and 2012. Because of the large proportion of zeros catches (36%) 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 and Sea Surface Temperature. A total of 10,531 sets were analyzed. The standardized CPUE series of blue shark caught by the Uruguayan longline fleet shows a fairly constant trend from 1992 to 2009 and a pronounced increase from 2010 onwards.*

RÉSUMÉ

*La présente étude fournit une actualisation du taux de capture standardisé du requin peau bleue (*Prionace glauca*) capturé par la flottille palangrière uruguayenne dans l'Atlantique Sud-Ouest, calculé au moyen d'informations provenant des carnets de pêche couvrant les années 1992 à 2012. Compte tenu de la quantité élevée de prises nulles (36%), 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 et température à la surface de l'eau. Un total de 10.531 opérations a été analysé. La série de la CPUE standardisée du requin peau bleue capturé par la flottille palangrière uruguayenne affiche une tendance relativement constante entre 1992 et 2009 et une augmentation prononcée à partir de 2010.*

RESUMEN

*Este estudio presenta una actualización de la tasa de captura estandarizada de la tintorera (*Prionace glauca*), capturada por la flota de palangre uruguaya en el Atlántico sudoccidental utilizando información de los cuadernos de pesca entre 1992 y 2012. A causa de la elevada proporción de capturas cero (36%), 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 y Temperatura de la superficie del mar. Se analizaron en total 10.531 lances. La serie de CPUE estandarizada de tintorera capturada por la flota de palangre uruguaya muestra una tendencia bastante constante desde 1992 a 2009 y un pronunciado incremento a partir de 2010.*

KEYWORDS

Blue shark, CPUE, Southwestern Atlantic, logbooks, GLMM

[1] Laboratorio de Recursos Pelágicos, Dirección Nacional de Recursos Acuáticos (DINARA). Constituyente 1497, CP 11200, Montevideo, Uruguay. Eadomingo@dinara.gub.uy
[2] Centro de Investigación y Conservación Marina (CICMAR), Uruguay.

1. Introduction

The Uruguayan tuna fleet began its activities in 1981 mainly targeting bigeye tuna, *Thunnus obesus*. Since 1992, the fleet has operated with American-type longline, except for some units that operate with Spanish-type longline, targeting mainly swordfish, *Xiphias gladius* (Domingo *et al.* 2008). Although it’s presumed that blue shark, *Prionace glauca* (BSH) is captured since the beginning of the fishery, it was considered bycatch and wasn´t retained. From 1992 the species is retained and reported in logbooks (Pons and Domingo, 2008). Also, between 2009 and 2012 there was a vessel operating mainly in international adjacent waters of Uruguay targeting BSH with good yields of production.

The present study updates the standardized catch rate of BSH captured by the Uruguayan longline fleet presented in Pons and Domingo (2009) up to 2012.

2. Material and methods

2.1. Data reduction and exclusions

We analyzed data from logbooks from the Uruguayan longline fleet between 1992 and 2012. Sets with no location information and spatial cells where the fleet operated occasionally were not considered for the analysis. In addition, data from one vessel that operated between 2009-2012 targeting BSH were also removed to consider only the sets were the species was captured as bycatch. A total of 1,382 (11.6%) sets were removed for the analysis. **Figure 1** shows distribution of the effort (sets) and in yellow dots sets removed.

2.2 Dataset

We analyzed a total of 10,531 sets from 1992 to 2012 with complete information. The percentage of sets that captured BSH (positive sets) respect to the total sets was 64% for the entire period, with a maximum of 87% in 1993 and a minimum of 1% in 2012 (**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 BSH caught. Catch per unit of effort (CPUE) was calculated as kilograms of BSH caught per 1000 hooks.

We defined two areas for the analysis according to the distribution of the effort (Pons *et al.* 2012). *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 between 26º and 41º S, and 40º and 55º W (**Figure 1**).

The SST was categorized into two levels, less than 20° C and higher or equal to 20° C. The seasonality was considered in quarters: 1 (January-March), 2 (April-June), 3 (July-September) and 4 (October-December).

2.3 Standardized methods

Because of a large proportion of zero catches (36%) 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. Frequency distributions of the log-transformed nominal CPUE for positive sets of BSH are presented in **Figure 3**.

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**. Interaction plots between factors *Year*, *Quarter*, *Area* and *SST* for the logCPUE are shown in **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 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 Standardized index

Deviance table analysis, one for Lognormal and other for the Binomial models, are shown in **Tables 2a** and **2b** respectively for CPUE. For both calculated CPUEs, the mean catch rates given in the positive sets, the factors *Year*, *Quarter* and *Area*, 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*, *Quarter* and *Area*, and the interactions *Year: Area*, *Year: Quarter* and *Year: SST* were significant (**Table 2b**).

After fixed factors 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:Area) + Random (Year:Quarter) + 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 6**).

Final standardized CPUE for BSH are shown in **Table 4** and **Figure 7**. The standardized series of BSH showed a fairly constant trend from 1992 to 2009 and increased from 2010 to the end of the studied period. The reason of this increase might be due to a vessel that operated between 2010 and 2012 targeting swordfish, but with high captures of BSH due to the good moment in the market.

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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 (21)	Period: 1992-2012
Quarter	Categorical (4)	Quarter 1: January-March Quarter 2: April-June Quarter 3: July-September Quarter 4: October-December
Sea surface temperature (*SST*)	Categorical (2)	In Celsius degrees (º C), range: 8º-29º C SST1: < 20º C SST2: ≥20º C
Area	Categorical (2)	Área 1: < 2000 m depth * Área 2: > 2000 m depth *

* See **Figure 1.**

Table 2. Deviance analysis table of positive catch rates (Lognormal) and proportion of positive sets (Binomial) models using CPUE. '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	10096		
Year	20	8586	1510	63.9
Year + Quarter	3	7954	632	26.7
Year + Quarter + Area	1	7808	146	6.2
Year + Quarter + Area+ SST	1	7733	75	3.2
Year + Quarter + Area+ SST + Year:Quarter	56	7233	500	17.5
Year + Quarter + Area+ SST + Year:Area	19	7476	258	9.8
Year + Quarter + Area+ SST + Year:SST	19	7574	159	6.3
Year + Quarter + Area+ SST + Quarter:SST	3	7718	15	0.6
Year + Quarter + Area+ SST + Quarter:Area	3	7688	45	1.9
Year + Quarter + Area+ SST + Area:SST	1	7725	9	0.4

b) Model factors proportion positives	**d.f.**	**Residual deviance**	**Change in deviance**	**% of total deviance**
NULL	1	4251		
Year	20	2893	1358	78.5
Year + Quarter	3	2759	134	7.7
Year + Quarter + Area	1	2541	218	12.6
Year + Quarter + Area+ SST	1	2521	20	1.2
Year + Quarter + Area+ SST + Year:Area	20	2310	210	10.8
Year + Quarter + Area+ SST + Year:Quarter	57	2075	446	20.5
Year + Quarter + Area+ SST + Year:SST	20	2361	159	8.4
Year + Quarter + Area+ SST + Quarter:Area	3	2474	47	2.6
Year + Quarter + Area+ SST + Quarter:SST	3	2505	16	0.9
Year + Quarter + Area+ SST + Area:SST	1	2504	16	0.9

Table 3. Analyses of the delta lognormal mixed model formulations for blue shark CPUE from the Uruguayan pelagic longline fishery (1992-2012).

GLMM	Akaike's Information Criterion	Bayesian Information Criterion	Log Likelihood	Likelihood Ratio Test
Positives catch rates				
Year Area Quarter SST	20076	20267	-10010	
Year Area Quarter SST *Year:Area*	19960	20151	-9952	<0.0001
Year Area Quarter SST *Year:Area Year:Quarter*	19760	19958	-9851	<0.0001
Year Area Quarter SST *Year:Area Year:Quarter Year:SST*	19749	19953	-9844	<0.0001
Proportion of positives				
Year Area Quarter SST	3447	3557	-1697	
Year Area Quarter SST *Year:Area*	3344	3455	-1645	<0.0001
Year Area Quarter SST *Year:Area Year:Quarter*	3109	3224	-1527	<0.0001
Year Area Quarter SST *Year:Area Year:Quarter Year:SST*	3053	3171	-1497	<0.0001

Table 4. Nominal and standardized index of relative abundance (CPUE) of blue shark in weight (kg) for the Uruguayan pelagic longline fleet (1992-2012). CV=coefficients of variation for the standardized index.

Year	N Observations	Nominal CPUE	Standard CPUE	CV
1992	217	220.4	140.1	0.62
1993	143	56.8	25.0	1.20
1994	228	345.1	311.6	0.62
1995	531	122.8	82.5	0.89
1996	594	412.3	346.7	0.57
1997	428	310.5	349.5	0.53
1998	545	368.2	315.6	0.53
1999	525	160.4	182.7	0.51
2000	466	145.8	165.8	0.59
2001	553	95.3	99.0	0.62
2002	681	87.6	72.6	0.66
2003	955	170.1	99.7	0.64
2004	1211	174.3	107.3	0.61
2005	1323	141.0	116.3	0.55
2006	741	123.2	110.3	0.56
2007	480	292.4	296.5	0.51
2008	458	335.8	249.8	0.51
2009	244	130.1	130.5	0.51
2010	100	565.1	438.3	0.53
2011	39	583.1	708.4	0.65
2012	69	972.5	1076.5	0.54

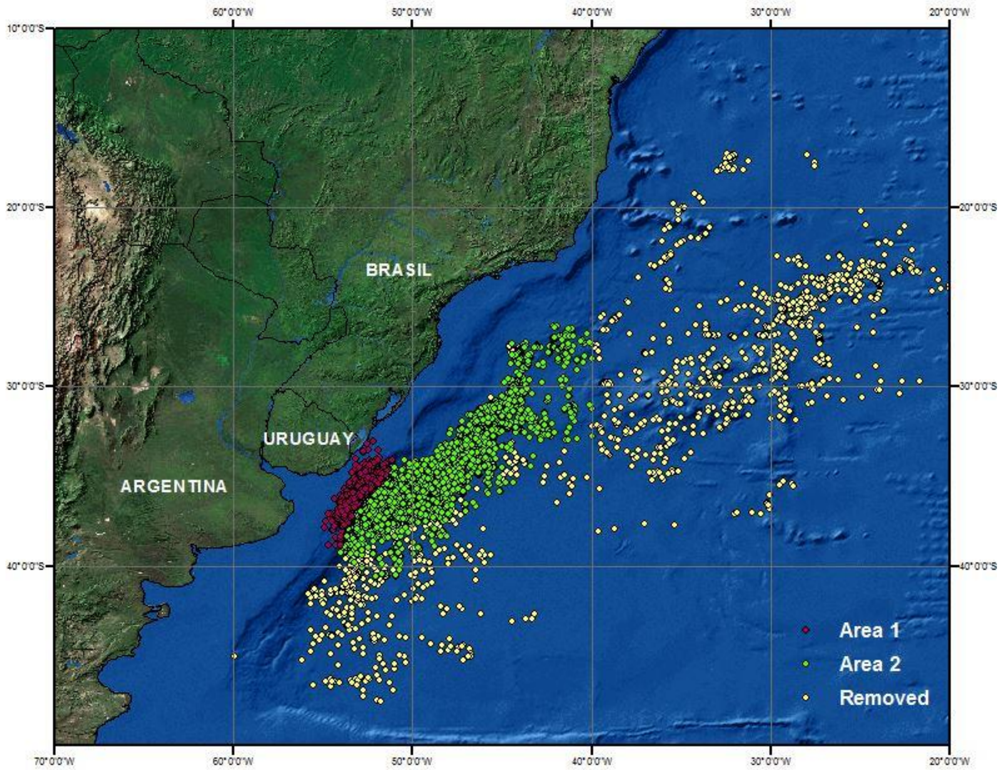

Figure 1. Distribution of longline sets deployed by Uruguayan longline fleet in the Southwestern Atlantic Ocean. Red and green dots represent the two areas selected for the models: Area 1, below 2000 m depth (red line); and Area 2, above 2000 m depth. Yellow dots were left out of analysis.

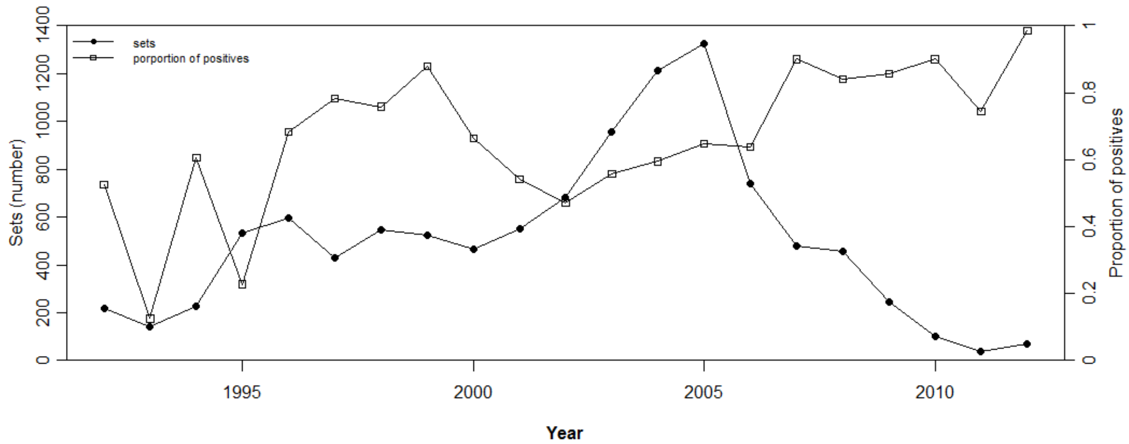

Figure 2. Number of sets and proportion of blue shark positive sets by year (1992-2012) for the Uruguayan longline fleet.

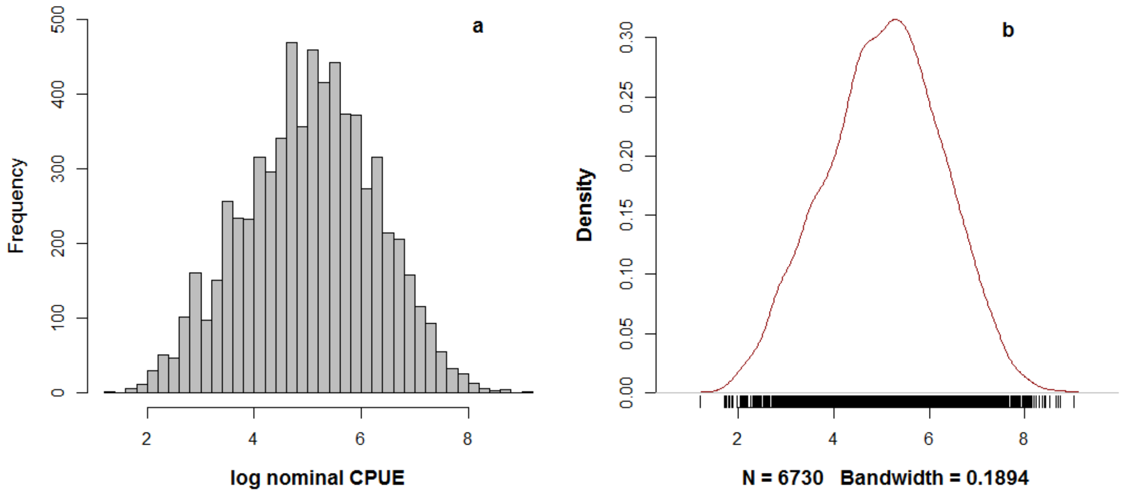

Figure 3. Frequency distribution of Log-tranformed nominal CPUE for positive sets of blue shark cauht by Uruguayan longliners between 1992 and 2012.

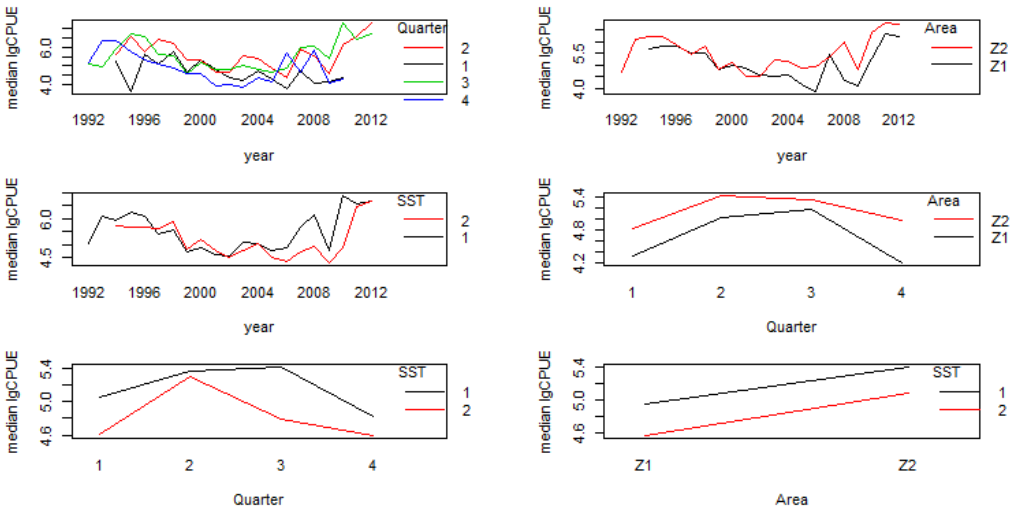

Figure 4. Interaction plots between factors for the logCPUE (Year, Quarter, Area and SST).

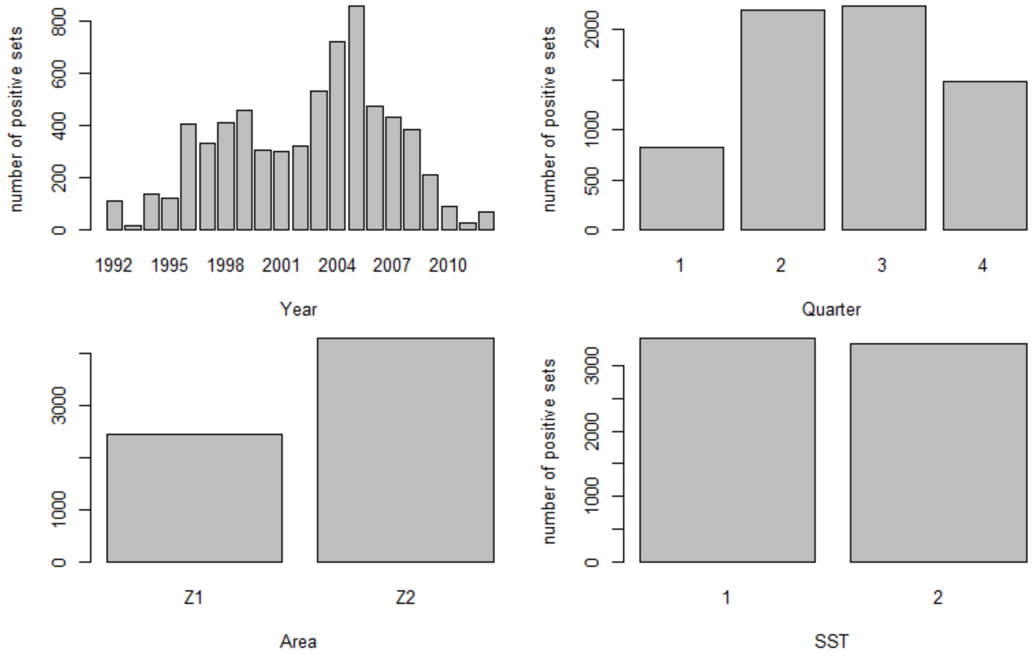

Figure 5. Number of positive sets by factors (Year, Quarter, Area and SST).

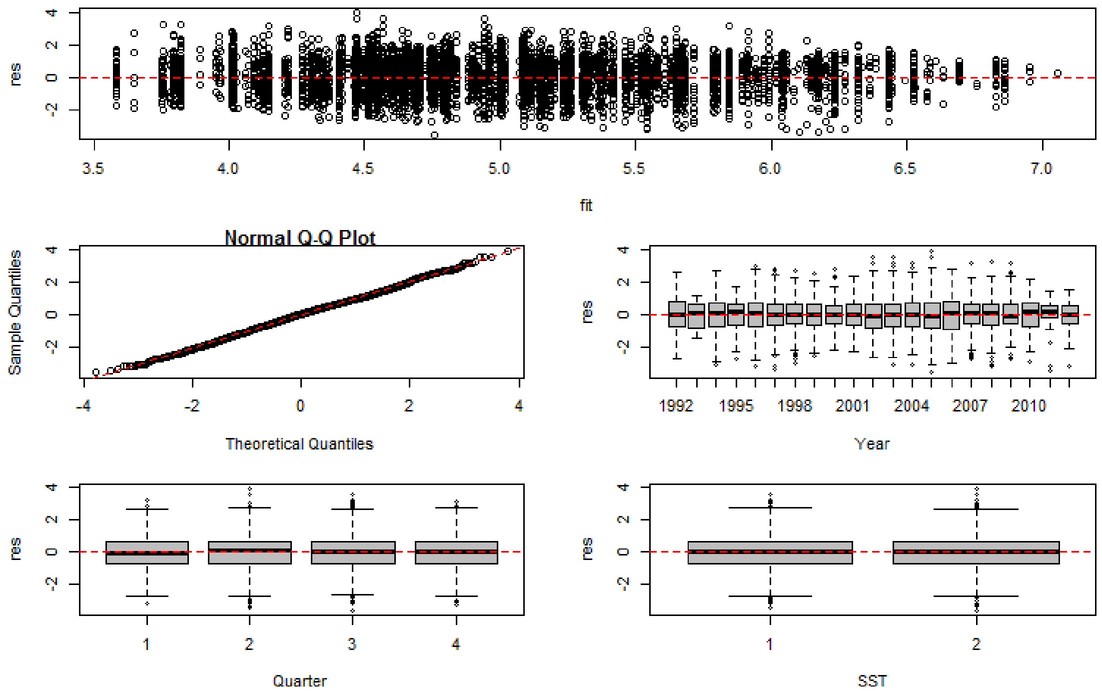

Figure 6. Diagnostic plots for positive blue shark catch rates (CPUE, Lognormal GLMM). In all plots the broken line represents the expected pattern of observations.

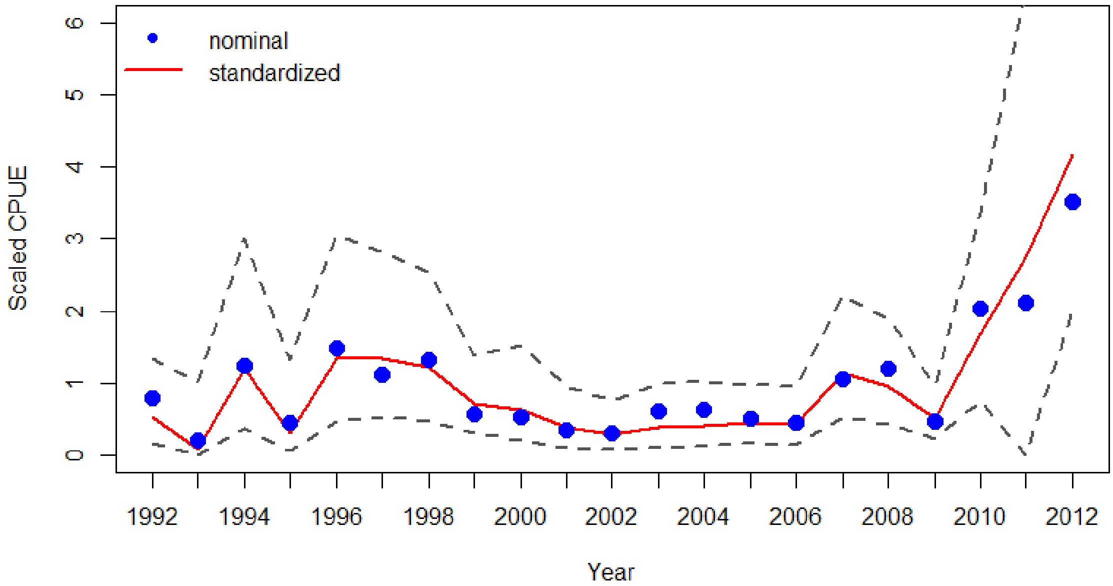

Figure 7. Scaled nominal and standardized index of abundance (CPUE) in biomass for blue shark caught by Uruguayan pelagic longline fleet. Dotted lines correspond to the 95% confidence interval of the estimated standardized index.