UPDATED STANDARDIZED CATCH RATES OF SWORDFISH (*Xiphias gladius*) CAUGHT BY THE SPANISH SURFACE LONGLINE FLEET IN THE INDIAN OCEAN DURING THE 2001-2018 PERIOD

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ABSTRACT

Standardized catch rates of the Spanish surface longline fleet targeting swordfish are provided for the period 2001-2018. Generalized Linear Models (GLM) log-normal were used to update standardized catch rates in number of fish and in weight. Factors such as 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) were taken into account. The model explained 54% and 57% of CPUE variability in number and weight, respectively.

Key words: swordfish, CPUE, GLM, longline**.**

1. INTRODUCTION

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 other than abundance 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 Spanish longline fleet has been fishing in the Indian Ocean since 1993. Important changes in the fishing strategy have occurred over time. Details on the activity of this fleet can be found in previous papers (i.e. Fernández-Costa *et al.* 2017, García-Cortés and Mejuto 2000, García-Cortés *et al.* 2003, 2004, 2008, 2010; Mejuto *et al.* 2011, Mejuto and De la Serna 2000, Ramos-Cartelle *et al.* 2011).

This document update the Spanish standardized CPUE series previously provided for the Indian Ocean swordfish stock.

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2. MATERIAL AND METHODS

The standardized log-normal CPUE analyses were performed using GLM procedures (*SAS 9.4*) for the period 2001-2018 assuming a log-normal distribution of catch rates as in a previous paper (Fernández-Costa *et al*. 2014, 2017). Data records were obtained per trip. Seeking compatibility with previous studies, 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 *quarter*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 (**Figure 1**), R= *ratio* effect (defined in order to categorize each type of trip record based on 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 (traditional multifilament or American-monofilament style), B = *bait* type (mackerel or 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. 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 2001-2018. A total number of 2,234 trip observations were available. The number of observations per spatial-temporal strata may be considered very satisfactory except for area 56 where no activity was observed. The final runs thus considered 7 areas.

A summary of the ANOVA results from base case GLM procedure can be seen in **Table 1**. The base case model explains the 54% and 57% of the CPUE variability in number and weight, respectively. 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).

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 intervals, 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, with the mean weight stable since 2005. If the catch rates are assumed to be indices of relative abundance, the results suggest that both number and weight standardized CPUE trends follow a sinusoidal soft pattern with peaks around years 2003, 2010-2012 and 2016-2017. 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 factors and interactions with ≥ 5.0% of deviance explained were considered in the sensitivity analysis (**Table 4**). A GLMM procedure was run with the resulting model:

$$\text{Ln (CPUE)} = u + Y + Q + A + G + R + e + \text{random } (Y*Q + Y*A + Y*R).$$

The standardized CPUE in weight obtained from the sensitivity analysis was scaled to compare it with the scaled standardized CPUE base case and its 95% confidence intervals (**Figure 6**). The comparison between the two scaled standardized CPUEs in weight obtained shows a very similar general trend over time, with the GLMM model being a bit more optimistic in recent years and always being within the GLM 95% confidence intervals. The updated index is consistent with that given in 2017 (Fernández-Costa *et al.* 2017).

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

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

Source	DF	Sum of Squares	Mean Square	F Value	Pr > F
Model	55	291.5480613	5.3008738	47.16	<.0001
Error	2178	244.7869542	0.1123907		
Corrected Total	2233	536.3350155			

R-Square	Coeff. Var.	Root MSE	cpue Mean
0.543593	12.65927	0.335247	2.648235

Source	DF	Type III SS	Mean Square	F Value	Pr > F
year	17	17.2585511	1.0152089	9.03	<.0001
quarter	3	0.6914520	0.2304840	2.05	0.1048
area	6	1.3022000	0.2170333	1.93	0.0724
gear	1	3.4783385	3.4783385	30.95	<.0001
bait	1	0.0395863	0.0395863	0.35	0.5529
ratio	9	186.8901057	20.7655673	184.76	<.0001
quarter*area	18	2.6941264	0.1496737	1.33	0.1574

CPUE in weight: Dependent variable: ln (CPUEw)

Source	DF	Sum of Squares	Mean Square	F Value	Pr > F
Model	55	324.4061253	5.8982932	3.11	<.0001
Error	2178	241.8820664	0.1110570		
Corrected Total	2233	566.2881917			

R-Square	Coeff. Var.	Root MSE	cpue Mean
0.572864	5.065894	0.333252	6.578348

Source	DF	Type III SS	Mean Square	F Value	Pr > F
year	17	28.7885209	16934424	15.25	<.0001
quarter	3	0.1763558	0.0587853	0.53	0.6222
area	6	15.2192872	2.5365479	22.84	<.0001
gear	1	8.4874658	8.4874658	76.42	<.0001
bait	1	0.9435455	0.9435455	8.50	0.0036
ratio	9	187.2226961	20.8025218	187.31	<.0001
quarter*area	18	6.9783436	0.3876858	3.49	<.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 2001-2018.

YEAR	LSMEAN	STDERR	CV%	UCPUEn	CPUEn	LCPUEn
2001	2.1290	0.0731	3.4334	9.727	8.429	7.304
2002	2.0241	0.0655	3.2344	8.624	7.585	6.672
2003	2.1774	0.0643	2.9509	10.028	8.841	7.795
2004	2.1297	0.0650	3.0509	9.575	8.430	7.422
2005	2.0993	0.0660	3.1445	9.308	8.178	7.186
2006	2.0174	0.0630	3.1210	8.523	7.533	6.659
2007	2.0156	0.0677	3.3587	8.590	7.522	6.588
2008	2.1015	0.0683	3.2524	9.373	8.198	7.170
2009	2.2291	0.0681	3.0556	10.643	9.313	8.149
2010	2.2695	0.0742	3.2693	11.220	9.701	8.388
2011	2.2608	0.0718	3.1753	11.068	9.615	8.353
2012	2.2389	0.0692	3.0888	10.771	9.406	8.213
2013	2.0339	0.0676	3.3236	8.746	7.661	6.710
2014	1.9447	0.0676	3.4755	8.000	7.007	6.138
2015	2.1073	0.0729	3.4591	9.514	8.248	7.150
2016	2.1868	0.0752	3.4398	10.350	8.932	7.707
2017	2.2056	0.0755	3.4245	10.553	9.101	7.849
2018	2.1248	0.0781	3.6747	9.785	8.397	7.205

Table 3. Estimated parameters (lsmean), standard error (stderr), CV%, standardized CPUE in round weight of swordfish (CPUEw) and upper and lower 95% confidence limits for the Spanish longline fleet in the Indian Ocean during the period analyzed 2001-2018.

YEAR	LSMEAN	STDERR	CV%	UCPUEw	CPUEw	LCPUEw
2001	5.9059	0.0727	1.2303	424.497	368.150	319.283
2002	5.8335	0.0651	1.1156	388.841	342.276	301.287
2003	5.9702	0.0639	1.0698	444.713	392.384	346.213
2004	5.8866	0.0646	1.0972	409.652	360.941	318.022
2005	5.6965	0.0656	1.1520	339.412	298.449	262.430
2006	5.6187	0.0626	1.1139	312.104	276.073	244.201
2007	5.6660	0.0673	1.1877	330.334	289.516	253.741
2008	5.7641	0.0679	1.1787	364.898	319.403	279.579
2009	5.8524	0.0677	1.1569	398.357	348.850	305.496
2010	5.9271	0.0738	1.2444	434.574	376.080	325.460
2011	5.8925	0.0714	1.2110	417.773	363.243	315.831
2012	5.9195	0.0687	1.1613	426.924	373.108	326.076
2013	5.7098	0.0672	1.1768	345.074	302.493	265.166
2014	5.5906	0.0672	1.2018	306.306	268.513	235.384
2015	5.7685	0.0725	1.2561	369.861	320.893	278.408
2016	5.8974	0.0748	1.2679	422.717	365.092	315.321
2017	5.8552	0.0751	1.2823	405.512	350.020	302.123
2018	5.7676	0.0776	1.3457	373.435	320.736	275.474

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	_	566.2882				
Year	17	492.8847	73.4035	21.0%	< 0.001	5.55E-09
Year Quarter	3	477.649	15.2357	4.4%	0.001626	1.63E-03
Year Quarter Area	6	467.0497	10.5993	3.0%	0.101579	1.02E-01
Year Quarter Area Gear	1	447.0735	19.9762	5.7%	< 0.001	7.84E-06
Year Quarter Area Gear Bait	1	446.7414	0.3321	0.1%	0.564	5.64E-01
Year Quarter Area Gear Bait Ratio	9	248.8604	197.8810	56.7%	< 0.001	9.21E-38
Year Quarter Area Gear Bait Ratio Gear*Ratio	4	248.5696	0.2908	0.1%	0.990	9.90E-01
Year Quarter Area Gear Bait Ratio Quarter*Gear	2	247.8132	1.0472	0.3%	0.592	5.92E-01
Year Quarter Area Gear Bait Ratio Year*Gear	1	247.8077	1.0527	0.3%	0.305	3.05E-01
Year Quarter Area Gear Bait Ratio Area*Bait	6	246.823	2.0374	0.6%	0.916	9.16E-01
Year Quarter Area Gear Bait Ratio Area*Gear	4	246.3739	2.4865	0.7%	0.647	6.47E-01
Year Quarter Area Gear Bait Ratio Quarter*Bait	3	245.8452	3.0152	0.9%	0.389	3.89E-01
Year Quarter Area Gear Bait Ratio Quarter*Ratio	26	244.2771	4.5833	1.3%	1.000	1.00E+00
Year Quarter Area Gear Bait Ratio Year*Bait	15	243.9137	4.9467	1.4%	0.993	9.93E-01
Year Quarter Area Gear Bait Ratio Bait*Ratio	9	242.1261	6.7343	1.9%	0.665	6.65E-01
Year Quarter Area Gear Bait Ratio Quarter*Area	18	241.8821	6.9783	2.0%	0.990	9.90E-01
Year Quarter Area Gear Bait Ratio Area*Ratio	43	235.873	12.9874	3.7%	1.000	1.00E+00
Year Quarter Area Gear Bait Ratio Year*Quarter	51	221.0732	27.7872	8.0%	0.997	9.97E-01
Year Quarter Area Gear Bait Ratio Year*Ratio	120	219.2046	29.6558	8.5%	1.000	1.00E+00
Year Quarter Area Gear Bait Ratio Year*Area	75	217.292	31.5684	9.0%	1.000	1.00E+00

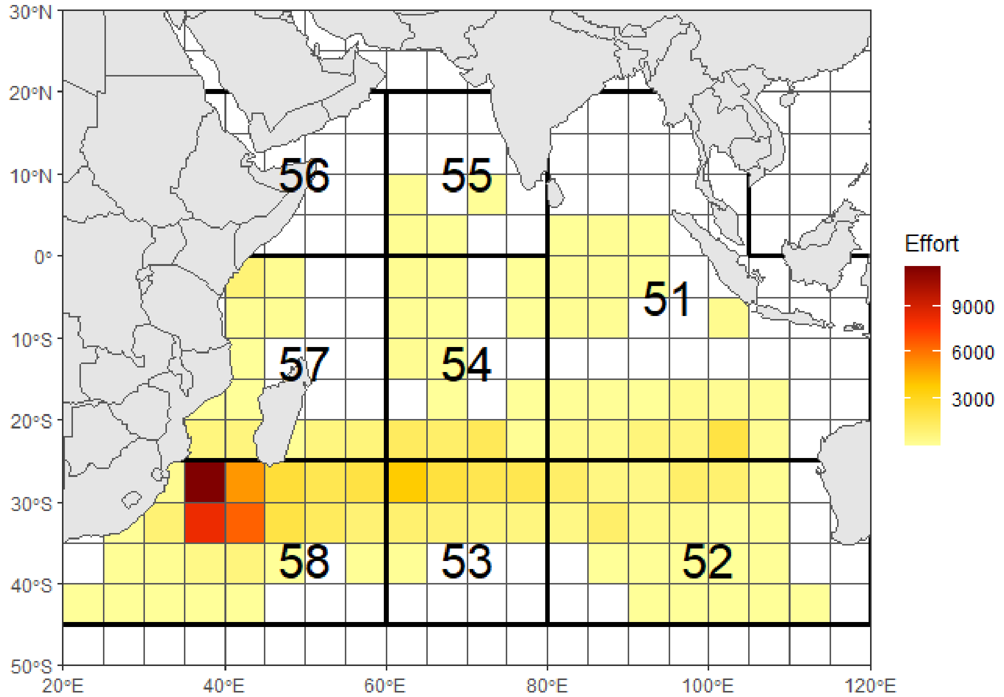

Figure 1. Area definition used for the GLM runs. Color scale represents the total nominal effort of this fleet (thousand of hooks) per 5x5 squares during the combined period 2001-2018.

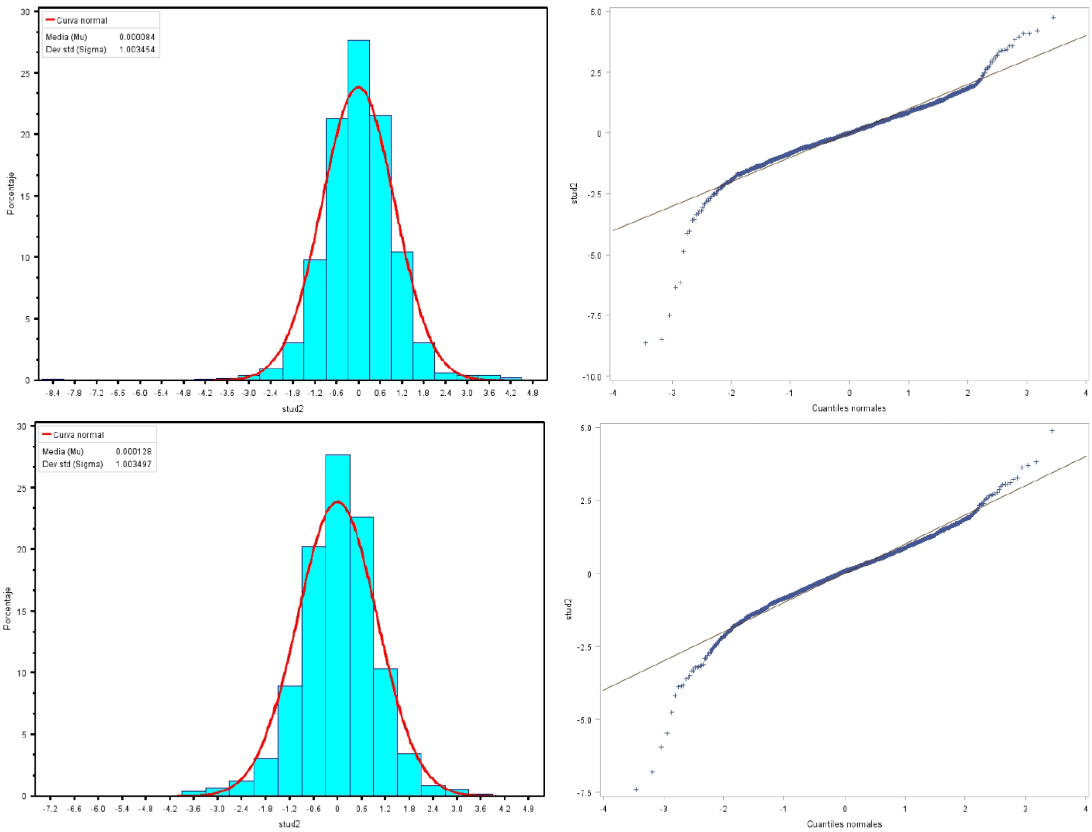

Figure 2. Diagnosis of the GLM runs for standardized CPUE in number of swordfish (upper) and in round weight (lower) for Indian Ocean: frequency distribution of the standardized residuals years combined (left panels) and normal probability qq-plot (right panels).

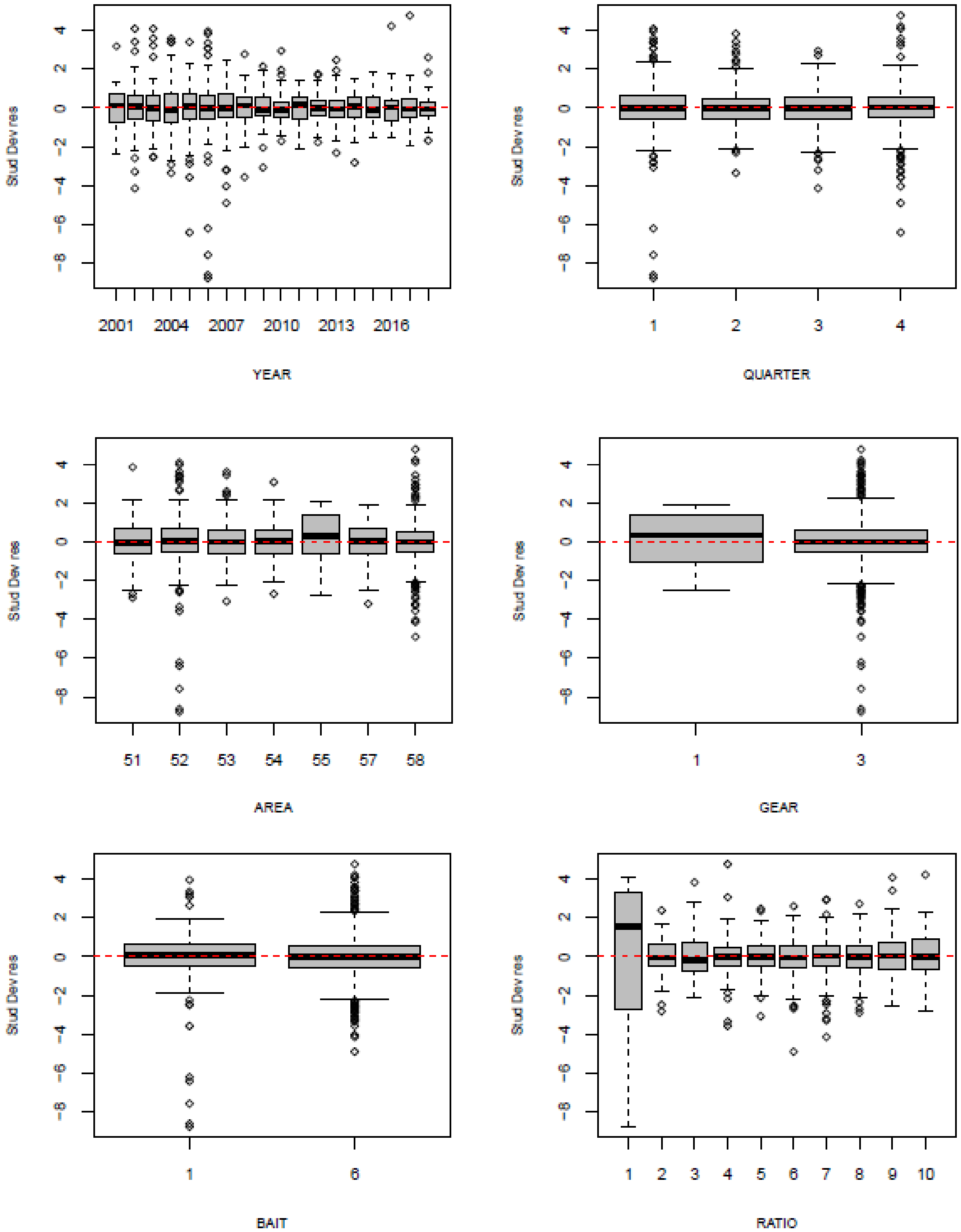

Figure 3. Box-plots of the standardized deviance residuals by explanatory variables obtained from the GLM base case in number of swordfish for the Indian Ocean.

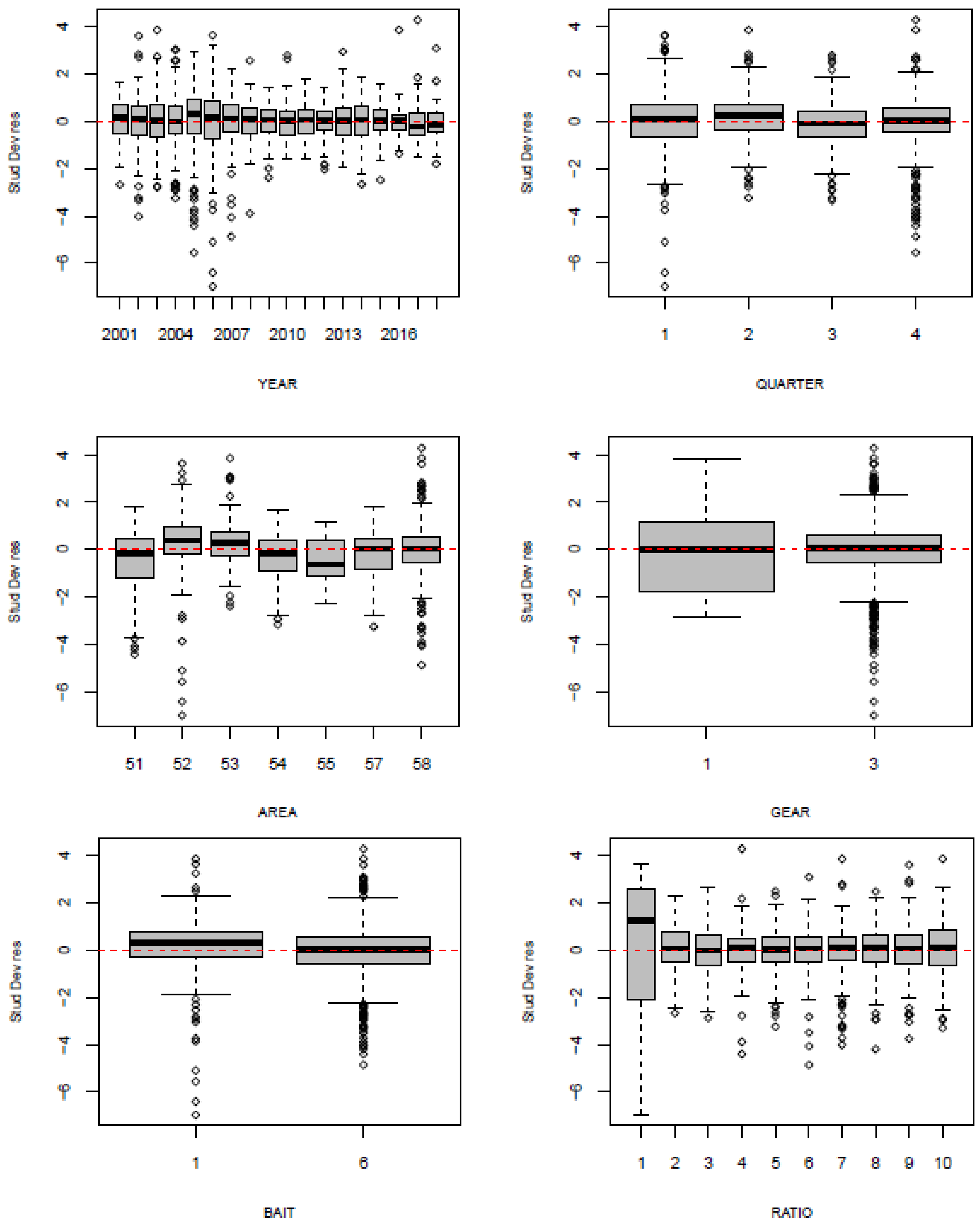

Figure 4. Box-plots of the standardized deviance residuals by explanatory variables obtained from the GLM base case in round weight of swordfish for the Indian Ocean.

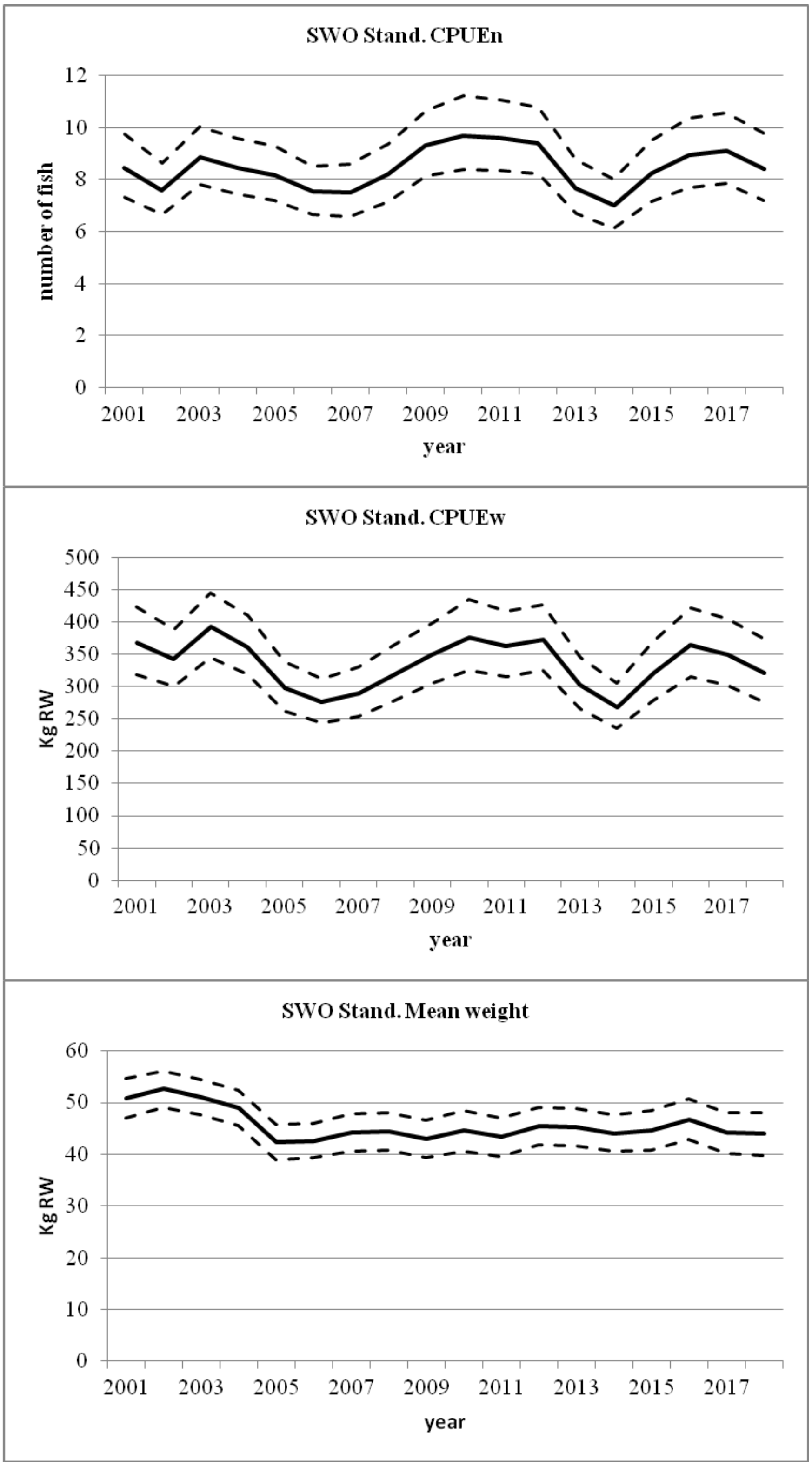

Figure 5. Standardized CPUEs per thousand hooks, in number of fish (upper), in kilograms round weight (middle) and standardized mean round weight in kilograms (lower) of swordfish and their respective confidence intervals (95%) observed in the Spanish surface longline fleet during the period analyzed (2001-2018) in the Indian Ocean.

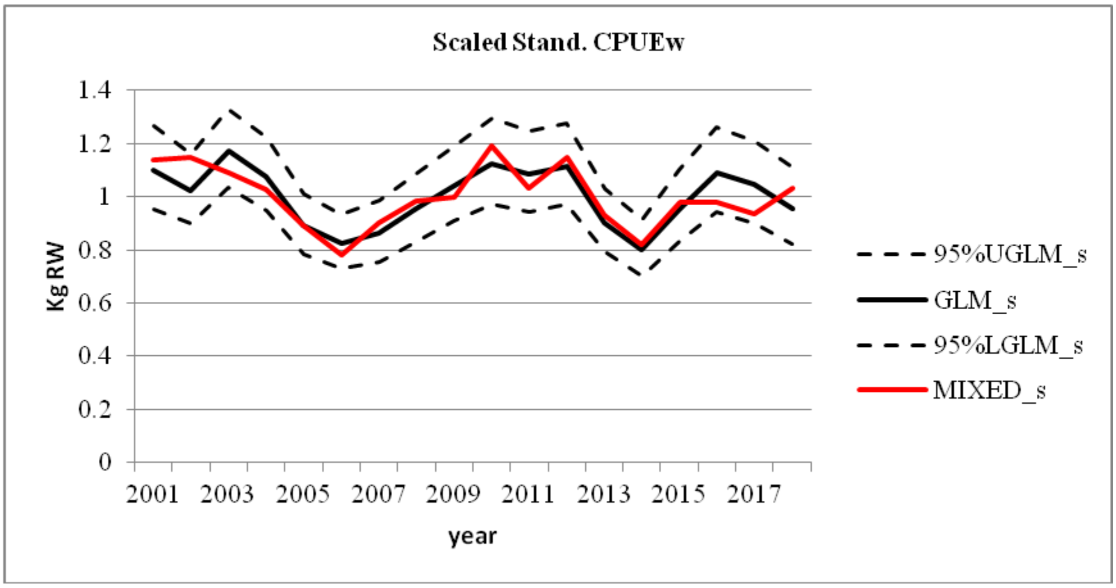

Figure 6. Comparative scaled standardized CPUE in weight, GLM *versus* GLMM (MIXED), obtained in the Indian Ocean for the period 2001-2018. Both series are scaled from their respective mean value.