UPDATED STANDARDIZED CATCH RATES OF SWORDFISH (*Xiphias gladius*) CAUGHT BY THE SPANISH SURFACE LONGLINE FLEET IN THE INDIAN OCEAN DURING THE 2001-2015 PERIOD

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ABSTRACT

*Standardized catch rates of the Spanish surface longline fleet targeting swordfish are provided for the period 2001-2015. Generalized Linear Models (GLM) log-normal were used to update standardized catch rates in number of fish and in weight. Factors such as year, area, quarter, gear and bait, as well as the fishing strategy (based on the ratio between the most prevalent species and that appreciated most by skippers) and the interaction quarter*area were taken into account. The models explained 56% and 58% of CPUE variability in number and weight, respectively.*

Key words: swordfish, CPUE, GLM, longline.

1. Introduction

The Spanish longline fleet has been active in the Indian Ocean since 1993. Its fishing areas have been mostly restricted to the western regions (García-Cortés *et al.* 2008). Important changes in the fishing strategy of the Spanish longline fleet occurred in the short period 1998-2001, when the multifilament longline style traditionally used was replaced by the American-style monofilament in most of the vessels (García-Cortés and Mejuto 2000, García-Cortés *et al.* 2003, 2004, 2008; Ramos-Cartelle *et al.* 2011). This new style was widely introduced on boats in the Spanish fleet fishing in the Atlantic as well as in the Pacific and Indian oceans (García-Cortés *et al.* 2010, Mejuto *et al.* 2011). The Spanish longline fishery continues to focus on a combination of swordfish and blue shark as the main valuable species. These changes in fishing strategy have an important impact on the nominal CPUE obtained for swordfish (Mejuto and De la Serna 2000, Ortiz and Scott 2003, Ortiz *et al.* 2010).

Catch per unit of effort data from a large number of commercial fleets have been one of the main sources of information used for the assessments of swordfish stocks as an indication of changes in abundance over time. The raw CPUE data needing to be standardized to obtain a catch rate series and an unbiased index of abundance for stock assessments (Maunder *et al.* 2006). The most common method for standardizing CPUE is the application of the generalized linear model (GLM) (Robson 1966, Gavaris 1980, Kimura 1981), which removes the effects of factors that bias the index. Indirect factors such as operational changes, technological advances, including changes in the target species or the criteria of the skippers, could be a good alternative to be considered in some cases.

The aim of this document is to update the standardized CPUE series previously provided for the Indian Ocean swordfish stock, in this case covering a 15-year period.

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2. Material and methods

The standardized log-normal CPUE analyses were performed using GLM procedures (*SAS 9.4*) for the new period 2001-2015 assuming a log-normal distribution of catch rates as in a previous paper (Fernández-Costa *et al.* 2014). Data records were obtained per trip. The factors included in the model were: *year*, *quarter*, *area*, *ratio* - as an indicator of the target criteria of the skipper regarding swordfish and/or blue shark during fishing activity (Mejuto and De la Serna 2000) -, *gear*, *bait* and the interaction q*uarter*area.*

The model defined as base case was: Ln (CPUE) = u + Y + Q + A + R + G + B + Q*A + e. Where: u = overall mean, Y = *year* effect, Q = *quarter* effect (Q1 = January-March; Q2 = April-June; Q3 = July-September; Q4 = October-December), A= *area* effect (the spatial definition considered 8 areas**)**, R= *ratio* effect (defined for each available trip record as the percentage of swordfish in weight related to the catches of swordfish and blue shark combined, broken down into ten ratio categories at 10% intervals), G = *gear* style effect (1 = traditional multifilament, 3 = American style monofilament), B = *bait* type (1 = mackerel, 6 = squid), Q*A= *quarter*area* interaction and e = logarithm of the normally distributed error term.

The response variable for the model is CPUE measured in number of fish and in kg of round weight per fishing effort. Nominal effort was defined by thousand of hooks set. Standardized residuals by year were plotted for the index of abundance to evaluate the extent of serial autocorrelation in the residuals. The standardized mean weight by year and the relevant confidence intervals were also obtained using the same GLM approach.

An alternative run considered as a sensitivity analysis was performed using a GLM MIXED (GLMM) procedure which allows some of the parameters in the linear predictor to be treated as random variables (Maunder and Punt 2004). The standardized CPUE in weight obtained from the sensitivity analysis (GLMM) was scaled for comparison with the also scaled standardized CPUE obtained by the base case GLM run. Both series were scaled to their respective mean values.

3. Results and discussion

Figure 1 shows the geographical area distribution defined for the GLM runs for the period analyzed, 2001-2015. A total number of 2,062 trip observations were available. The number of observations per spatial-temporal strata may be considered very satisfactory for this type of fishery except for area 56, where no trips were observed. The final runs thus considered only 7 of the 8 areas predefined.

A summary of the ANOVA results from base case GLM procedure can be seen in **Table 1**. 56% and 58% of CPUE variability in number and weight, respectively, was explained by the significant base case models defined. CPUE variability (Type III SS) could be mostly explained by the type of trip (*ratio* effect), which was highly significant, as in previous analyses. The impact of certain changes on the fishing strategy of the Spanish fleet has already been assessed in other papers and compared with the results obtained using other possible approaches (Mejuto and De la Serna 2000, Mejuto *et al*. 2000, Anon. 2001). Similar findings were described for other fleets (Santos *et al*. 2012, 2013). The factors *year* and *area* were quite important but influenced the variability of CPUE in number or weight in a different way.

The fit of the model does not seem to be biased and **Figure 2** shows a normal frequency distribution of standardized residuals as well as the probability qq-plot for number and weight. **Figures 3** and **4** show the variability box-plot for standardized residuals obtained by the main factors considered in the base case runs, in number and in weight respectively. **Tables 2** and **3** provide information on estimated parameters lsmean, standard error, CV%, standardized CPUE and upper and lower 95% confidence limits, in number and in weight, respectively.

Figure 5 shows the base case standardized CPUE in number and weight as well as the standardized mean round weight obtained by year and their respective 95% confidence intervals. Both trends of standardized CPUE in number and weight are similar. If the catch rates are assumed to be indices of relative abundance, the results suggest that all standardized CPUE trends experienced a peak at the year 2003 with a steady decline until 2007, followed by an increase until 2012, followed by a decrease in the years 2013 and 2014 and an upward trend in 2015, the last year analyzed. It is important to note that these indices include all ages-sizes combined, as regularly reported in CAS data. Any comparison of these results with CPUE indices obtained for other fleets should take into consideration the respective age-fractions included.

The results obtained from the GLMM procedure were very similar to the base case GLM model. The factors and interactions with ≥ 5.0% of deviance explained were considered in the sensitivity analysis (**Table 4**). The random interactions *year*quarter*, *year*area* and *year*ratio* were considered: Ln (CPUE) = u + Y + Q + A + G + R + e + random (Y*Q + Y*A + Y*R).

The standardized CPUE in weight obtained from the sensitivity analysis was scaled to compare it with the scaled standardized CPUE base case. The comparison between the two scaled standardized CPUEs in weight obtained, show a very similar general trend over time regardless of the model used. So, the scenarios tested suggest that after a decline of abundance in the years 2013 and 2014 there is a rising trend in the last year analyzed (**Figure 6**). The updated index is consistent with that given in 2014 (Fernández-Costa *et al*. 2014).

4. Acknowledgments

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Table 1. Summary of ANOVA for the base case CPUE analysis, in number of fish (upper table) and in weight (lower table).

CPUE in number of fish: Dependent variable: ln (CPUEn)

Source	DF	Sum of Squares	Mean Square	F Value	Pr > F
Model	52	288.3086801	5.5443977	48.58	<.0001
Error	2009	229.2946788	0.1141337		
Corrected Total	2061	517.6033588			

R-Square	Coeff. Var.	Root MSE	cpue Mean
0.557007	12.77449	0.337837	2.644621

Source	DF	Type III SS	Mean Square	F Value	Pr > F
year	14	16.5358882	1.1811349	10.35	<.0001
quarter	3	0.7412873	0.2470958	2.16	0.0902
area	6	1.8280680	0.3046780	2.67	0.0139
gear	1	3.4498431	3.4498431	30.23	<.0001
bait	1	0.0147745	0.0147745	0.13	0.7190
ratio	9	182.5836539	20.2870727	177.75	<.0001
quarter*area	18	3.1002831	0.1722383	1.51	0.0773

CPUE in weight: Dependent variable: ln (CPUEw)

Source	DF	Sum of Squares	Mean Square	F Value	Pr > F
Model	52	320.3204381	6.1600084	54.21	<.0001
Error	2009	228.3032330	0.1136402		
Corrected Total	2061	548.6236711			

R-Square	Coeff. Var.	Root MSE	cpue Mean
0.583862	5.125634	0.337106	6.576858

Source	DF	Type III SS	Mean Square	F Value	Pr > F
year	14	27.3530804	1.9537915	17.19	<.0001
quarter	3	0.1980309	0.6601030	0.58	0.6276
area	6	15.1457131	2.5242855	22.21	<.0001
gear	1	8.1933720	8.1933720	72.10	<.0001
bait	1	0.9109998	0.9109998	8.02	0.0047
ratio	9	182.5989560	20.2887729	178.54	<.0001
quarter*area	18	7.5891371	0.4216187	3.71	<.0001

Table 2. Estimated parameters (lsmean), standard error (stderr), CV%, standardized CPUE in number of swordfish (CPUEn) and upper and lower 95% confidence limits for the Spanish longline fleet in the Indian Ocean during the period analyzed 2001-2015.

YEAR	LSMEAN	STDERR	CV%	UCPUEn	CPUEn	LCPUEn
2001	2.13382	0.074072	3.471333	9.794	8.470	7.326
2002	2.03083	0.066200	3.259751	8.695	7.637	6.708
2003	2.17737	0.064931	2.982084	10.042	8.842	7.785
2004	2.12729	0.065700	3.088436	9.566	8.410	7.394
2005	2.10314	0.066705	3.171686	9.357	8.210	7.204
2006	2.01837	0.063791	3.160521	8.546	7.541	6.655
2007	2.02204	0.068369	3.381189	8.657	7.571	6.622
2008	2.10605	0.069062	3.279219	9.429	8.235	7.193
2009	2.23463	0.068831	3.080197	10.718	9.365	8.183
2010	2.27895	0.074996	3.290814	11.345	9.794	8.455
2011	2.27617	0.072584	3.188866	11.258	9.765	8.470
2012	2.25074	0.069938	3.107334	10.916	9.518	8.299
2013	2.04016	0.068299	3.347728	8.814	7.710	6.744
2014	1.95259	0.068301	3.497969	8.075	7.063	6.178
2015	2.11443	0.073640	3.482735	9.597	8.307	7.191

Table 3. Estimated parameters (lsmean), standard error (stderr), CV%, standardized CPUE in weight (CPUEw) of swordfish and upper and lower 95% confidence limits for the Spanish longline fleet in the Indian Ocean during the period analyzed 2001-2015.

YEAR	LSMEAN	STDERR	CV%	UCPUEw	CPUEw	LCPUEw
2001	5.91263	0.073911	1.250053	428.473	370.689	320.697
2002	5.84010	0.066057	1.131094	392.192	344.564	302.721
2003	5.97358	0.064790	1.084609	447.050	393.737	346.781
2004	5.89063	0.065558	1.112920	412.104	362.413	318.713
2005	5.70164	0.066560	1.167383	341.830	300.022	263.327
2006	5.62699	0.063653	1.131209	315.378	278.387	245.734
2007	5.67380	0.068221	1.202386	333.566	291.818	255.294
2008	5.76962	0.068912	1.194394	367.623	321.176	280.598
2009	5.85922	0.068682	1.172204	401.898	351.280	307.036
2010	5.93406	0.074833	1.261076	438.578	378.745	327.075
2011	5.90406	0.072427	1.226732	423.538	367.486	318.852
2012	5.92812	0.069786	1.177203	431.531	376.364	328.250
2013	5.71555	0.068151	1.192378	347.736	304.256	266.212
2014	5.59786	0.068154	1.217501	309.131	270.476	236.655
2015	5.77696	0.073480	1.271949	373.785	323.649	280.238

Table 4. Deviance table analyses of the factors tested in the GLMM process for the Indian Ocean swordfish stock. Highlighted are the factors with ≥ 5.0% of deviance explained.

Model factors	d.f.	Residual deviance	Change in deviance	% of total deviance	*p*	chi-sq
1	_	548.6237				
Year	14	476.0997	72.5240	21.2%	< 0.001	6.71E-10
Year Quarter	3	460.7346	15.3651	4.5%	0.00153	1.53E-03
Year Quarter Area	6	449.3403	11.3943	3.3%	0.076928	7.69E-02
Year Quarter Area Gear	1	429.3828	19.9575	5.8%	< 0.001	7.92E-06
Year Quarter Area Gear Bait	1	429.0115	0.3713	0.1%	0.542	5.42E-01
Year Quarter Area Gear Bait Ratio	9	235.8924	193.1191	56.4%	< 0.001	9.16E-37
Year Quarter Area Gear Bait Ratio Gear*Ratio	4	235.5978	0.2946	0.1%	0.990	9.90E-01
Year Quarter Area Gear Bait Ratio Year*Gear	1	234.8495	1.0429	0.3%	0.307	3.07E-01
Year Quarter Area Gear Bait Ratio Quarter*Gear	2	234.8354	1.0570	0.3%	0.589	5.89E-01
Year Quarter Area Gear Bait Ratio Area*Bait	6	233.6260	2.2664	0.7%	0.894	8.94E-01
Year Quarter Area Gear Bait Ratio Area*Gear	4	233.4120	2.4804	0.7%	0.648	6.48E-01
Year Quarter Area Gear Bait Ratio Quarter*Bait	3	232.6052	3.2872	1.0%	0.349	3.49E-01
Year Quarter Area Gear Bait Ratio Year*Bait	12	231.0387	4.8537	1.4%	0.963	9.63E-01
Year Quarter Area Gear Bait Ratio Quarter*Ratio	26	230.6348	5.2576	1.5%	1.000	1.00E+00
Year Quarter Area Gear Bait Ratio Bait*Ratio	9	229.1007	6.7917	2.0%	0.659	6.59E-01
Year Quarter Area Gear Bait Ratio Quarter*Area	18	228.3032	7.5892	2.2%	0.984	9.84E-01
Year Quarter Area Gear Bait Ratio Area*Ratio	42	222.7270	13.1654	3.8%	1.000	1.00E+00
Year Quarter Area Gear Bait Ratio Year*Quarter	42	209.1753	26.7171	7.8%	0.968	9.68E-01
Year Quarter Area Gear Bait Ratio Year*Ratio	106	208.6124	27.2800	8.0%	1.000	1.00E+00
Year Quarter Area Gear Bait Ratio Year*Area	66	205.9800	29.9124	8.7%	1.000	1.00E+00

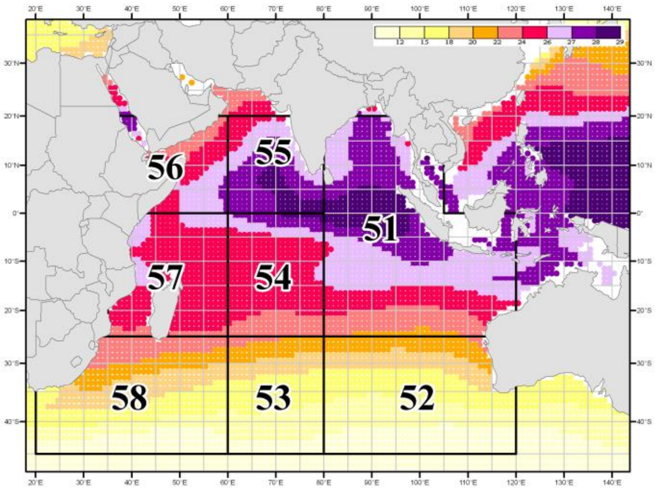

Figure 1. Area definition used for the GLM runs used for the CPUE standardization of swordfish of the Spanish surface longline fleet in the Indian Ocean, during the period 2001-2015.

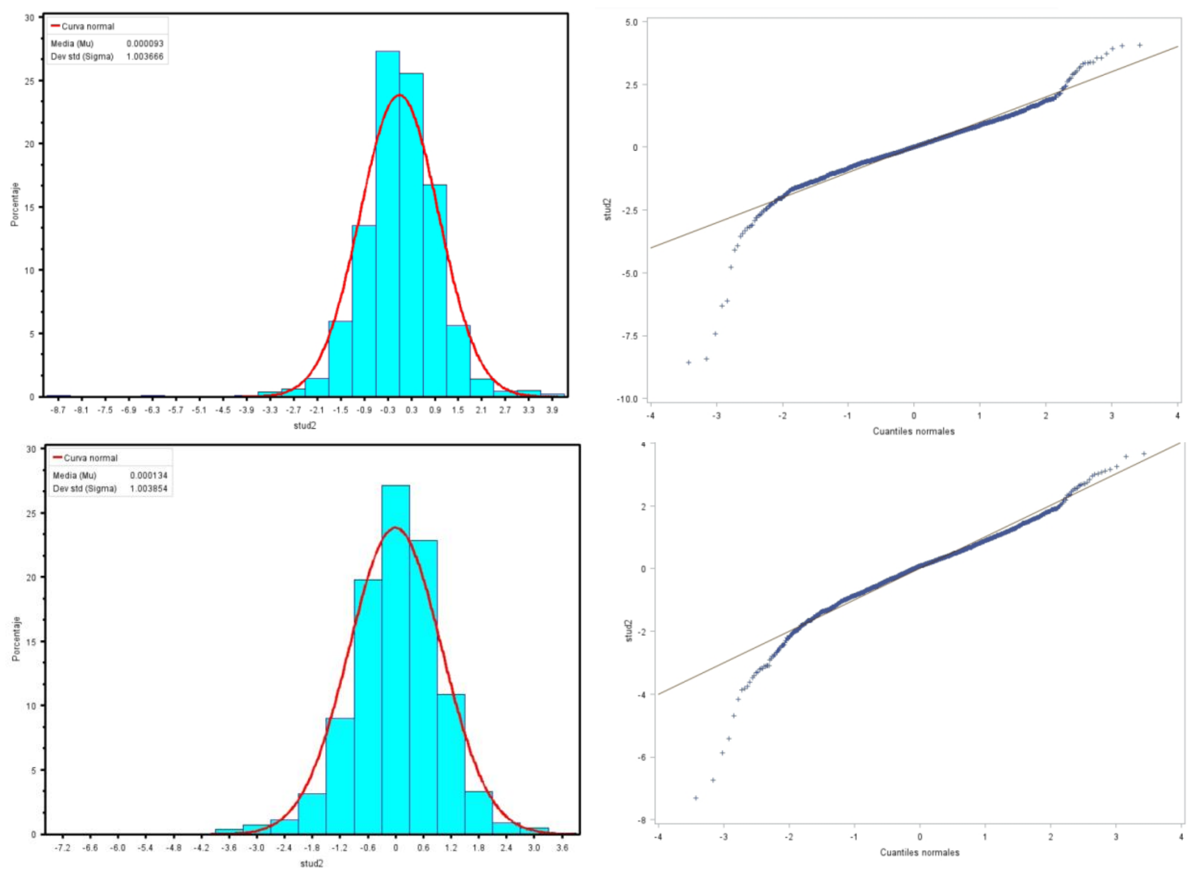

Figure 2. Diagnosis of the GLM runs for standardized CPUE in number of swordfish (upper) and in round weight (lower) for Indian Ocean: frequency distribution of the standardized residuals years combined (left panels) and normal probability qq-plot (right panels).

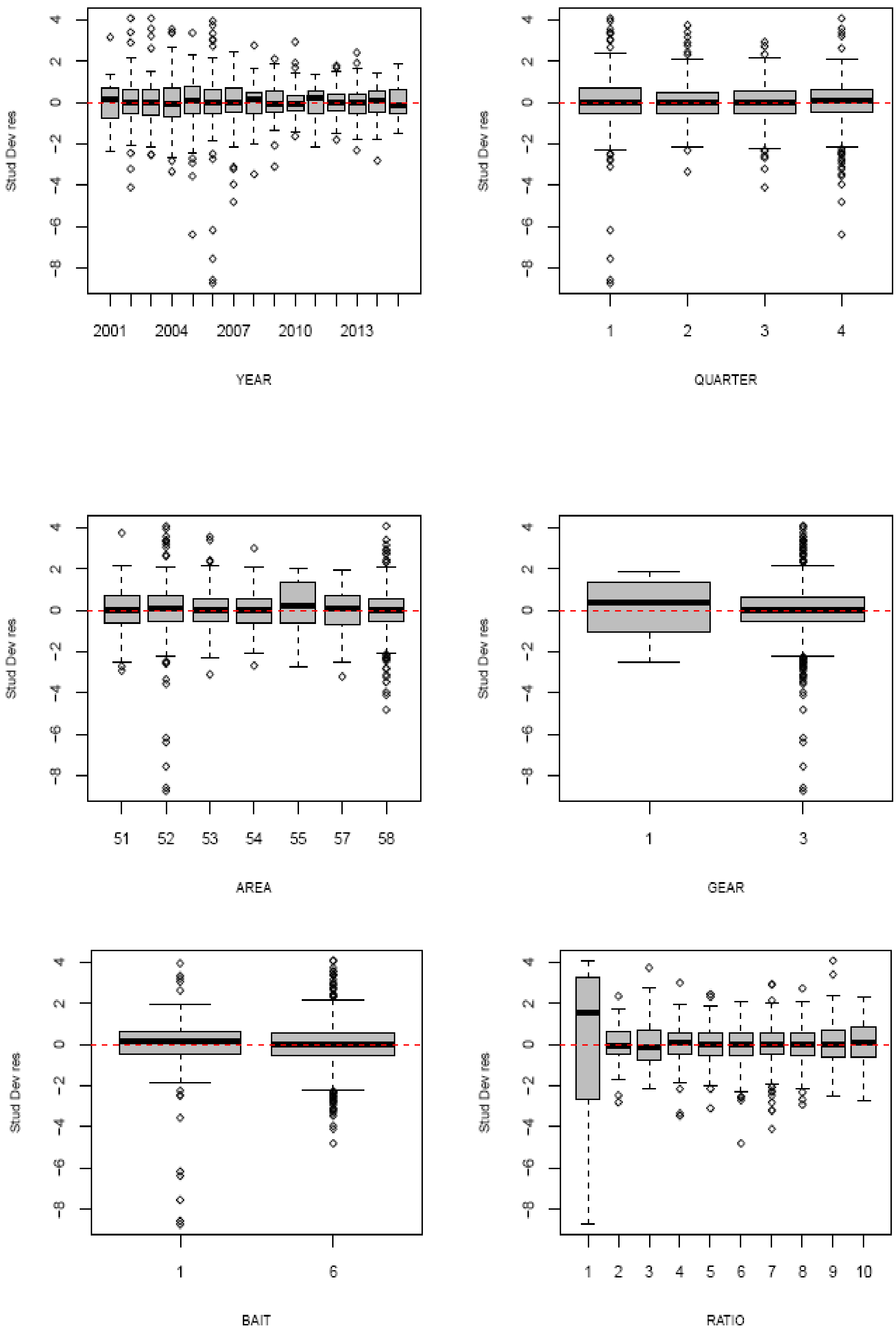

Figure 3. Box-plots of the standardized deviance residuals by explanatory variables obtained from the GLM base case in number of swordfish for the Indian Ocean.

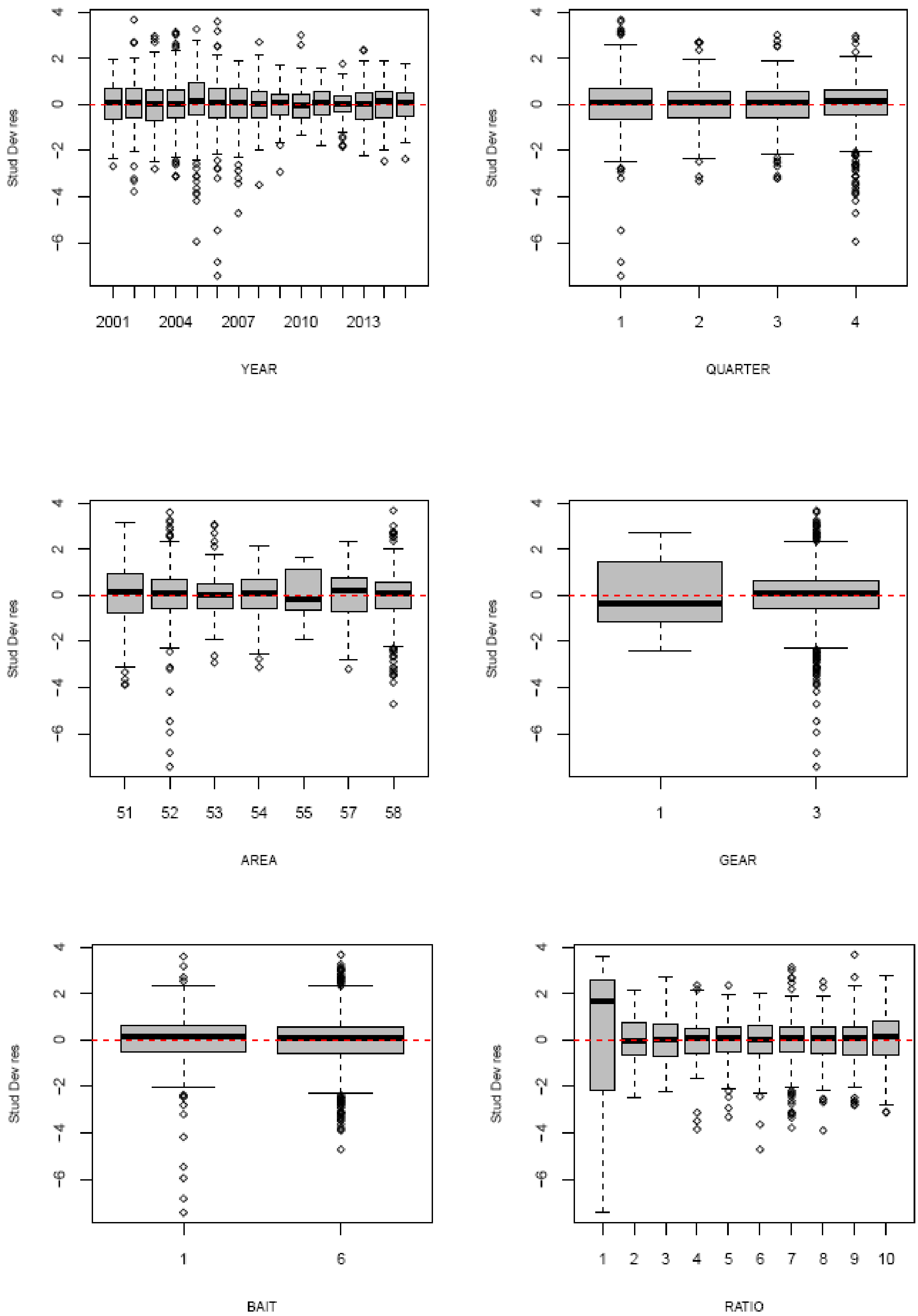

Figure 4. Box-plots of the standardized deviance residuals by explanatory variables obtained from the GLM base case in weight of swordfish for the Indian Ocean.

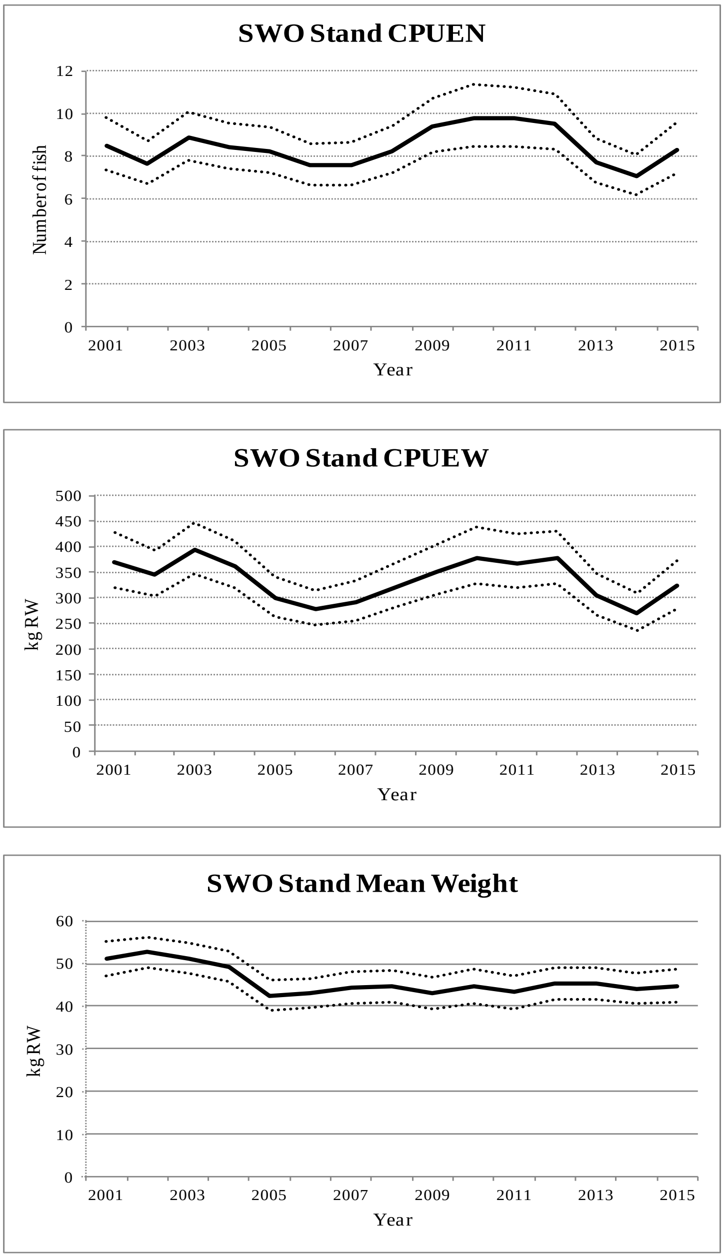

Figure 5. Standardized CPUEs per thousand hooks, in number of fish (upper), in kilograms round weight (middle) and standardized mean round weight in kilograms (lower) of swordfish and their respective confidence intervals (95%) observed in the Spanish surface longline fleet during the period analyzed (2001-2015) in the Indian Ocean.

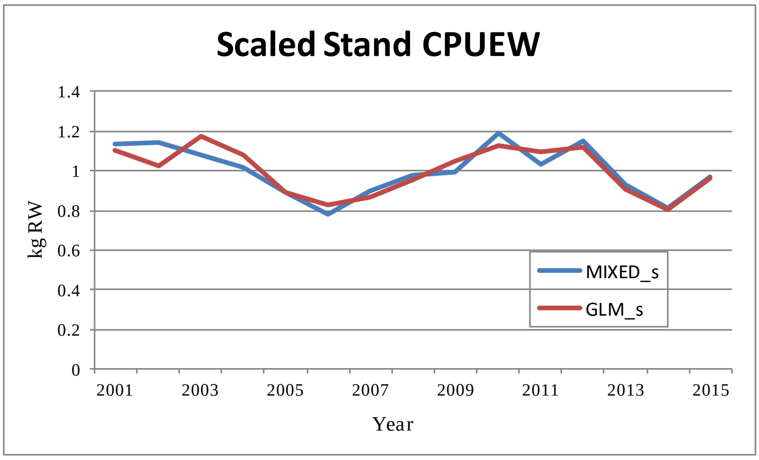

Figure 6. Comparative scaled standardized CPUE in weight, GLM *versus* GLMM (MIXED), obtained in the Indian Ocean for the period 2001-2015. Both series are scaled from their respective mean value.