STANDARDIZED CPUE OF SHORTFIN MAKO, *ISURUS OXYRINCHUS*, BASED ON DATA GATHERED BY THE NATIONAL OBSERVER PROGRAM ON BOARD THE URUGUAYAN LONGLINE FLEET (2001-2012)

Federico Mas[1,2], Rodrigo Forselledo[1], Maite Pons[2,3] and Andrés Domingo[1]

SUMMARY

This study presents the standardized catch rate of shortfin mako shark, Isurus oxyrinchus, *caught by the Uruguayan longline fleet in the Southwestern Atlantic using information from national onboard observed program between 2001 and 2012. Because of the large proportion of zeros catches (23%) 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 in some cases were: Year, Quarter, Area, Sea Surface Temperature and Gear. A total of 1,706 sets were analyzed. Standardized CPUE showed an apparent increasing trend during the last six years of the study period.*

RÉSUMÉ

La présente étude fournit le taux de capture standardisé du requin-taupe bleu (Isurus oxyrinchus) capturé par la flottille palangrière uruguayenne dans l'Atlantique Sud-Ouest, calculé au moyen d'informations provenant du programme d'observateurs nationaux déployés à bord entre 2001 et 2012. Compte tenu de la quantité élevée de prises zéros (23%), 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 dans certains cas étaient : année, trimestre, zone, température de la surface de l'eau et engin. Un total de 1.706 opérations a été analysé. La CPUE standardisée a fait apparaître une claire tendance ascendante au cours des six dernières années de la période à l'étude.

RESUMEN

*Este estudio presenta la tasa de captura estandarizada del marrajo dientuso (*Isurus oxyrinchus*), capturado por la flota de palangre uruguaya en el Atlántico sudoccidental utilizando información del programa nacional de observadores a bordo entre 2001 y 2012. A causa de la elevada proporción de capturas cero (23%), 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 en algunos casos: Año, Trimestre, Área, Temperatura de la superficie del mar y Arte. Se analizaron en total 1.706 lances. La CPUE estandarizada presentaba una clara tendencia ascendente durante los últimos seis años del periodo de estudio.*

KEYWORDS

Shortfin mako, CPUE, Observer Program, Southwestern Atlantic

[1] Dirección Nacional de Recursos Acuáticos (DINARA), Laboratorio de Recursos Pelágicos (LaRPe), Montevideo, Uruguay. Constituyente 1497, CP 11200, Montevideo, Uruguay, adomingo@dinara.gub.uy.
[2] Centro de Investigación y Conservación Marina (CICMAR), Uruguay.
[3] School of Aquatic and Fishery Sciences, Box 355020, University of Washington, Seattle, WA 98195, USA.

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*.

In 1998 the National Directorate of Aquatic Resources (DINARA) implemented a National Observer Program Onboard Tuna Fishing Vessels (PNOFA). Since then, scientific observers have covered a portion of each year total fishing trips, recording information related to fishing gear configuration, date and geographic position of each fishing set, effort, number of species captured and specific catch disposition, size, sex, environmental variables related to each fishing set, among others. This program has allowed DINARA to record catch and biological information of species that are not considered as a target for the fishery and therefore are not reported in logbooks catch statistics.

In this document, a standardization of the catch per unit of effort of the shortfin mako, *Isurus oxyrinchus*, captured by the Uruguayan pelagic longline fishery is presented for the period 2001-2012.

2. Material and methods

2.1 Data reduction and exclusions

We analyzed data collected by observers of the PNOFA operating in the Southwestern Atlantic Ocean between 1998 and 2012. The first three years of the time series of data (1998-2000) were removed due to convergence problems with the binomial model (proportion of positive sets), probably caused for the large amount of NAs. In addition, sets with no geographic position information and spatial cells where the fleet operated only occasionally were not considered for the analysis. A total of 438 (20.4%) sets were removed for the analysis (**Figure 1)**.

2.2 Dataset

From each fishing set the following information was used: date, geographical position (latitude and longitude) and mean SST (at the beginning and end of the set and at the beginning and end of hauling), effort (number of hooks), and number of shortfin mako caught. Catch per unit of effort (CPUE) was calculated as number of shortfin mako caught per 1,000 hooks. We defined two areas for the analysis according to the distribution of the effort. *Area 1*, depths less than 3000 m, comprising mainly Uruguayan waters on the continental shelf and slope; and *Area 2,* depths higher than 3000 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 15ºC (mainly Sub-Antarctic waters), between 15º and 20ºC (frontal zone) and above 20°C (mainly tropical waters). Sets corresponding to the first category were removed from the analysis due to an unbalance of the data with the other two categories (n = 47). The seasonality was considered in quarters: 1 (January-March), 2 (April-June), 3 (July-September) and 4 (October-December).

The gears used by the Uruguayan longline fleet were divided in two categories according the configuration of the branch lines: 1) simple monofilament branch lines (MF) and 2) reinforced stainless steel branch lines (AL).

2.3 Standardized methods

Because of a large proportion of zero catches (23%) the CPUE was standardized 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 occurs (Binomial). We used a Generalized Linear Mixed Models (GLMMs) with an *identity* link function for the positive observations and a Generalized Linear Model (GLM) with a *logit* link function for the proportion of positive observations. A GLM instead of a GLMM was used in the Binomial model. No interactions with the factor *Year* were considered due to a lack of convergence when trying to run GLMMs in the Binomial model.

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 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 in the LogNormal part of the model (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).

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 *Quarter* was not considered in any model because there were no data in some quarters for some specific years. All 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), lmerTest (Kuznetsova et al., 2016) and pbkrtest (Halekoh and Højsgaard, 2014).

3. Results and discussion

We analyzed a total of 1,706 sets from 2001 to 2012. The percentage of sets that captured shortfin mako (positive sets) respect to the total sets was 75.5% for the entire period, with a maximum of almost 89.1% in 2003 and a minimum of 45.0% in 2001 (**Figure 2**).

Frequency distribution of the log-transformed nominal CPUE for positive sets of shortfin mako 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,* and the interactions *Year:Area, Year:SST, Year:Gear, Quarter:SST* and *Quarter:Gear* were significant (**Table 2a**). In addition, for the proportion of positive sets the factors *Year, Quarter, Gear* and the interactions *Year:Area, Year:SST, Year:Gear, Quarter:Area, Quarter:SST* and *Quarter:Gear* were significant (**Table 2b**).

After fixed factor were selected the interactions with the factor *Year* were included as random effects in the LogNormal model 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 + Gear + Quarter:SST + Quarter:Gear + Random (Year:Area) + Random (Year:SST) + Random (Year:Gear)*

Binomial Model: *positive/total= Year + Quarter + Area + SST + Gear + Quarter:SST + Quarter:Gear*

Note that *SST*, although not significant in the LogNormal model, was included as a fixed effect since it was considered as random effect in interaction with *Year*. The same applied for *Area* and *SST* in the Binomial model. Diagnostic plots for the final Lognormal GLMM confirmed model assumptions of homogeneity of variance and lognormal distribution of CPUE (**Figure 5**). The final standardized CPUE of shortfin mako for the period 2001-2012 is shown in **Table 4** and **Figure 6**. The standardized series of shortfin mako showed an apparent increasing trend starting in 2007 onwards.

References

Bates, D., Maechler, M., Bolker, B. and Walker, S. 2014. lme4: Linear mixed-effects models using Eigen and S4. R package version 1.1-7. 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.

Halekoh, U. and Højsgaard, S. 2014. A Kenward-Roger Approximation and Parametric Bootstrap Methods for Tests in Linear Mixed Models - The R Package pbkrtest. Journal of Statistical Software, 59(9), 1-30. URL http://CRAN.R-project.org/package=pbkrtest

Kuznetsova, A., Brockhoff PB. and RH. Bojesen Christensen. 2016. lmerTest: Tests in Linear Mixed Effects Models. R package version 2.0-33. https://CRAN.R-project.org/package=lmerTest

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.

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. 2014. R: A language and environment for statistical computing. R Foundation for Statistical Computing, Vienna, Austria. URL 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: 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.

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 (12)	Period: 2001-2012
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: 15º-29º C SST1: between 15º and 20º C SST2: > 20º C
Area	Categorical (2)	Área 1: < 3,000 m depth Área 2: > 3,000 m depth
Gear (Branch line type)	Categorical (2)	AL: Stainless steel MF: Monofilament

Table 2. Deviance analysis table of positive catch rates (Lognormal) and proportion of positive sets (Binomial) models using CPUE for the period 2001-2012. '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 rate	**d.f.**	**Residual Deviance**	**Change in Deviance**	**% of Total Deviance**
NULL		1287		
Year	11	1276	97.29	48.63
Year + Quarter	3	1273	40.48	20.24
Year + Quarter + Area	1	1272	46.58	23.28
Year + Quarter + Area + SST	1	1271	2.50	1.25
Year + Quarter + Area + SST + Gear	1	1270	13.21	6.60
Year + Quarter + Area + SST + Gear + Year:Area	10	1260	37.81	15.89
Year + Quarter + Area + SST + Gear + Year:SST	11	1259	39.57	16.51
Year + Quarter + Area + SST + Gear + Year:Gear	7	1263	45.35	18.48
Year + Quarter + Area + SST + Gear + Quarter:Area	3	1267	5.53	2.69
Year + Quarter + Area + SST + Gear + Quarter:SST	3	1267	17.78	8.16
Year + Quarter + Area + SST + Gear + Quarter:Gear	3	1267	12.17	5.74
Year + Quarter + Area + SST + Gear + Area:SST	1	1269	3.12	1.54
Year + Quarter + Area + SST + Gear + Area:Gear	1	1269	0.22	0.11
Year + Quarter + Area + SST + Gear + SST:Gear	1	1269	6.65	3.22
(b) Model factors proportion of positive	**d.f.**	**Residual Deviance**	**Deviance**	**% of Total Deviance**
NULL		141		
Year	11	130	120.73	48.67
Year + Quarter	3	127	94.24	37.99
Year + Quarter + Area	1	126	0.80	0.32
Year + Quarter + Area + SST	1	125	1.27	0.51
Year + Quarter + Area + SST + Gear	1	124	31.00	12.50
Year + Quarter + Area + SST + Gear + Year:Area	11	113	62.74	20.19
Year + Quarter + Area + SST + Gear + Year:SST	11	113	32.61	11.62
Year + Quarter + Area + SST + Gear + Year:Gear	7	117	27.14	9.86
Year + Quarter + Area + SST + Gear + Quarter:Area	3	121	14.64	5.57
Year + Quarter + Area + SST + Gear + Quarter:SST	3	121	58.57	19.10
Year + Quarter + Area + SST + Gear + Quarter:Gear	3	121	23.90	8.79
Year + Quarter + Area + SST + Gear + Area:SST	1	123	9.18	3.57
Year + Quarter + Area + SST + Gear + Area:Gear	1	123	1.40	0.56
Year + Quarter + Area + SST + Gear + SST:Gear	1	123	11.39	4.39

Table 3. Analyses of proportion of positive mixed model formulation for shortfin mako, *Isurus oxyrinchus*, CPUE from the Uruguayan pelagic longline fishery (2001-2012).

GLMM	AIC	BIC	logLik	Pr(>Chisq)
Year + Quarter + Area + SST + Gear + Quarter:SST + Quarter:Gear	3082	3216	-1515	
Year + Quarter + Area + SST + Gear + Quarter:SST + Quarter:Gear + *Year:Area*	3073	3207	-1511	< 0.0001
Year + Quarter + Area + SST + Gear + Quarter:SST + Quarter:Gear + *Year:Area* + *Year:SST*	3039	3178	-1492	< 0.0001
Year + Quarter + Area + SST + Gear + Quarter:SST + Quarter:Gear + *Year:Area* + *Year:SST* + *Year:Gear*	3030	3175	-1487	0.0011

Table 4. Nominal and standardized index of relative abundance (CPUE in numbers/1000 hooks) of shortfin mako, *Isurus oxyrinchus*, for the Uruguayan pelagic longline fleet (2001-2012). CV=coefficients of variation for the standardized index.

Year	Nominal CPUE	Standard CPUE	CI_low	CI_upp	CV
2001	0.75	0.89	0.12	2.56	1.37
2002	1.77	1.38	0.29	3.32	1.10
2003	1.87	1.68	0.71	2.82	0.63
2004	1.44	1.57	0.64	2.58	0.62
2005	0.95	0.82	0.26	1.48	0.74
2006	0.81	1.18	0.40	2.08	0.71
2007	0.72	0.75	0.22	1.30	0.72
2008	2.13	1.32	0.44	2.29	0.70
2009	1.65	1.16	0.38	1.99	0.69
2010	3.49	2.61	1.10	4.40	0.63
2011	1.99	1.19	0.29	2.41	0.89
2012	2.57	1.73	0.61	4.00	0.98

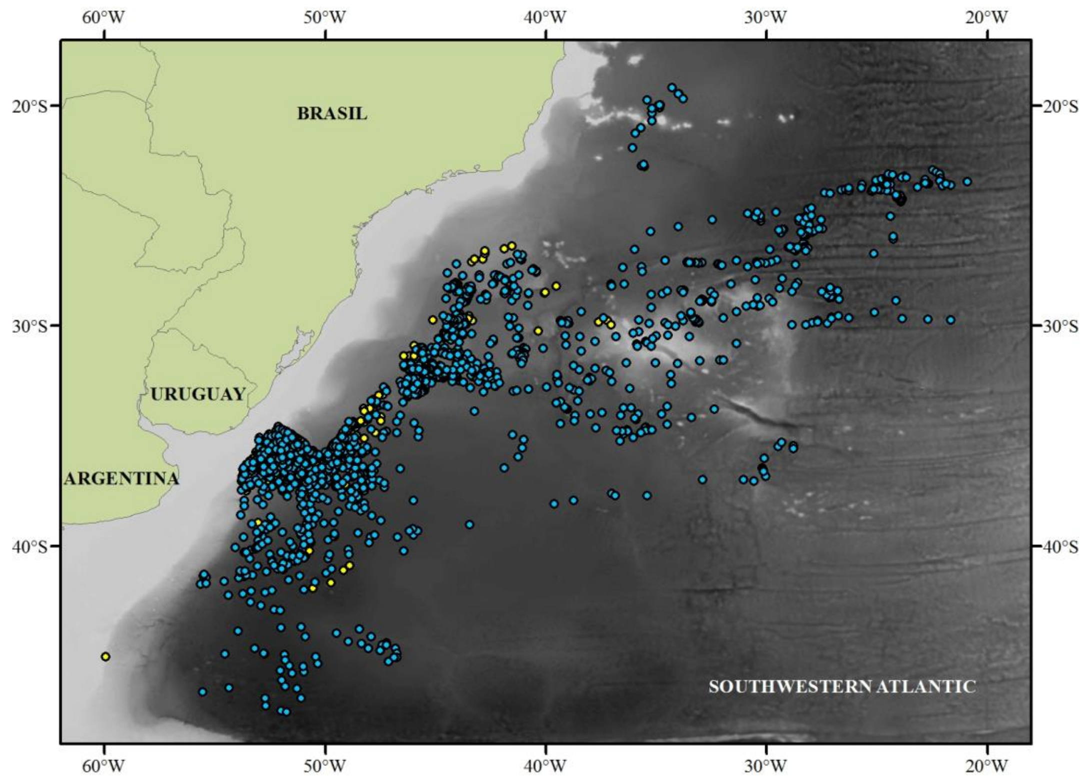

Figure 1. Distribution of longline sets deployed by Uruguayan longline fleet in the Southwestern Atlantic Ocean. Yellow dots depicts fishing sets that were left out of the analysis.

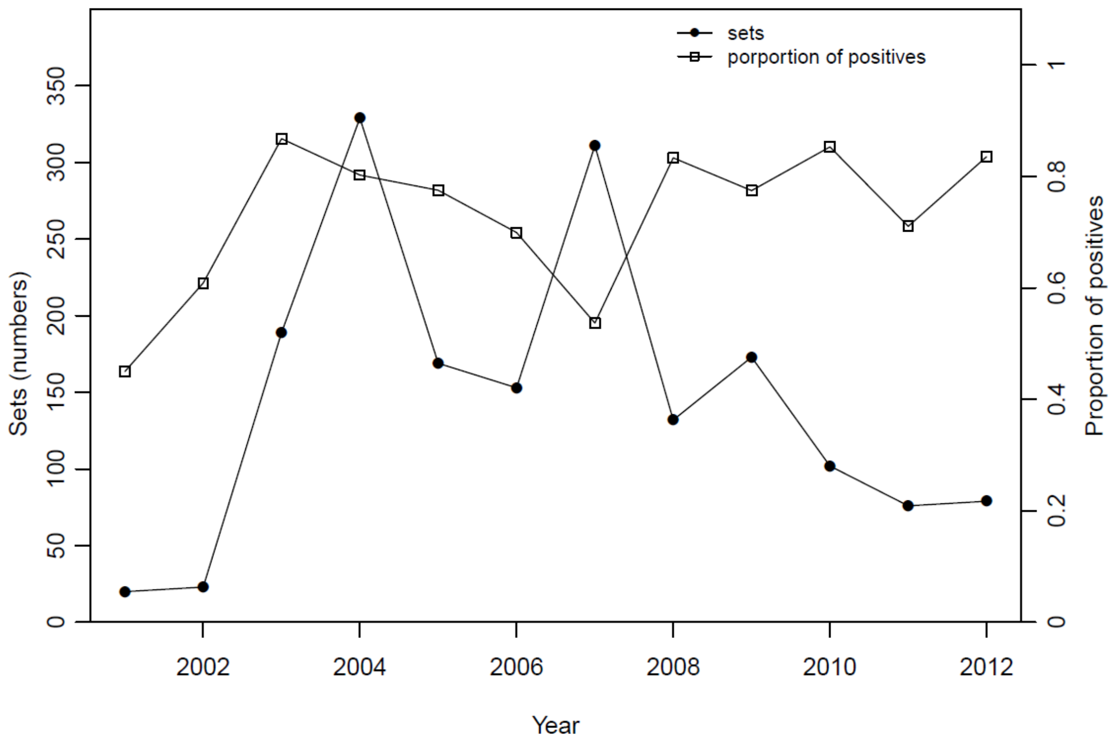

Figure 2. Number of sets and proportion of positive sets of shortfin mako, *Isurus oxyrinchus*, by year (2001-2012) for the Uruguayan longline fleet.

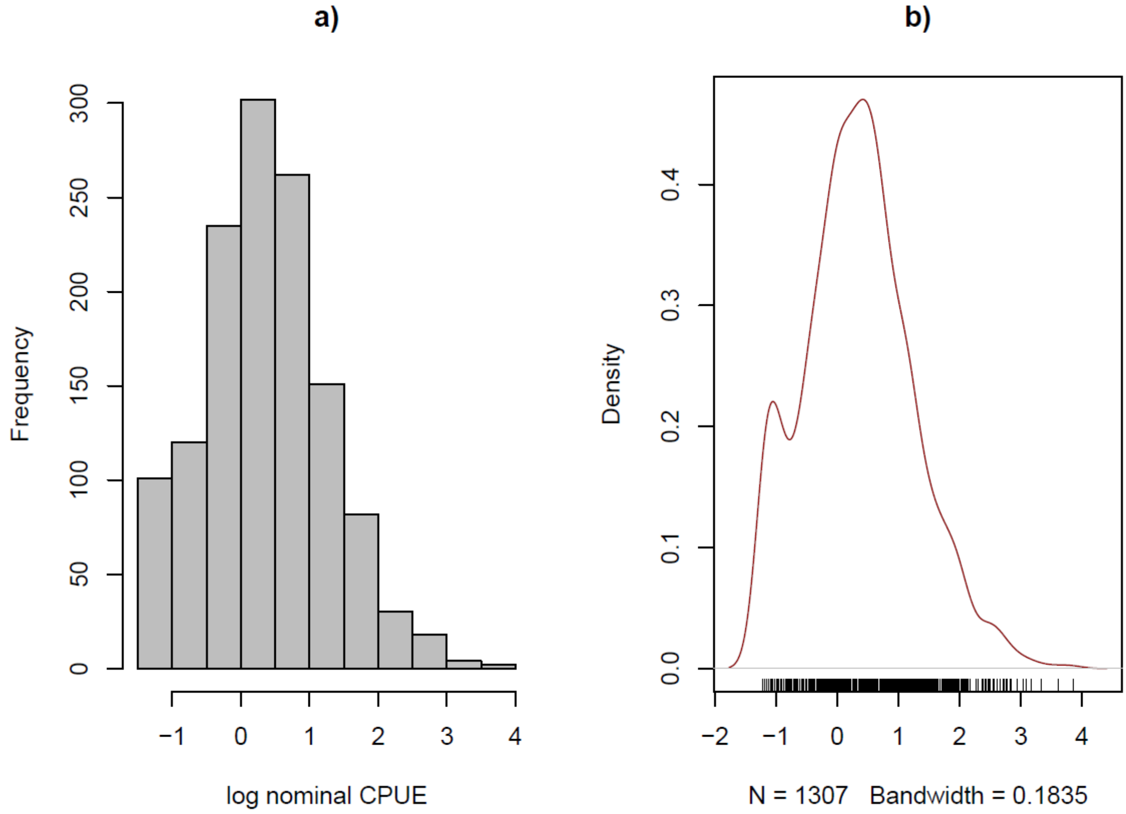

Figure 3. Frequency distribution of Log-tranformed nominal CPUE for positive sets of shorfin mako, *Isurus ixyrinchus*, caught by Uruguayan longliners between 2001 and 2012.

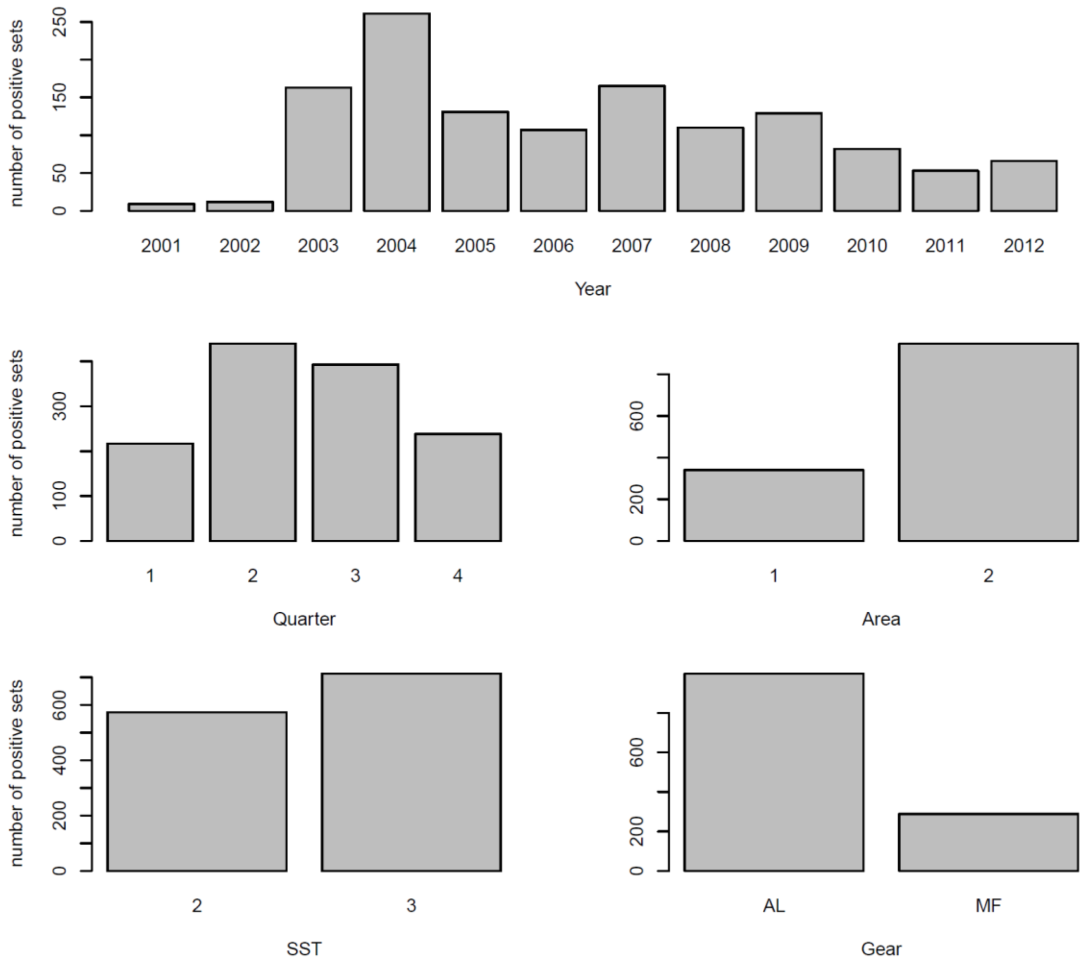

Figure 4. Number of positive sets of shortfin mako by factors (Year, Quarter, Area, SST and Gear type) for the period 2001-2012.

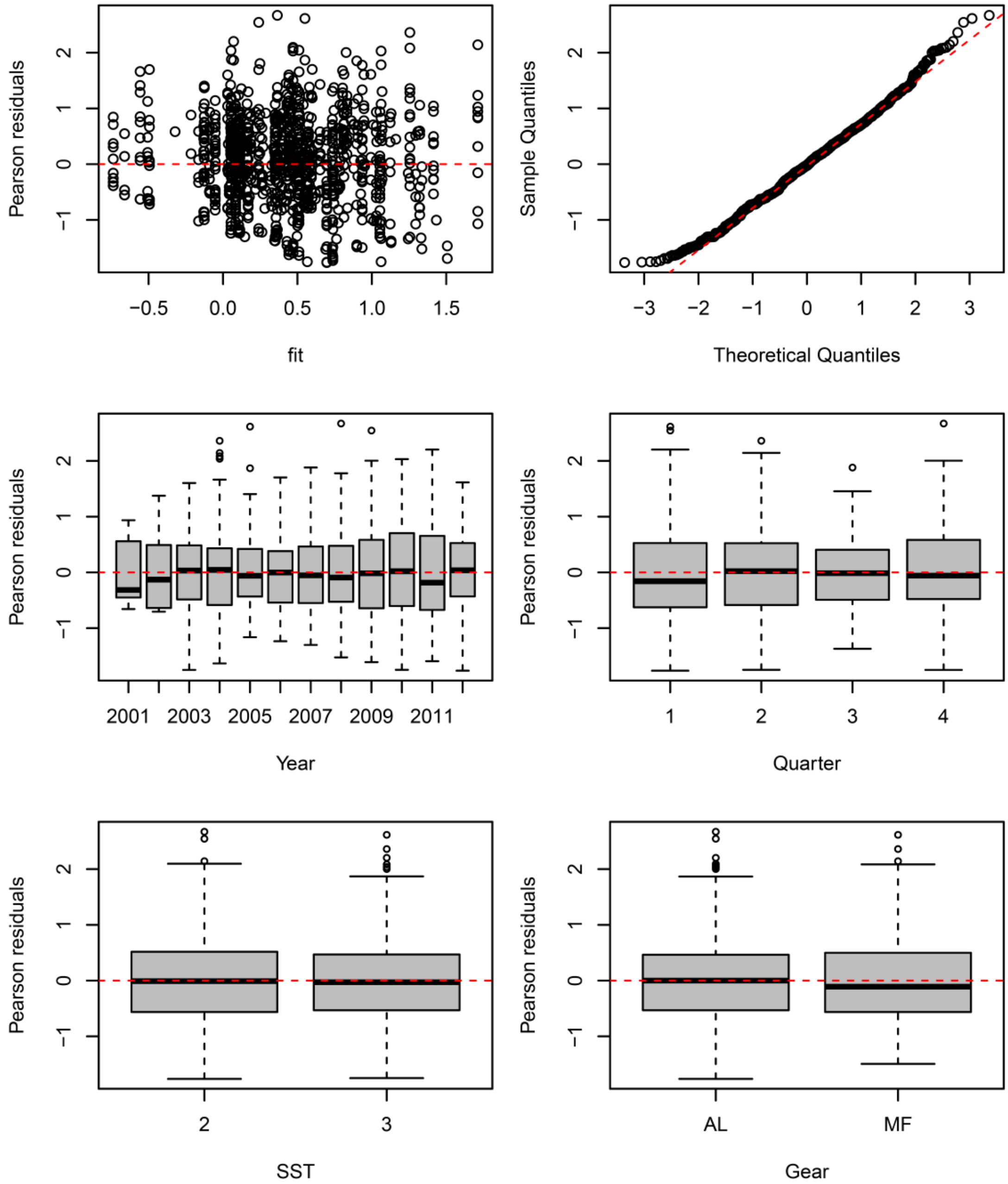

Figure 5. Diagnostic plots for positive shortfin mako catch rates (CPUE, Lognormal GLMM) for the period 2001-2012. In all plots the broken line represents the expected pattern of observations.

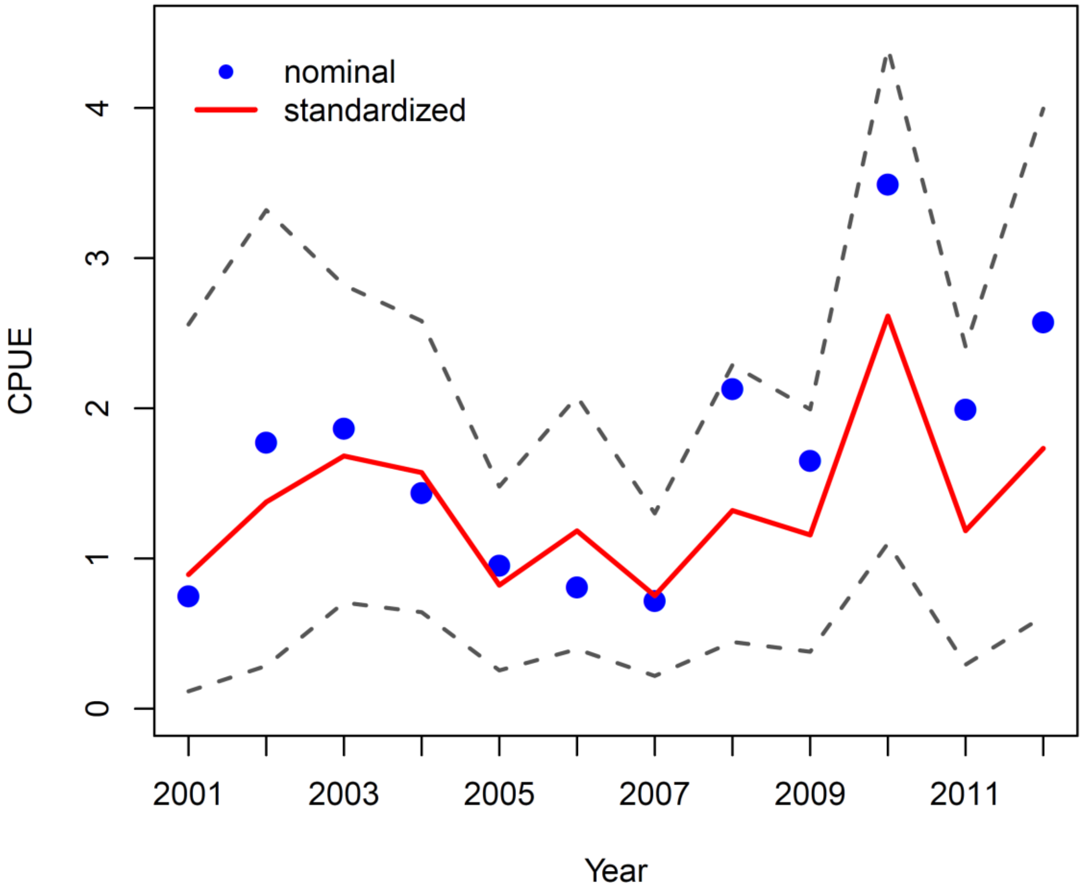

Figure 6. Scaled nominal and standardized index of abundance (CPUE) in numbers for the shortfin mako, *Isurus oxyrinchus*, caught by the Uruguayan pelagic longline fleet in the period 2001-2012. Dashed lines correspond to the 95% confidence interval of the estimated standardized index.