STANDARDIZED CPUE OF SWORDFISH, *XIPHIAS GLADIUS*, BASED ON DATA GATHERED BY THE NATIONAL OBSERVER PROGRAM ON BOARD THE URUGUAYAN LONGLINE FLEET (2001-2012)

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

SUMMARY

This study presents the standardized catch rate of swordfish, Xiphias gladius*, caught by the Uruguayan longline fleet in the southwestern Atlantic using information from national onboard observed program between 2001 and 2012. Because 8.3% of sets had zero swordfish catches, the CPUE (catch per unit of effort) was standardized by Generalized Linear Mixed Models (GLMMs) using a Delta Lognormal approach. The independent variables included in the final models as main factors and first-order interactions were: Year, Quarter, Area, Sea Surface Temperature and Gear. A total of 1,706 sets were analyzed. Standardized CPUE showed decreasing trend during the study period and was in agreement with previous standardized series based on logbooks data.*

RÉSUMÉ

*La présente étude fournit le taux de capture standardisé de l'espadon (*Xiphias gladius*) 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. Étant donné que 8,3% des opérations se sont soldées par des prises nulles d'espadon, la CPUE (capture par unité d'effort) 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 finaux comme facteurs principaux et interactions de premier ordre 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 présentait une tendance à la baisse pendant la période de l'étude et coïncidait avec la série standardisée antérieure fondée sur les données des journaux de bord.*

RESUMEN

*Este estudio presenta la tasa de captura estandarizada del pez espada (*Xiphias gladius*), capturado por la flota de palangre uruguaya en el Atlántico sudoccidental utilizando información del programa nacional de observadores a bordo entre 2001 y 2012. Dado que el 8,3% de los lances tenían capturas cero de pez espada, la CPUE (captura por unidad de esfuerzo) se estandarizó mediante modelos lineales mixtos generalizados (GLMM) utilizando un enfoque Delta lognormal. Las variables independientes incluidas en los modelos finales como factores principales e interacciones de primer orden fueron: Año, Trimestre, Área, Temperatura de la superficie del mar y Arte. Se analizaron en total 1.706 lances. La CPUE estandarizada presentaba una tendencia descendente durante el periodo de estudio y era conforme a las series estandarizadas anteriores basadas en los datos de cuadernos de pesca.*

KEYWORDS

Swordfish, 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, effort (*i.e.* number of hooks), 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 swordfish, *Xiphias gladius*, captured by the Uruguayan pelagic longline fishery is presented for the period 2001-2012 based on the PNOFA database.

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 by 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. In total, 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 swordfish caught. Catch per unit of effort (CPUE) was calculated as number of swordfish caught per 1,000 hooks. We defined two areas for the analysis according to the distribution of the fishing 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 8.3% of the sets had zero catches of swordfish 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 swordfish (positive sets) respect to the total sets was 91.7% for the entire period, with a maximum of 100% in 2001 and 2006 and a minimum of 52.1% in 2011 (**Figure 2**).

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

Deviance table analysis for the Lognormal and 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*, *Gear* and the interactions *Year:Area*, *Year:Gear* and *Quarter:SST* were significant (**Table 2a**). For the proportion of positive sets the factors *Year*, *Quarter*, *SST* and the interactions *Year:Area*, *Year:SST*, *Year:Gear* and *Quarter:SST* were significant (**Table 2b**).

After fixed factors 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 + Random (Year:Area)*

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

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 swordfish for the period 2001-2012 is shown in **Table 4** and **Figure 6**. The standardized series of swordfish showed a decreasing trend between 2001 and 2011 with an increase in the last year of the series. This study is general agreement with the decreasing trend observed by Pons *et al.* (2014) for the same period when working with CPUE (in weight) based on logbooks data.

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.

Pons, M., Forselledo, R. and Domingo, A. 2014. Standardized CPUE of swordfish (*Xiphias gladius*) caught by Uruguayan longliners in the Southwestern Atlantic ocean (1982-2012). Collect. Vol. Sci. Pap. ICCAT, 70: 1758–1776.

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 degrees 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		1309		
Year	11	1092	216.91	44.56
Year + Quarter	3	1040	51.47	10.57
Year + Quarter + Area	1	956	84.18	17.29
Year + Quarter + Area + SST	1	928	27.98	5.75
Year + Quarter + Area + SST + Gear	1	822	106.30	21.83
Year + Quarter + Area + SST + Gear + Year:Area	11	766	55.45	10.23
Year + Quarter + Area + SST + Gear + Year:SST	11	800	21.87	4.30
Year + Quarter + Area + SST + Gear + Year:Gear	7	782	40.26	7.64
Year + Quarter + Area + SST + Gear + Quarter:Area	3	814	7.75	1.57
Year + Quarter + Area + SST + Gear + Quarter:SST	3	792	29.32	5.68
Year + Quarter + Area + SST + Gear + Quarter:Gear	3	812	10.01	2.02
Year + Quarter + Area + SST + Gear + Area:SST	1	810	11.47	2.30
Year + Quarter + Area + SST + Gear + Area:Gear	1	809	12.37	2.48
Year + Quarter + Area + SST + Gear + SST:Gear	1	820	2.10	0.43
(b) Model factors proportion of positive	**d.f.**	**Residual Deviance**	**Deviance**	**% of Total Deviance**
NULL		508		
Year	11	300	208.22	69.44
Year + Quarter	3	266	34.09	11.37
Year + Quarter + Area	1	265	0.13	0.04
Year + Quarter + Area + SST	1	209	56.40	18.81
Year + Quarter + Area + SST + Gear	1	208	1.04	0.35
Year + Quarter + Area + SST + Gear + Year:Area	11	153	54.86	15.46
Year + Quarter + Area + SST + Gear + Year:SST	11	185	23.25	7.20
Year + Quarter + Area + SST + Gear + Year:Gear	7	169	38.57	11.40
Year + Quarter + Area + SST + Gear + Quarter:Area	3	200	8.41	2.73
Year + Quarter + Area + SST + Gear + Quarter:SST	3	191	17.34	5.47
Year + Quarter + Area + SST + Gear + Quarter:Gear	3	195	12.81	4.10
Year + Quarter + Area + SST + Gear + Area:SST	1	206	2.31	0.77
Year + Quarter + Area + SST + Gear + Area:Gear	1	198	9.84	3.18
Year + Quarter + Area + SST + Gear + SST:Gear	1	207	0.62	0.21

Table 3. Analyses of proportion of positive mixed model formulation for swordfish, *Xiphias gladius*, CPUE from the Uruguayan pelagic longline fishery (2001-2012).

GLMM	AIC	BIC	logLik	Pr(>Chisq)
Year + Quarter + Area + SST + Gear + Quarter:SST	3422	3545	-1688	
Year + Quarter + Area + SST + Gear + Quarter:SST + Year:Area	3389	3512	-1671	0
Year + Quarter + Area + SST + Gear + Quarter:SST + Year:Area + Year:Gear	3389	3517	-1670	0.18

Table 4. Nominal and standardized index of relative abundance (CPUE in numbers/1,000 hooks) of swordfish, *Xiphias gladius*, 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	15.25	6.47	3.51		
2002	7.04	4.13	0.38	6.62	0.76
2003	6.01	6.17	3.19	8.46	0.43
2004	6.70	5.22	1.98	6.36	0.42
2005	5.76	5.21	2.68	7.17	0.43
2006	7.45	5.50	3.92	7.72	0.34
2007	6.97	4.96	2.81	6.64	0.39
2008	3.64	3.23	0.98	3.84	0.44
2009	3.32	3.51	1.02	3.92	0.41
2010	3.62	3.29	1.30	4.24	0.45
2011	0.68	2.00	0.35	2.05	0.43
2012	3.40	5.08	3.02	7.80	0.47

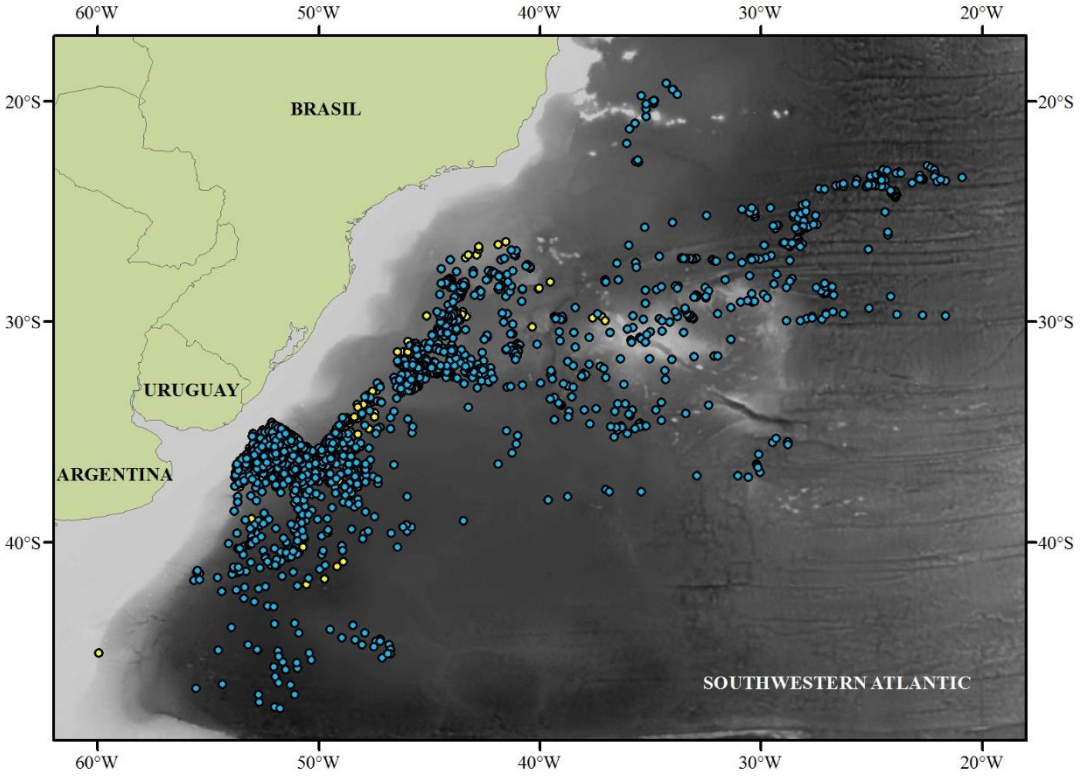

Figure 1. Distribution of longline sets deployed by Uruguayan longline fleet in the Southwestern Atlantic Ocean between 2001 and 2012. Fishing sets that were left out of the analysis are shown in yellow.

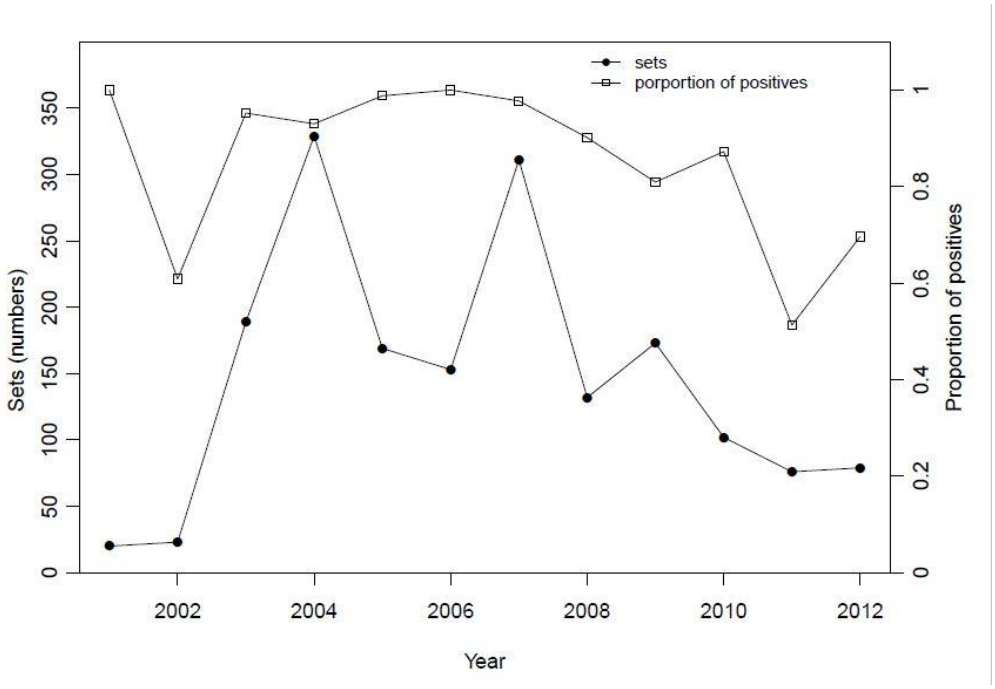

Figure 2. Number of sets and proportion of positive sets of swordfish, *Xiphias gladius*, by year (2001-2012) for the Uruguayan longline fleet.

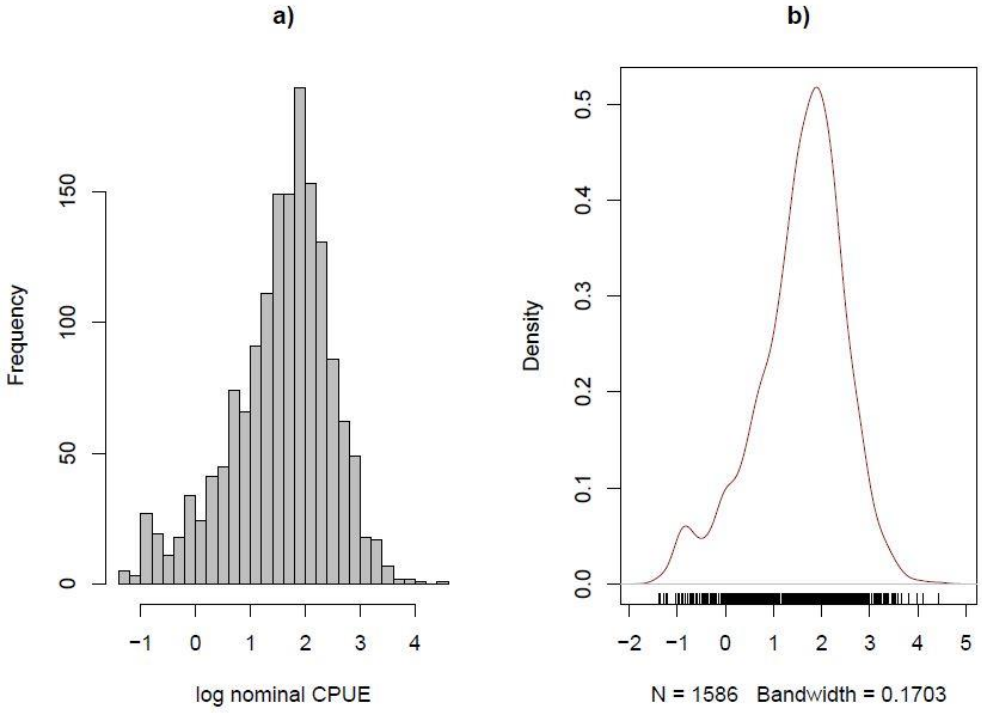

Figure 3. Frequency distribution of Log-tranformed nominal CPUE for positive sets of swordfish, *Xiphias gladius*, caught by Uruguayan longliners between 2001 and 2012.

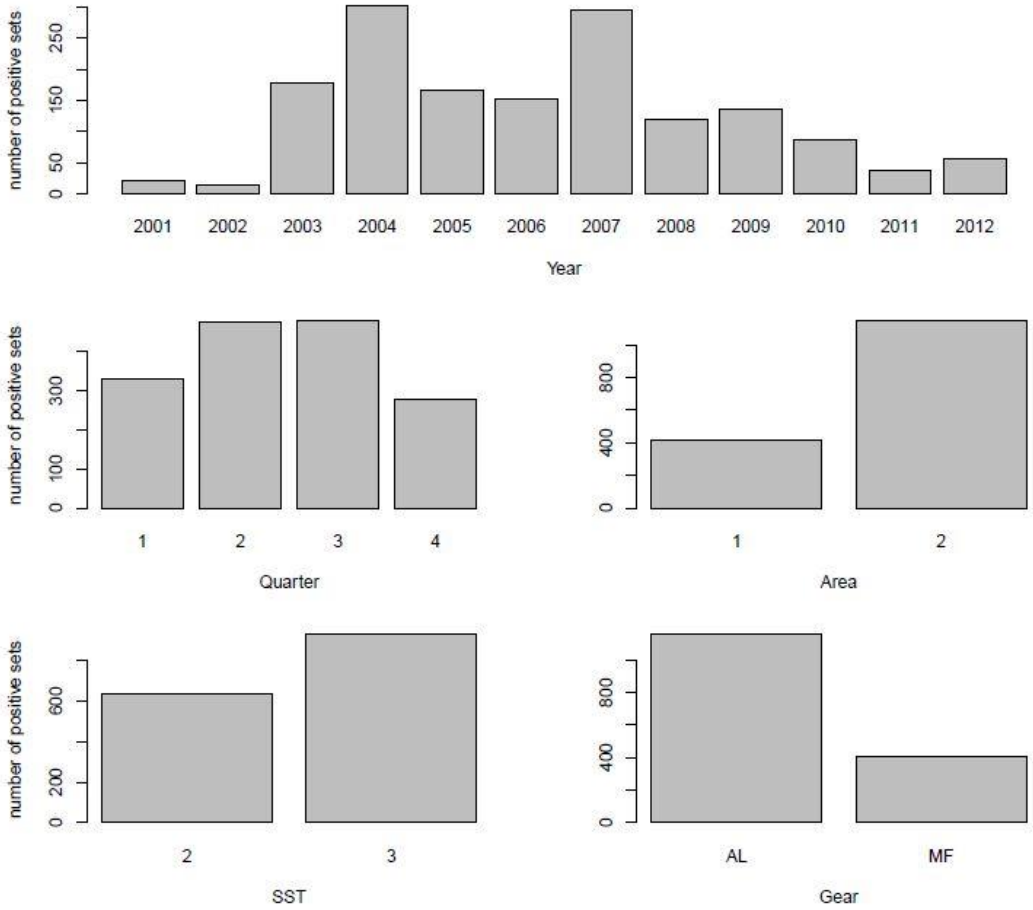

Figure 4. Number of positive sets of swordfish by factors (Year, Quarter, Area, SST and Gear type) for the period 2001-2012.

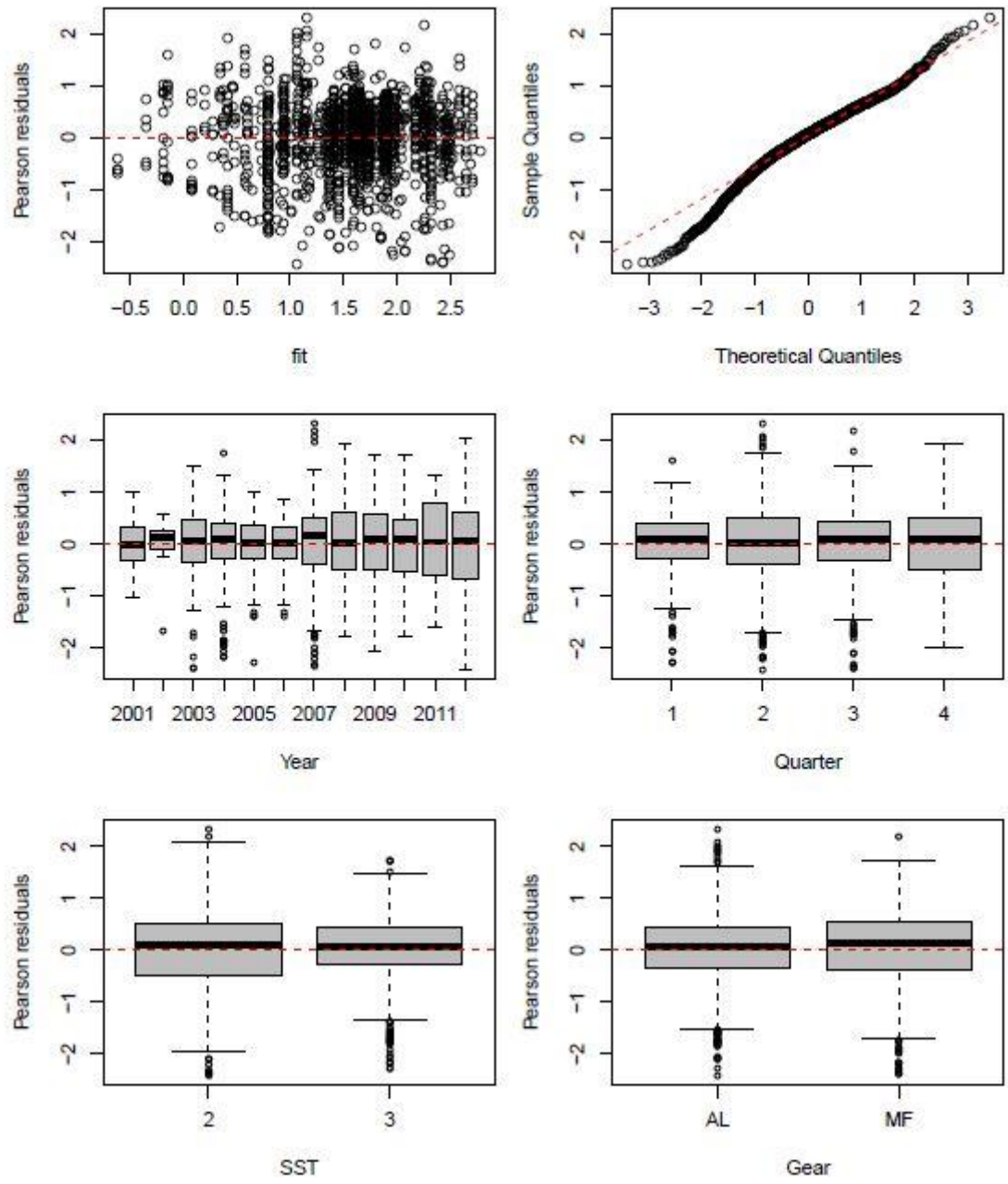

Figure 5. Diagnostic plots for positive swordfish catch rates (CPUE, Lognormal GLMM) for the period 2001-2012. In all plots the broken line represents the expected pattern of observations.

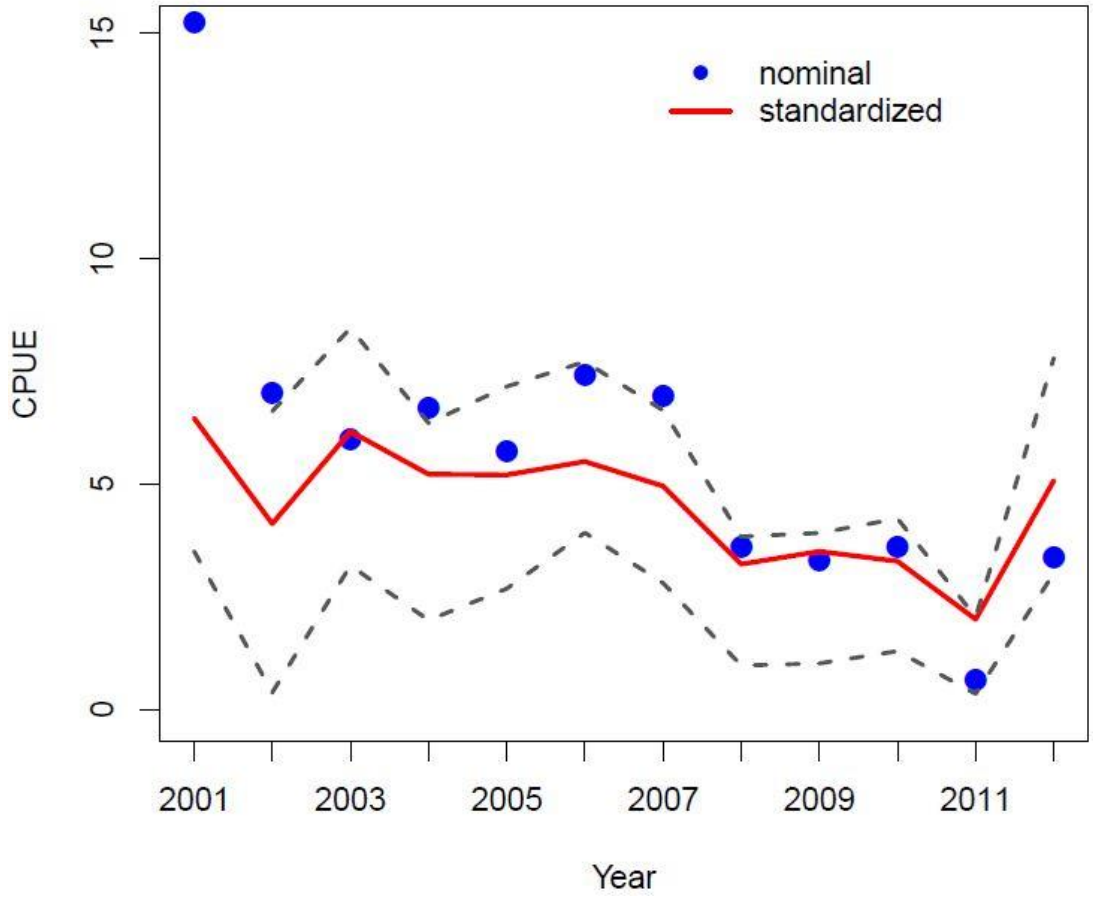

Figure 6. Scaled nominal and standardized index of abundance (CPUE) in numbers for the swordfish, *Xiphias gladius*, caught by the Uruguayan pelagic longline fleet in the period 2001-2012. Dashed lines correspond to the 95% confidence interval of the estimated standardized index.