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STANDARDIZED CPUE OF SWORDFISH (*XIPHIAS GLADIUS)* CAUGHT BY URUGUAYAN LONGLINERS IN THE SOUTHWESTERN ATLANTIC OCEAN (1982-2012)

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SUMMARY

This study presents an update of the standardized catch rate of swordfish, Xiphias gladius, *caught by the Uruguayan longline fleet in the Southwestern Atlantic Ocean between 1982 and 2012 using information obtained from logbooks. Until 1992 this fleet targeted mainly bigeye tuna; however, since 1993 the fishery shifted their target to swordfish. Thus, the CPUE series was analyzed not only as a whole but also it was split in two periods as was suggested and used in the last swordfish stock assessment session. Because there was a 15% of sets with zero swordfish catches, the CPUE was standardized by Generalized Linear Mixed Models (GLMMs) using a Delta Lognormal approach. The independent variables considered as main factors and first-order interactions were: year, quarter, area, sea surface temperature and gear style. The significant interactions with the factor Year was included in the final model as random effects. The standardized index for the first period showed a decrease in the CPUE in the first four years of the series and then an increase with a relative stabilized tendency up to 1992. For the second period a marked decrease in the CPUE index was observed from 1993 to 2012. The gear style used by Uruguayan longliners has been changed since 1993 and the GLMM method cannot fully standardize the effect of this change when the whole period was analyzed. So, the split series should be used to include in stock assessment models as was used in the last swordfish assessment session.*

RÉSUMÉ

La présente étude fournit une actualisation du taux de capture standardisé de l'espadon (Xiphias gladius*) capturé par la flottille palangrière uruguayenne dans l'Atlantique Sud-Ouest entre 1982 et 2012 au moyen d'informations provenant des carnets de pêche. Jusqu'en 1992, cette flottille a essentiellement ciblé le thon obèse ; or, depuis 1993, la pêcherie s'est mise à cibler l'espadon. C'est pourquoi la série de CPUE a été analysée dans son ensemble mais elle a également été divisée en deux périodes, comme cela a été suggéré et utilisé dans la dernière session d'évaluation du stock d'espadon. Étant donné que 15% des opérations se sont soldées par des captures nulles d'espadon, la CPUE a été standardisée au moyen de modèles mixtes linéaires généralisés (GLMM) à l'aide d'une approche delta log-normale. Les variables indépendantes considérées comme facteurs principaux et interactions de premier ordre étaient: année, trimestre, zone, température à la surface de la mer et style d'engin. Les importantes interactions avec le facteur année ont été incluses dans le modèle final comme effets aléatoires. L'indice standardisé pour la première période a fait apparaître une baisse de la CPUE au cours des quatre premières années de la série, suivie d'une hausse accompagnée d'une tendance relativement stable jusqu'en 1992. Pour la deuxième période, une baisse marquée de l'indice de la CPUE a été observée de 1993 à 2012. Le style de l'engin utilisé par les palangriers uruguayens a été modifié depuis 1993 et la méthode GLMM n'a pas pu entièrement standardiser l'effet de ce changement lorsque toute la période a été analysée. C'est pourquoi les séries divisées devraient être utilisées afin d'être incluses dans les modèles, comme cela s'est fait dans la dernière session d'évaluation de l'espadon.*

RESUMEN

Este estudio presenta una actualización de la tasa de captura estandarizada del pez espada, Xiphias gladius, *capturado por la flota de palangre uruguaya en el Atlántico sudoccidental entre 1982 y 2012 utilizando información de los cuadernos de pesca. Hasta 1992 esta flota se dirigía principalmente al patudo, sin embargo, desde 1993, la pesquería cambió de objetivo para dirigir su actividad al pez espada. Por tanto, la serie de CPUE se analizó no solo como un*

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todo, sino que también fue separada en dos periodos tal y como se sugirió y utilizó en la última sesión de evaluación del stock de pez espada. Dado que había un 15% de lances con capturas cero de pez espada, la CPUE se estandarizó mediante modelos lineales mixtos generalizados (GLMM) utilizando un enfoque Delta lognormal. Las variables independientes consideradas factores principales e interacciones de primer orden fueron: año, trimestre, área, temperatura de la superficie del mar y tipo de arte. Las interacciones significativas con el factor Año se incluyeron en el modelo final como efectos aleatorios. El índice estandarizado para el primer periodo mostraba un descenso en la CPUE en los primeros cuatro años de la serie y luego un aumento con una tendencia relativamente estabilizada hasta 1992. Para el segundo periodo, se observó un marcado descenso en el índice de CPUE desde 1993 hasta 2012. El tipo de arte utilizado por los palangreros uruguayos ha cambiado desde 1993 y el método GLMM no puede estandarizar plenamente el efecto de este cambio cuando se analiza el periodo en su conjunto. Por ello, debería usarse la serie separada para su inclusión en los modelos de evaluación de stock al igual que se hizo en la última sesión de evaluación del stock de pez espada.

KEYWORDS

Swordfish, Southwestern Atlantic, Logbooks, GLMM, Longline

1. Introduction

The Uruguayan longline fleet started its activities in 1981 and until 1992 this fleet consisted mainly of freezing vessels operating with Japanese-style longline targeting bigeye tuna, *Thunnus obesus* (Domingo *et al*., 2008). Since 1992-1993, these vessels were replaced by fresh-fishing vessels operating with American-style longline, except for some freezing units that operate with a Spanish-style longline. During this latter period the longline fleet targeted mainly swordfish, *Xiphias gladius*. Because of that, the CPUE series was analyzed not only as a whole but also it was split in two periods -before and after 1992- as was suggested and used in the last swordfish stock assessment session (ICCAT 2010).

The present study updates the standardized catch rate of swordfish captured by the Uruguayan tuna longline fleet presented in SCRS/2009/127(Pons and Domingo, 2010) up to 2012.

2. Material and methods

2.1 Data reduction and exclusions

We analyzed data from logbooks of the Uruguayan longline fleet between 1981 and 2012. However, in order to improve the database we remove the first year of the time series because the data was partial and incomplete, *i.e.* the fleet started its activities in November 1981. In addition, sets with no location information and spatial cells were the fleet operated occasionally (grey dots in **Figure 1**) were not considered for the analysis, removing 5% of the total sets. Finally, a total of 19,524 sets from 1982 to 2012 with complete information were analyzed.

2.2 Data and variables used

From each fishing set the following information was used: date, geographical position (latitude and longitude) and Sea Surface Temperature (SST) at the beginning of each set and effort (in thousands of hooks). The CPUE was calculated as swordfish weight (in kilograms) per 1000 hooks.

We defined two areas for the analysis according to the distribution of the effort (Pons *et al*., 2012). *Area 1*, at 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-42º S and 38º-55º W (**Figure 1**).

The SST was categorized in three levels according to the presence of different water masses in the region (Pons and Domingo, 2011; Pons *et al*., 2012): below 15º C (mainly Sub-Antarctic waters), between 15º and 20º C (frontal zone) and above 20° C (mainly tropical waters). In addition, the seasonality was considered as annual quarters: 1 (January to March), 2 (April to June), 3 (July to September) and 4 (October to December).

Finally, to take into account potential differences between gear styles (Pons and Domingo, 2011; Pons *et al*., 2012) we used the variable *Gear* with two levels: 1) monofilament mainline (American style longline) and 2) multifilament mainline (including Japanese style for the first period and Spanish style for the second).

2.3 Standardized methods

Because of the presence of zero catches in 15% of the sets, the CPUE was standardized by Generalized Linear Mixed Models (GLMMs) using a Delta Lognormal approach (Lo *et al*. 1992) to treated separately the positive observations (with a Lognormal distribution) to the probability that a positive observation occurs (with a Binomial response). We used an *identity* link function for the Lognormal and a *logit* link function for the Binomial models.

Deviance tables (for both components of the delta model) were used to select the fixed 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/interactions whose deviation exceeds 5% of the total deviation were selected as explanatory variables.

Once selected the fixed factors and interactions, all interactions involving the factor *Year* were evaluated as random effect variables to obtain the estimated index per year, transforming the GLMs into 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) 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 for 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 R software (R Development Core Team, 2012) with the packages MASS (Venables *et al*., 2002), lme4 (Bates, 2012), lsmeans (Lenth, 2013) and pbkrtest (Højsgaard and Halekoh, 2012).

2.4 Swordfish size data

Swordfish fork length (FL) data presented was obtained by the Uruguayan on board observer program (PNOFA) between 1998 and 2011. Finally, a boxplot of swordfish FL by year was presented.

3. Results and discussion

3.1 Swordfish catches

In **Figure 2** annual total catches, for the period 1982-2012, from ICCAT Task I database are presented. Although, there were high catches of swordfish between 1983 and 1985, until 1992 swordfish was caught as by-catch. That peak was related directly with an increase in effort during this period (**Figure 2**) when 5 vessels from China-Taipei operated with Uruguayan flag in the region. In 1993 the Uruguayan longline fleet changed their target to swordfish what led to an increase in the proportion of swordfish in relation to total tunas (**Figure 3**).

3.2 Standardized indices

The percentage of sets that captured swordfish (positive sets) to the total sets was 85% for the entire period, with a minimum of 64% in 2002 and a maximum of 97% in 2007 (**Figure 4**). Even though during the first period swordfish was caught as bycatch, the percentage of positive sets in both periods analyzed (bycatch and target periods) were 85%.

Regarding the positive sets, **Figure 5** shows the frequency distribution of the log-transformed nominal CPUE for the entire series and by period.

3.2.1 Whole period (1982-2012)

The first order interactions considered to include in the GLMs are plotted in **Figure 6**. However, the interaction *Year: Gear* were not used in the analysis because there was not continuity in time of each *Gear* category, *i.e.* during the first period only vessels using multifilament mainline were operating (**Figure 6**). In addition, **Figure 7** shows the number of positive observations by factors for the whole period.

Deviance table analysis, one for the 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* and *Gear*, and the interactions *Year: Quarter* and *Year: Area* were significant (**Table 2a**). Also, for the proportion of positives/total sets the factors *Year, Area* and *Quarter* and the interactions *Year: Area, Year: Quarter, Year: SST* and *Area: Gear* were significant (**Table 2b**).

Thus, after fixed factors were selected, the interactions with *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 + Area + Quarter + Gear* + Random (*Year: Area*) + Random (*Year: Quarter*)

Binomial Model: *positive/total= Year + Area + Quarter + SST + Area: 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 the CPUE. However, some deviation from normality could be observed towards the lower side of the distribution (**Figure 8**).

The final standardized swordfish CPUE index for the entire period is shown in **Figure 9** and presented in **Table 4**. The standardized index showed a decrease in the CPUE in the first four years of the time series and then an increase with a relative stabilized tendency up to 1992. Then, a marked decrease was observed in the CPUE index from 1993 to 2012 (**Figure 9**).

3.2.2 First period (1982-1992)

The first order interactions considered for the first period of the time series are plotted in **Figure 10**. The factor *Gear* was not considered because the Uruguayan longline vessels during this period operated only with one type of gear: Japanese-style longline with multifilament mainline. In **Figure 11** the numbers of positive observations by factors are presented.

Deviance table analysis, one for the 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 fixed factors *Year* and *Quarter*, and the interactions *Year: Quarter*, *Year: Area*, *Quarter: SST* and *Quarter: Area* were significant (**Table 5a**). In addition, for the proportion of positive/total sets the factors *Year* and *Quarter*, and the interactions *Year: Area, Year: Quarter, Year: SST* and *Quarter: Area* were significant (**Table 5b**).

After these fixed factors were selected the interactions with the *Year* factor 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 + Area + Quarter + SST + Quarter: SST + Quarter: Area* + Random (*Year: Area*) + Random (*Year: Quarter*)

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

Diagnostic plots for the final Lognormal GLMM confirmed model assumptions of homogeneity of variance and lognormal distribution of the CPUE (**Figure 12**).

The final standardized CPUE index for the period 1982-1992 is shown in **Figure 13** and presented in **Table 4**. The standardized index showed a decrease in the CPUE in the first four years with an increase in 1987 and a stable tendency between 1988 and 1992.

3.2.3 Second period (1993-2012)

The first order interactions considered to include in the GLM models in the second period of the time series are shown in **Figure 14**. The interaction *Year: Gear*, *Year: SST* and *Quarter: SST* were not included in the analysis because there was discontinuity in time of each factors category (**Figure 14**). In **Figure 15** the numbers of positive observations by factors are presented.

Deviance table analysis, one for the Lognormal and other for the Binomial models, are presented in **Tables 7a** and **7b** respectively. For the mean catch rates given in the positive sets, the factors *Year*, *Quarter* and *Gear*, and the interaction *Year: Quarter* were significant (**Table 7a**). In addition, for the proportion of positive/total sets the factors *Year*, *Area*, *Quarter* and *SST*, and the interactions *Year: Area* and *Year: Quarter* were significant (**Table 7b**).

After fixed factor were selected the interactions with the factor *Year* were included as random effects (see **Table 8**). The final models selected for the Lognormal and Binomial components were:

Lognormal Model: *log (CPUE) = Year* + *Quarter* + *Gear* + Random (*Year: Quarter*)

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

Diagnostic plots for the final Lognormal GLMM confirmed in general model assumptions however some deviation from normality can be observed in the left side of the residuals distribution (**Figure 16**).

The final standardized index for swordfish catch rates between1993 and 2012 is shown in **Figure 17** and presented in **Table 4**. The standardized CPUE showed a marked decrease since 1993 up to 2012.

The Gear style used by Uruguayan longliners changed in1992 and the GLMM method cannot fully standardize the effect of this change when the whole period was analyzed (**Figure 18**). Thus, the split series should be used to include in stock assessment models as was used in the last swordfish stock assessment session (ICCAT 2010).

The differences observed between the last standardized series presented in SCRS/2009/127 and the present study (**Figure 18**) is due to differences in explanatory variables definitions, data reductions and exclusions, and models used. In the last assessment (2010) the series was split after the standardization process and not before like in the present study.

3.3 Swordfish size data

For the period 1998-2011, the Uruguayan tuna fleet captured swordfish between 57 and 319 cm fork length, with an overall mean of 156 cm (N=24,309, **Figure 19**). This mean length matched with the size in which the 50% of the swordfish females reach sexual maturity in the Southwestern Atlantic (Hazin *et al*., 2002).

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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 factor variable.

Variable	Type	Observations
Year	Categorical (31)	Period: 1982-2012
Quarter	Categorical (4)	Quarter 1: January-March Quarter 2: April-June Quarter 3: July-September Quarter 4: October-December
Sea surface temperature (*SST*)	Categorical (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*
Gear	Categorical (2)	1: Monofilament mainline 2: Multifilament mainline

* See **Figure 1**.

Table 2. Deviance analysis table of positive catch rates (**a:** Lognormal) and proportion of positive sets (**b:** Binomial) models. '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	27057		
Year	30	22634	4423	56.3
Year Quarter	3	20098	2536	32.3
Year Quarter Area	1	19988	110	1.4
Year Quarter Area SST	2	19984	4	0.0
Year Quarter Area SST Gear	1	19200	784	10.0
Year Quarter Area SST Gear Year* Quarter	88	17854	1346	14.6
Year Quarter Area SST Gear Year* Area	30	18690	510	6.1
Year Quarter Area SST Gear Year* SST	53	18852	347	4.2
Year Quarter Area SST Gearr Quarter* SST	6	19056	144	1.8
Year Quarter Area SST Gear Quarter* Area	3	19027	173	2.1
Year Quarter Area SST Gear Area* SST	2	19113	87	1.1
Year Quarter Area SST Gear Area* Gear	1	19119	80	1.0

b) Model factors proportion positives	d.f.	Residual deviance	Change in deviance	% of total deviance
NULL	1	4429		
Year	30	3622	807	39.0
Year Area	1	2930	693	33.5
Year Area Quarter	3	2417	513	24.8
Year Area Quarter SST	2	2364	53	2.6
Year Area Quarter SST Gear	1	2362	1	0.1
Year Area Quarter SST Gear Year* Area	30	1525	837	28.8
Year Area Quarter SST Gear Year* Quarter	88	1752	610	22.8
Year Area Quarter SST Gear Year* SST	53	2049	314	13.2
Year Area Quarter SST Gearr Quarter* SST	3	2342	20	1.0
Year Area Quarter SST Gear Quarter* Area	6	2344	18	0.9
Year Area Quarter SST Gear Area* SST	2	2269	93	4.3
Year Area Quarter SST Gear Area* Gear	1	1959	404	16.3

Table 3. Analyses of the delta lognormal mixed model formulations for swordfish catch rates from the Uruguayan pelagic longline fishery (1982-2012).

GLMM	Akaike's Information Criterion	Bayesian Information Criterion	Log Likelihood	Likelihood Ratio Test
Positives catch rates				
Year Area Quarter Gear	49616	49909	-24770	
Year Area Quarter Gear *Year:Area*	49345	49639	-24635	<0.0001
Year Area Quarter Gear *Year:Area Year:Quarter*	**48395**	**48696**	**-24158**	**<0.0001**
Proportion of positives				
Year Area Quarter SST Area:Gear	2039	2211.6	-979.41	
Year Area Quarter SST Area:Gear *Year:Area*	1787	1959.5	-853.36	<0.0001
Year Area Quarter SST Area:Gear *Year:Area Year:Quarter*	1501	1678.4	-709.68	<0.0001
Year Area Quarter SST Area:Gear *Year:Area Year:Quarter Year:SST*	**1441**	**1622.4**	**-678.5**	**<0.0001**

Table 4. Nominal and standardized index of relative abundance of swordfish in weight (kg) for the Uruguayan pelagic longline fleet for the whole period (1982-2012) and for each specific period considered in the analysis (before and after 1992). CV=coefficients of variation for the standardized indices.

Year	Nominal CPUE	Standardized CPUE (whole period)	CV	Standardized CPUE (by period)	CV
1982	577	736	0.48	368	0.58
1983	325	407	0.48	219	0.57
1984	280	283	0.49	162	0.58
1985	273	155	0.53	97	0.60
1986	356	189	0.54	111	0.62
1987	492	386	0.49	219	0.58
1988	496	272	0.51	149	0.60
1989	560	347	0.54	179	0.62
1990	511	270	0.52	149	0.61
1991	448	270	0.56	130	0.65
1992	333	189	0.57	147	0.65
1993	740	463	0.56	554	0.31
1994	610	334	0.53	320	0.31
1995	1015	500	0.50	540	0.28
1996	883	416	0.48	439	0.25
1997	996	452	0.51	565	0.27
1998	713	347	0.51	422	0.28
1999	661	330	0.48	372	0.25
2000	580	376	0.50	380	0.28
2001	674	334	0.50	365	0.27
2002	432	188	0.55	246	0.39
2003	354	193	0.55	213	0.38
2004	446	312	0.51	314	0.28
2005	368	250	0.50	262	0.26
2006	375	303	0.50	294	0.27
2007	434	284	0.48	326	0.25
2008	261	177	0.51	172	0.31
2009	236	210	0.51	199	0.30
2010	233	206	0.53	193	0.33
2011	100	91	0.61	89	0.42
2012	147	121	0.54	114	0.35

Table 5. Deviance analysis table of positive catch rates (**a:** Lognormal) and proportion of positive sets (**b:** Binomial) models. '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	13586		
Year	10	12960	626	18.9
Year Quarter	3	10306	2654	80.2
Year Quarter Area	1	10305	1	0.0
Year Quarter Area SST	2	10277	27	0.8
Year Quarter Area SST Year* Quarter	29	9728	550	14.2
Year Quarter Area SST Year* Area	10	9960	317	8.8
Year Quarter Area SST Year* SST	20	10135	142	4.1
Year Quarter Area SST Quarter* SST	6	9972	306	8.5
Year Quarter Area SST Quarter* Area	3	9922	355	9.7
Year Quarter Area SST Area* SST	2	10191	87	2.6

b) Model factors proportion positives	d.f.	Residual deviance	Change in deviance	% of total deviance
NULL	1	1333		
Year	10	1135	197	27.6
Year Area	1	1119	16	2.3
Year Area Quarter	3	621	498	69.6
Year Area Quarter SST	2	617	4	0.6
Year Area Quarter SST Year* Area	10	482	134	15.8
Year Area Quarter SST Year* Quarter	29	399	218	23.3
Year Area Quarter SST Year* SST	20	521	96	11.8
Year Area Quarter SST Quarter* Area	3	570	47	6.1
Year Area Quarter SST Area* SST	2	599	18	2.4

Table 6. Analyses of the delta lognormal mixed model formulations for swordfish catch rates from the Uruguayan pelagic longline fishery (1982-1992).

GLMM	Akaike's Information Criterion	Bayesian Information Criterion	Log Likelihood	Likelihood Ratio Test
Positives catch rates				
Year Area Quarter SST Quarter:SST Quarter:Area	22958	23151	-11451	
Year Area Quarter SST Quarter:SST Quarter:Area *Year:Area*	22830	23024	-11387	<0.0001
Year Area Quarter SST Quarter:SST Quarter:Area *Year:Area Year:Quarter*	**22707**	**22908**	**-11325**	**<0.0001**
Proportion of positives				
Year Area Quarter SST Area:Quarter	612	680	-285	
Year Area Quarter SST Area:Quarter *Year:Area*	551	619	-255	<0.0001
Year Area Quarter SST Area:Quarter *Year:Area Year:Quarter*	**450**	**540**	**-197**	**<0.0001**
Year Area Quarter SST Area:Quarter *Year:Area Year:Quarter Year:SST*	468	542	-211	<0.0001

Table 7. Deviance analysis table of positive catch rates (**a:** Lognormal) and proportion of positive sets (**b:** Binomial) models. '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	11090		
Year	19	9674	1417	51.3
Year Quarter	3	9198	475	17.2
Year Quarter Area	1	9081	118	4.3
Year Quarter Area SST	2	9073	8	0.3
Year Quarter Area SST Gear	1	8329	745	27.0
Year Quarter Area SST Gear Year* Quarter	56	7979	350	11.2
Year Quarter Area SST Gear Year* Area	19	8191	137	4.7
Year Quarter Area SST Gearr Quarter* SST	5	8313	15	0.6
Year Quarter Area SST Gear Quarter* Area	3	8272	56	2.0
Year Quarter Area SST Gear Area* SST	2	8318	11	0.4
Year Quarter Area SST Gear Area* Gear	1	8328	0	0.0

b) Model factors proportion positives	d.f.	Residual deviance	Change in deviance	% of total deviance
NULL	1	3084		
Year	19	2475	608	31.7
Year Area	1	1499	976	50.8
Year Area Quarter	3	1303	197	10.2
Year Area Quarter SST	2	1193	110	5.7
Year Area Quarter SST Gear	1	1162	30	1.6
Year Area Quarter SST Gear Year* Area	19	869	293	13.2
Year Area Quarter SST Gear Year* Quarter	56	836	327	14.5
Year Area Quarter SST Gearr Quarter* SST	3	1155	8	0.4
Year Area Quarter SST Gear Quarter* Area	5	1134	29	1.5
Year Area Quarter SST Gear Area* SST	2	1124	39	2.0
Year Area Quarter SST Gear Area* Gear	1	1160	3	0.1

Table 8. Analyses of the delta lognormal mixed model formulations for swordfish catch rates from the Uruguayan pelagic longline fishery (1982-1992).

GLMM	Akaike's Information Criterion	Bayesian Information Criterion	Log Likelihood	Likelihood Ratio Test
Positives catch rates				
Year Quarter Gear	25745	25931	-12847	
Year Quarter Gear *Year: Quarter*	**25547**	**25732**	**-12747**	**<0.0001**
Proportion of positives				
Year Area Quarter SST	1247	1352	-596	
Year Area Quarter SST *Year:Area*	1052	1157	-499	<0.0001
Year Area Quarter SST *Year:Area Year:Quarter*	**935**	**1045**	**-440**	**<0.0001**

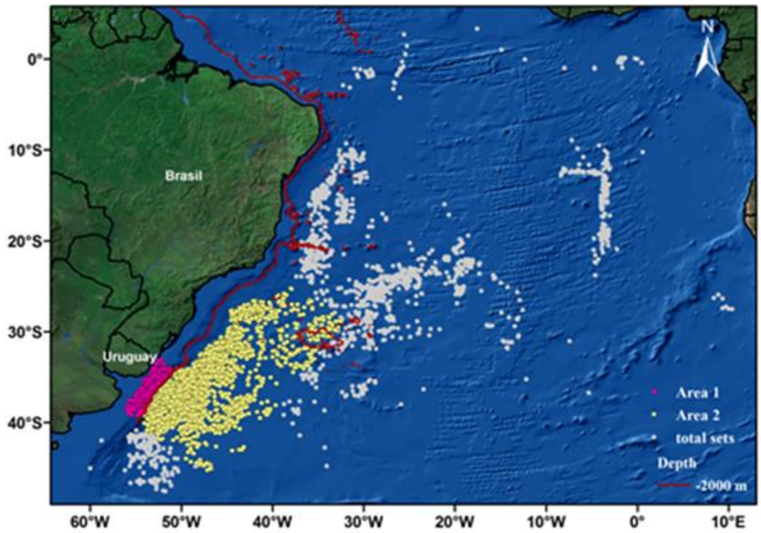

Figure 1. Distribution of longline sets deployed by Uruguayan longline fleet in the Southwestern Atlantic Ocean registered on logbooks between 1982 and 2012. Color dots represent the two areas selected for the analysis: **Area 1**, below 2000 m depth (red line); and **Area 2**, above 2000 m depth. Gray dots were left out of analysis.

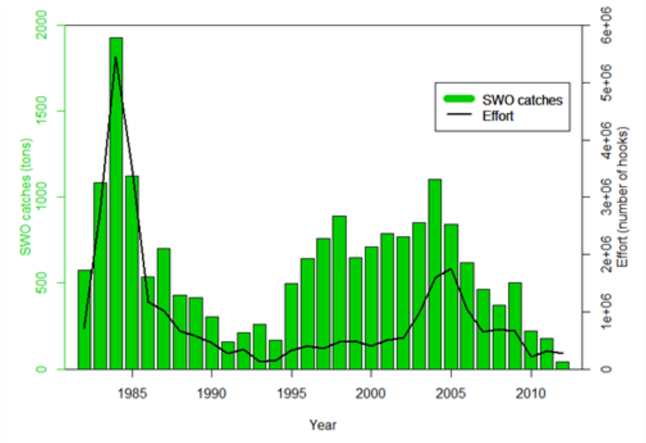

Figure 2. Annual total catches in tons (ICCAT, Task I) and effort (in number of hooks) for the period 1982-2012.

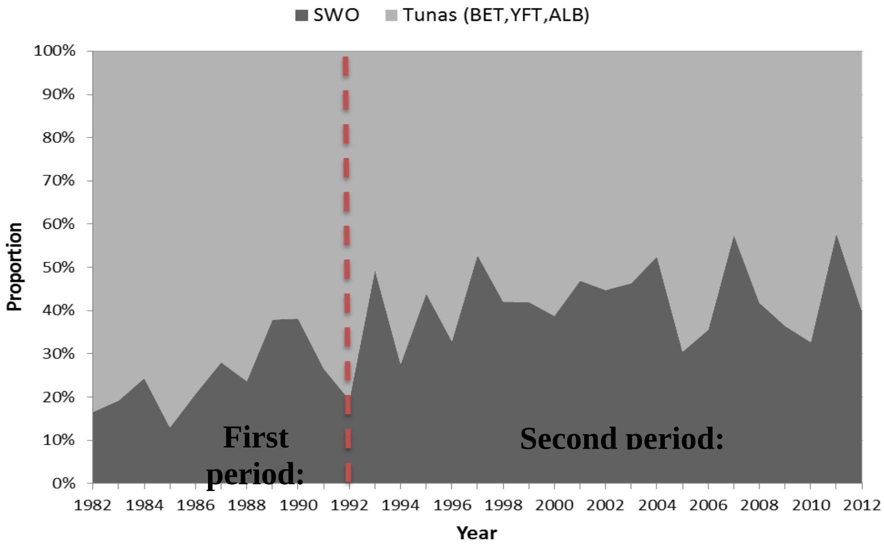

Figure 3. Proportion of swordfish to tunas catches by year and period (First period: 1982-1992; Second period: 1993-2012). BET: bigeye, YFT: yellowfin, ALB: albacore.

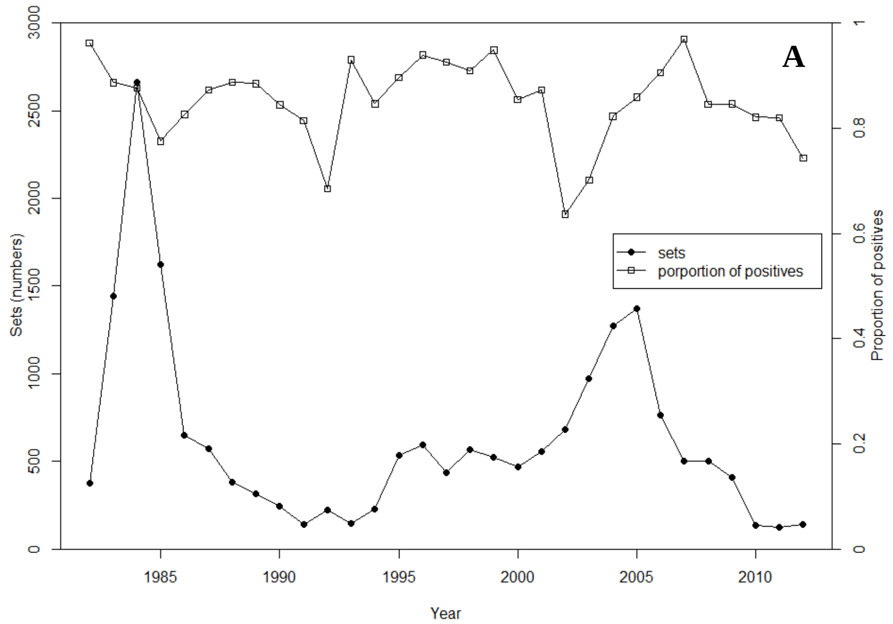

Figure 4. Number of sets and proportion of swordfish positive sets by year for the Uruguayan longline fleet.

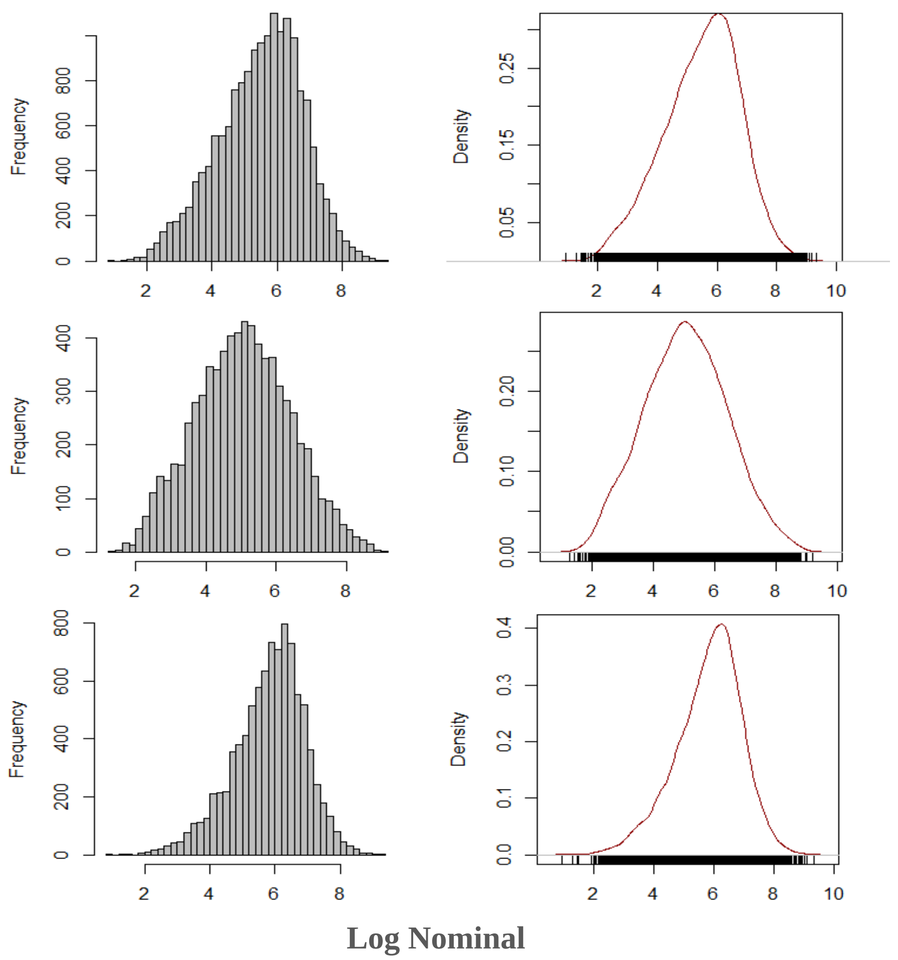

Figure 5. Frequency distribution of Log-transformed nominal CPUE for positive sets of swordfish caught by Uruguayan longliners. In **A**: from logbooks between 1982 and 2012; **B**: first period (1982-1992); and **C**: second period (1993-2012).

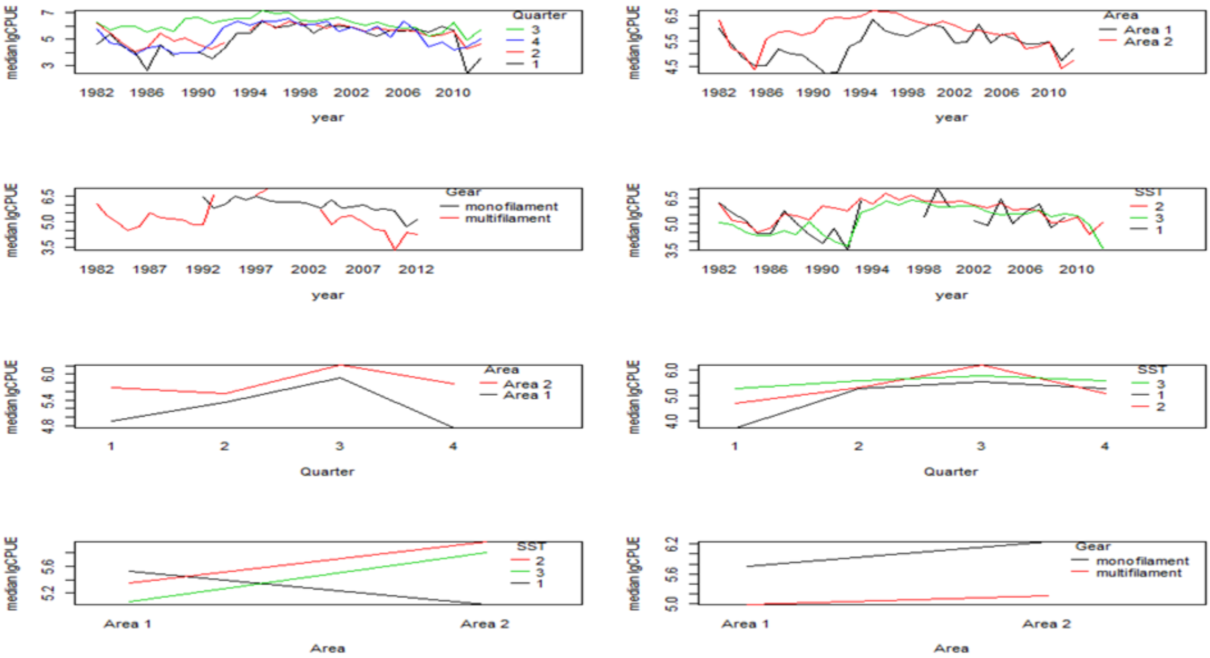

Figure 6. Interaction plots between factors for the logCPUE for the period 1982-2012 (Factors: *Year*, *SST*, *Area*, *Quarter and Gear.*

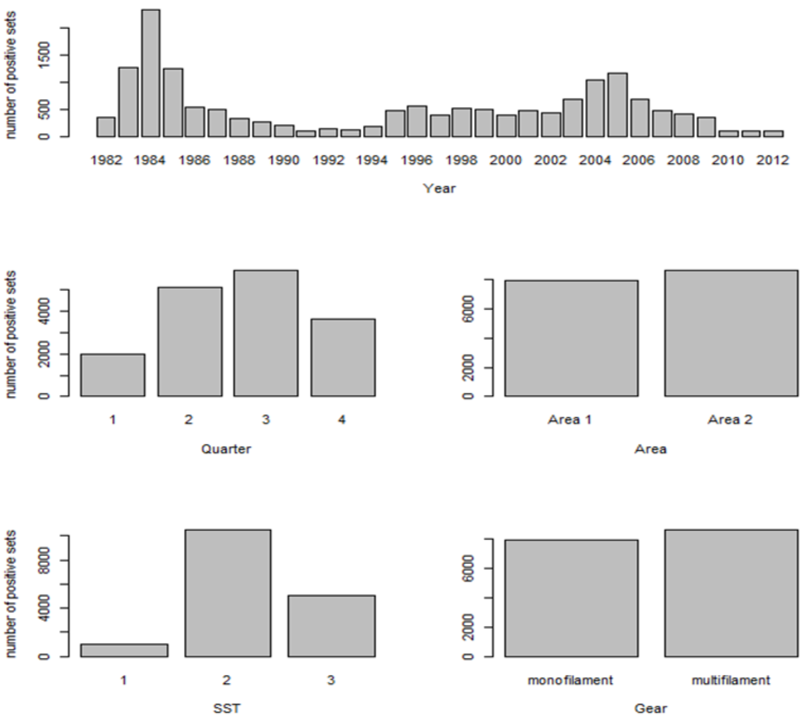

Figure 7. Number of positive sets by factors for the period 1982-2012(Factors: *Year*, *SST*, *Area*, *Quarter* and *Gear*).

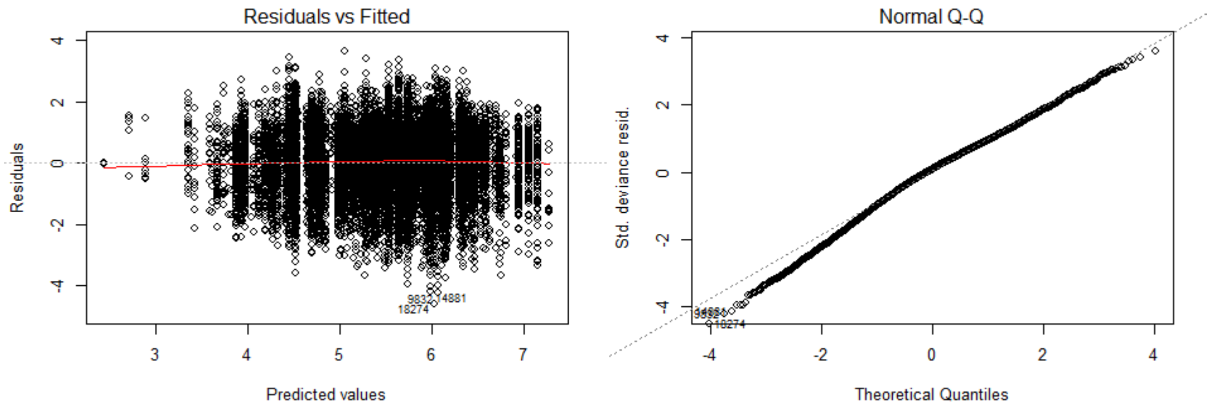

Figure 8. Diagnostic plots for positive swordfish catch rates (Lognormal GLMM). In all plots the broken line represents the expected pattern of observations.

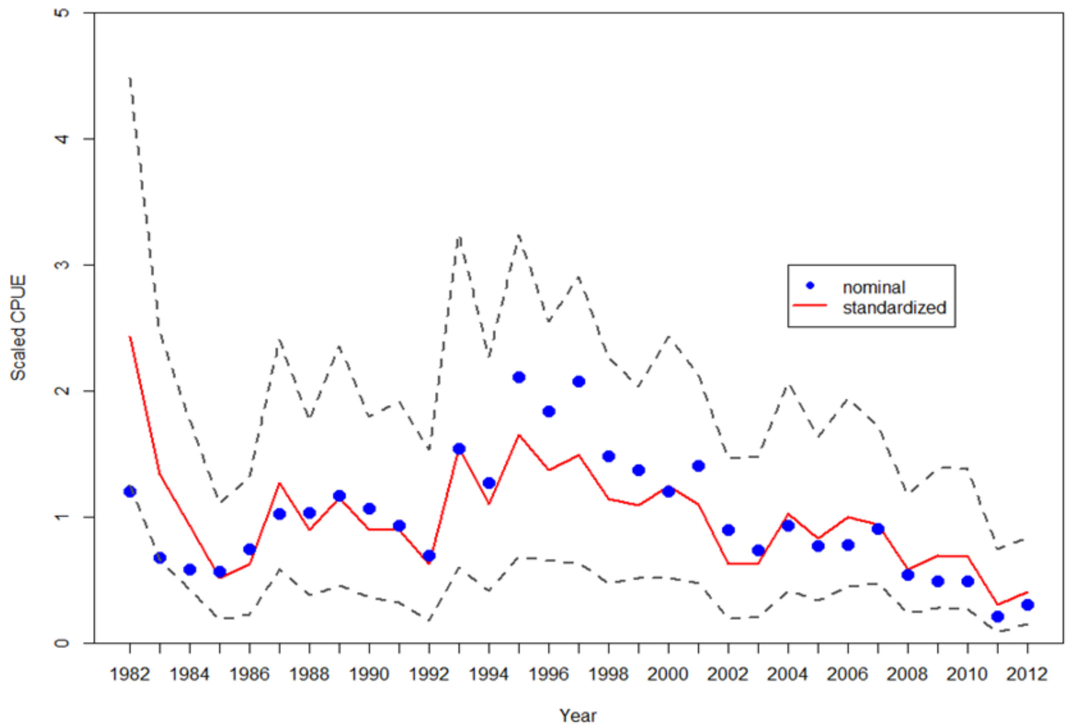

Figure 9. Scaled nominal and standardized indices of abundance in biomass for swordfish caught by Uruguayan pelagic longline fleet for the period 1982-2012. Dotted lines correspond to the 95% confidence interval of the estimated standardized index.

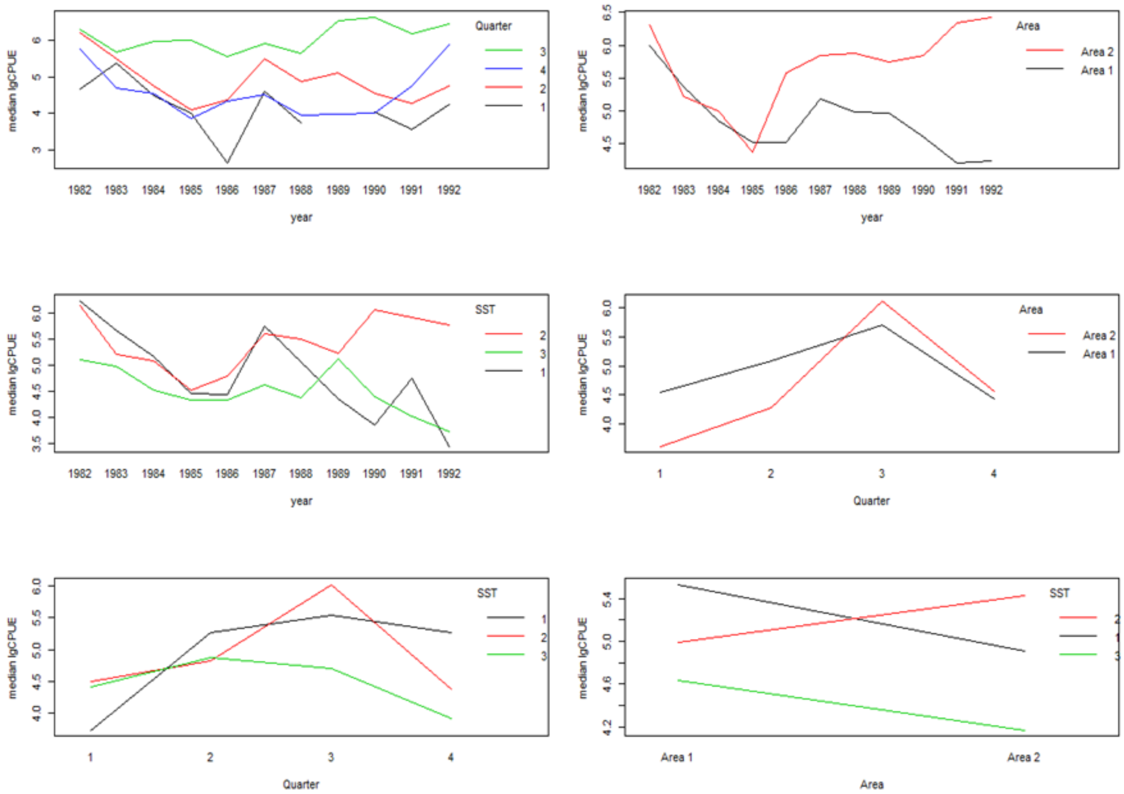

Figure 10. Interaction plots between factors for the logCPUE, period 1982-1992 (Factors: Year, SST, Area and Quarter).

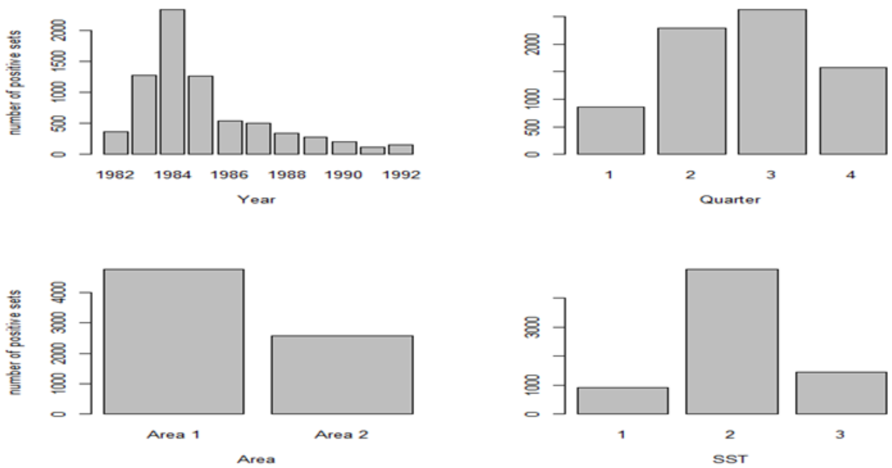

Figure 11. Number of positive sets by factors, period 1982-1992(Factors: *Year*, *SST*, *Area* and *Quarter*).

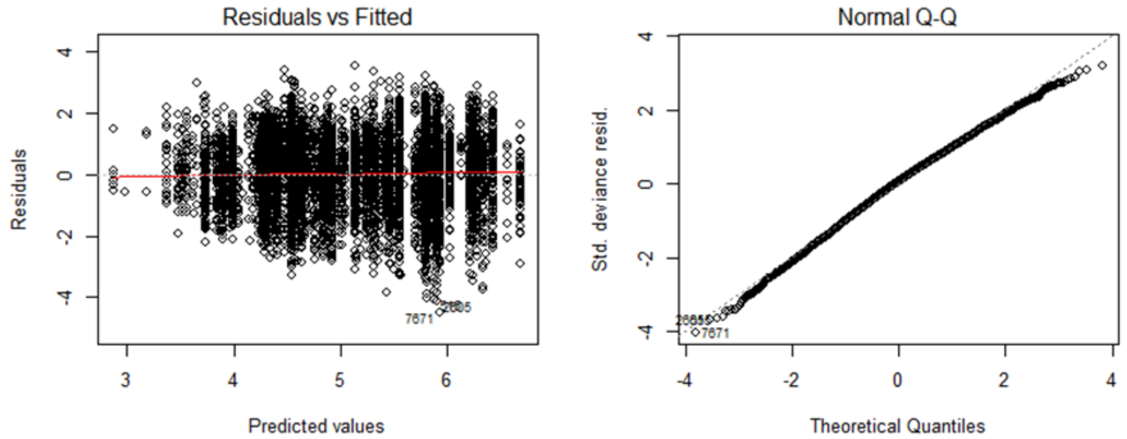

Figure 12. Diagnostic plots for positive swordfish catch rates (Lognormal GLMM). In all plots the broken line represents the expected pattern of observations.

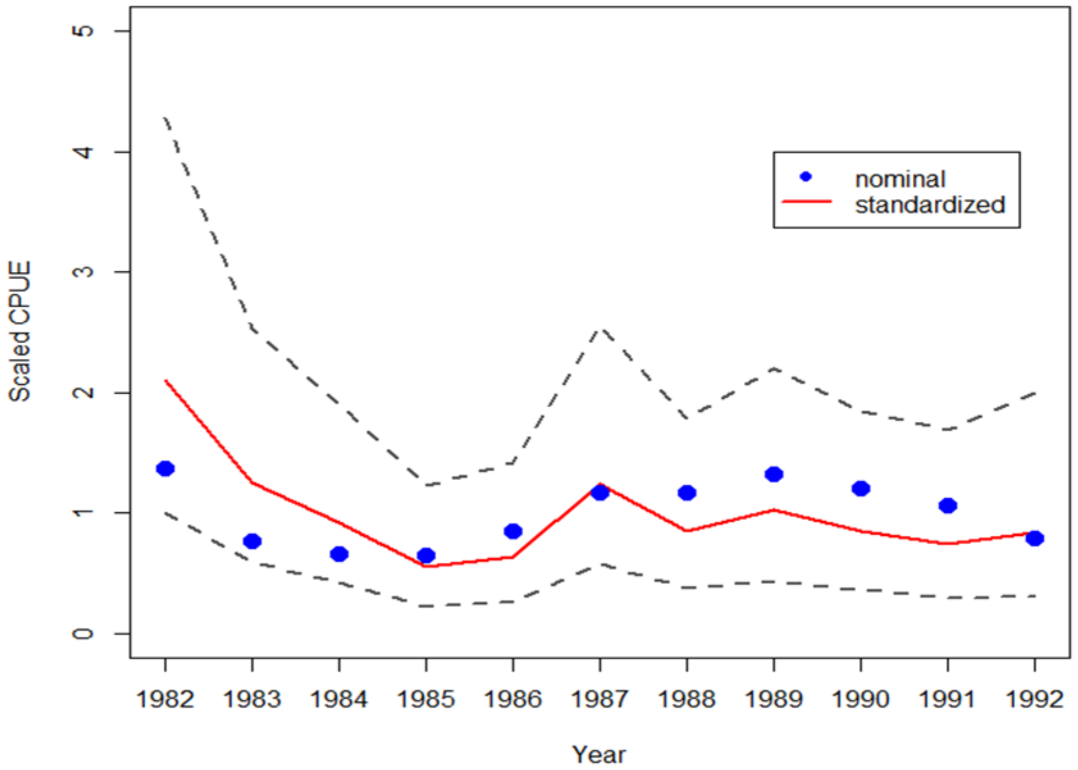

Figure 13. Scaled nominal and standardized indices of abundance in biomass for swordfish, caught by Uruguayan pelagic longline fleet for the period 1982-1992. Dotted lines correspond to the 95% confidence interval of the estimated standardized index.

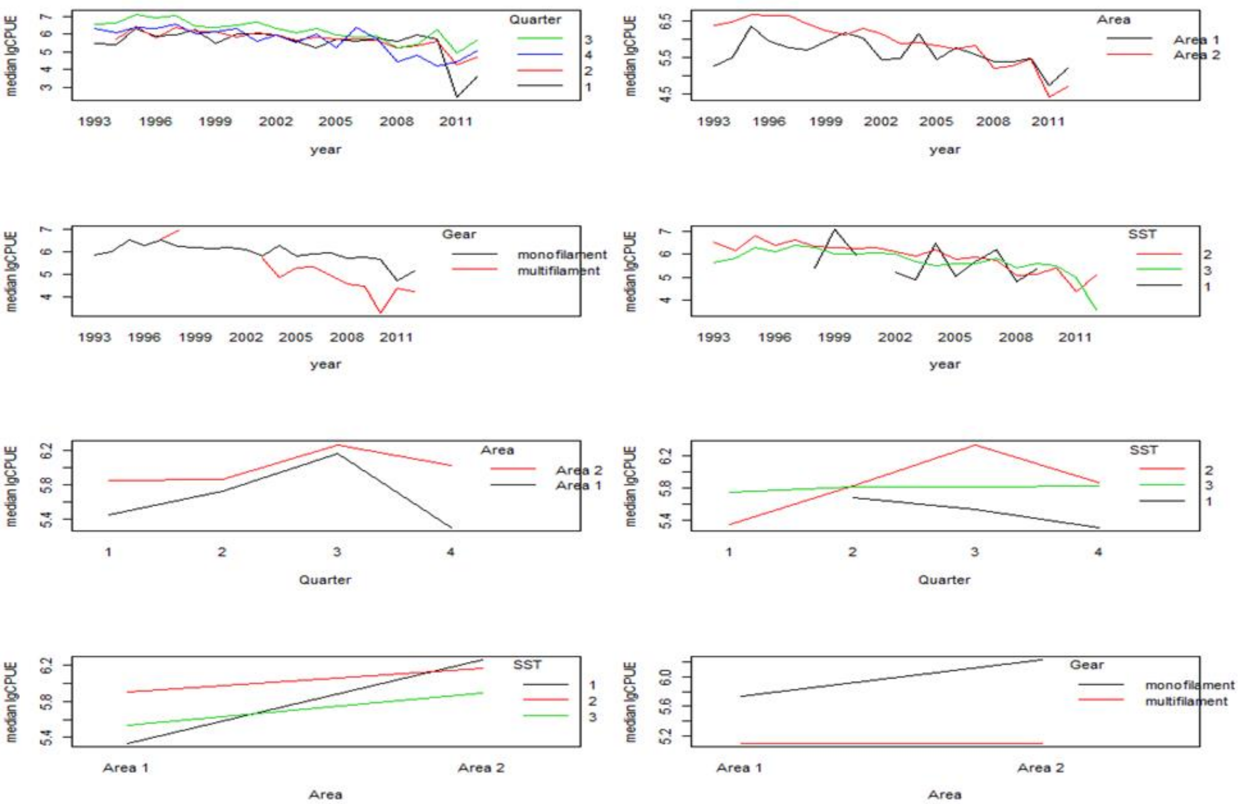

Figure 14. Interaction plots between factors for the logCPUE fo the period 1993-2012 (Factors: *Year*, *SST*, *Area*, *Quarter* and *Gear*).

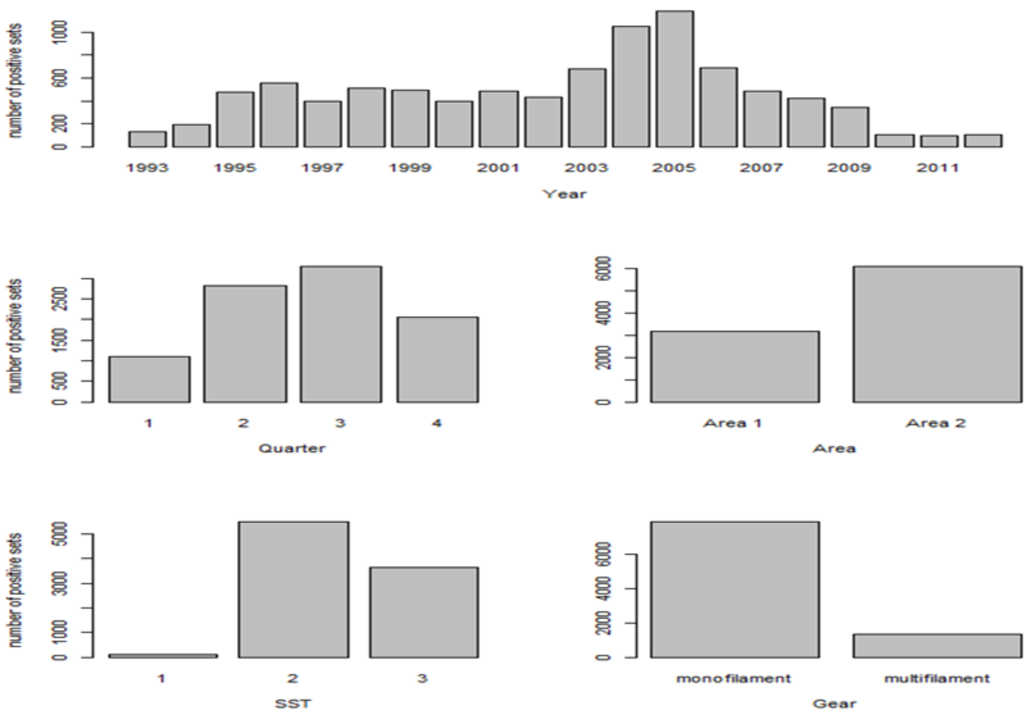

Figure 15. Number of positive sets by factors, period 1993-2012(Factors: *Year*, *SST*, *Area* and *Quarter*).

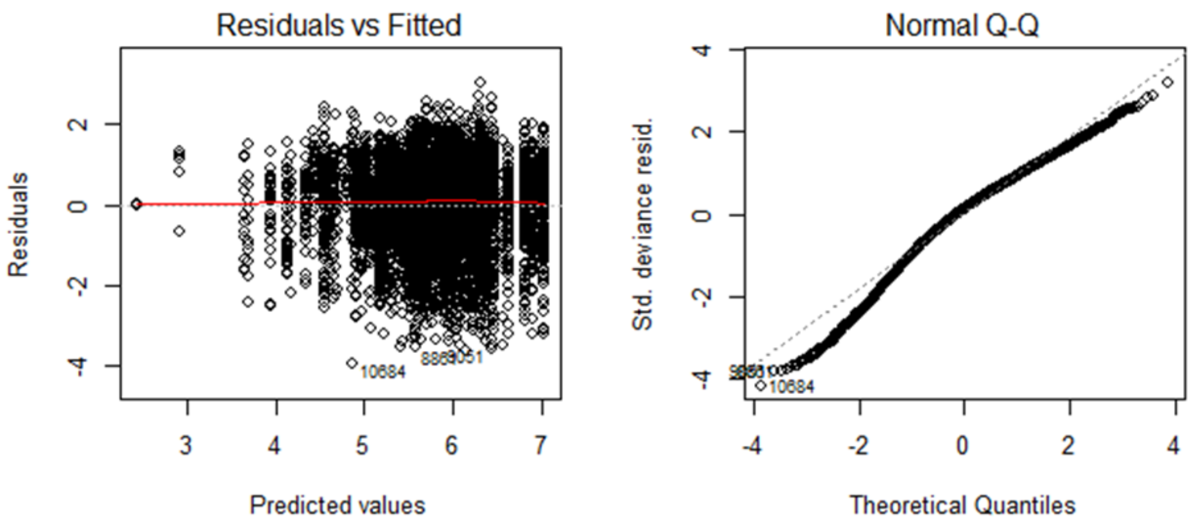

Figure 16. Diagnostic plots for positive swordfish catch rates (Lognormal GLMM). In all plots the broken line represents the expected pattern of observations.

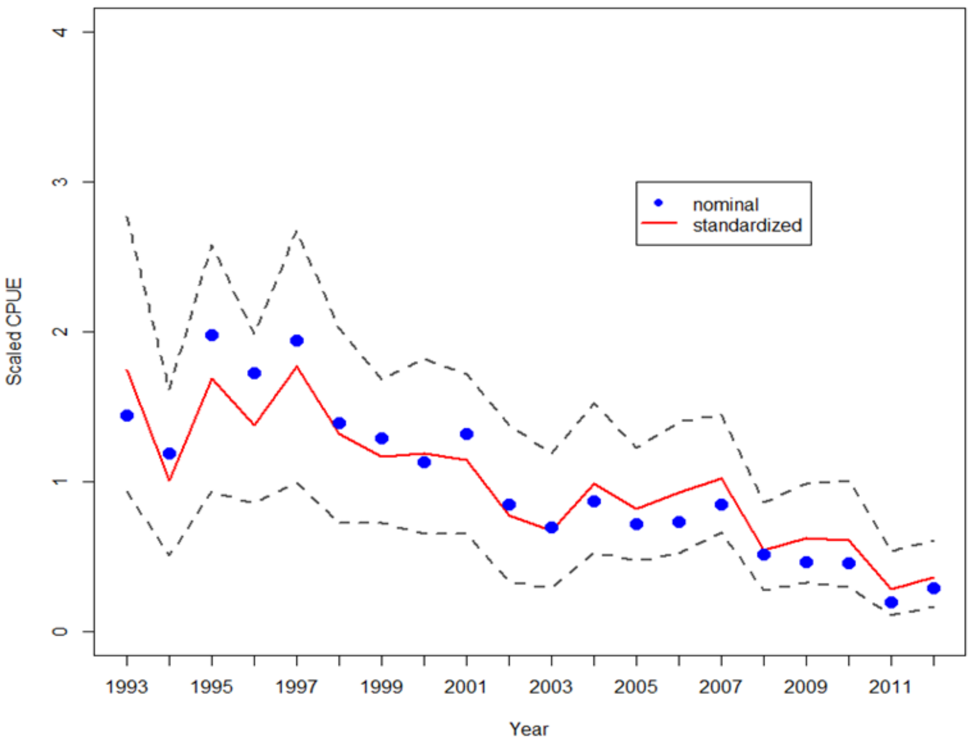

Figure 17. Scaled nominal and standardized indices of abundance in biomass for swordfish, caught by Uruguayan pelagic longline fleet for the period 1993-2012. Dotted lines correspond to the 95% confidence interval of the estimated standardized index.

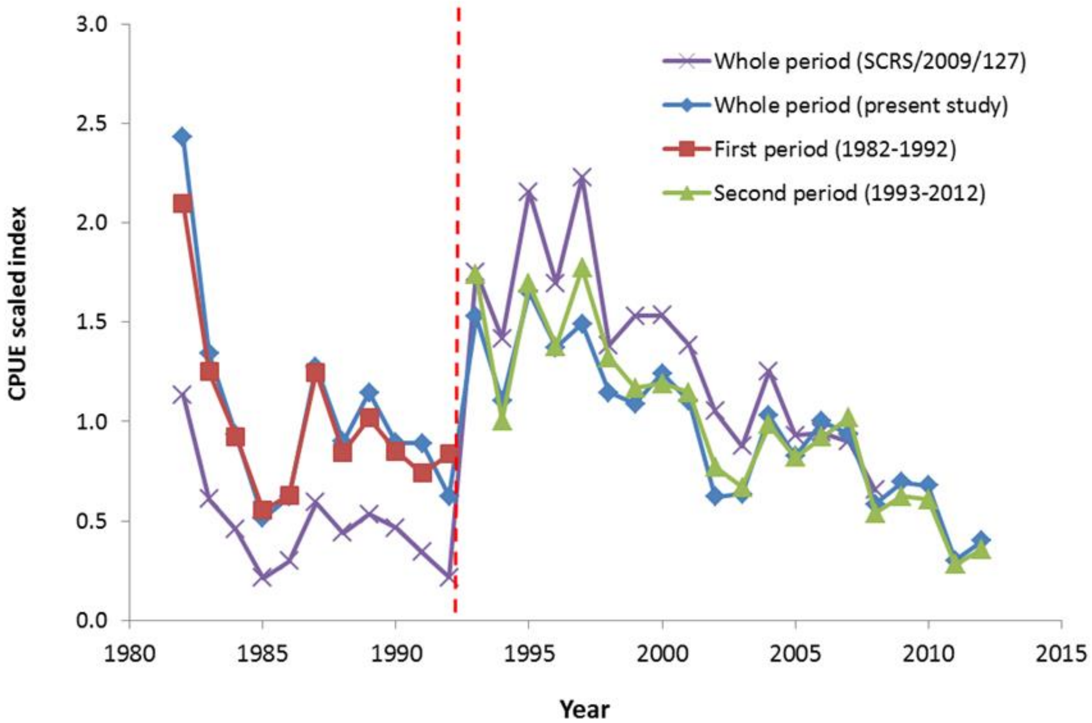

Figure 18. Scaled standardized indices of abundance in biomass for swordfish caught by Uruguayan pelagic longline fleet presented in the SCRS/2009/127 and in this study (whole period and before and after 1992).

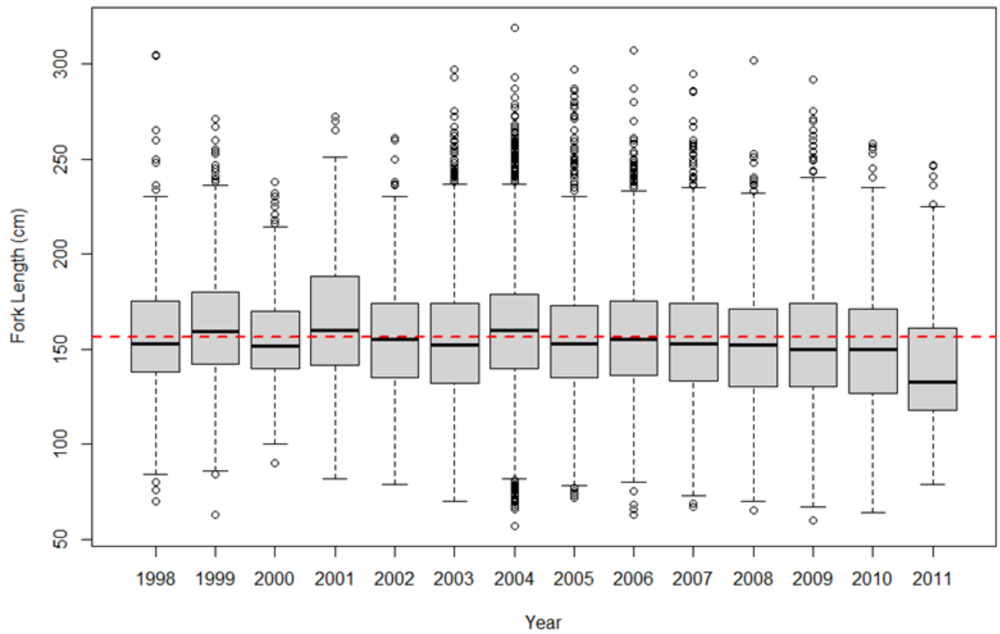

Figure 19. Length frequency (N=24,309) of the swordfish captured by the Uruguayan tuna fleet (sex combined) per year (1998-2011). The red line represents the overall mean fork length.