UPDATED STANDARDIZED CATCH RATES OF SWORDFISH (*Xiphias gladius*) CAUGHT BY THE SPANISH SURFACE LONGLINE FLEET IN THE INDIAN OCEAN DURING THE 2001-2021 PERIOD

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ABSTRACT

This paper provides an updated of the standardized catch rates per unit of effort (CPUE) in number and in biomass for the swordfish Indian Ocean stock using Generalized Linear Models. A total of 2,832 trips, representing 90% of coverage of the Spanish surface longline fleet targeting swordfish, are analyzed for the period 2001-2021. The main factors considered in the analysis were year, quarter, area, targeting criteria of skippers, gear and the interaction quarter-area. The results indicate that the target criteria of the skippers was the most important factor which explained the CPUE variability followed by year and in less extent the other factors considered. The model explained 54% and 57% of CPUE variability in number and weight, respectively. The standardized CPUE show a slight decrease until 2005 followed by a stable trend until 2021.

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 generalized linear models (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 targeting criteria of the skippers over time, could be a good alternative to be considered in some cases.

The Spanish surface longline fishery was developed since late 1970's in the North Atlantic areas targeting mainly swordfish (*Xiphias gladius*) and since 1993 in the Indian Ocean. The present document updates the standardized CPUE series of the swordfish in the Indian Ocean stock previously provided (Ramos-Cartelle *et al.* 2020[a]) for the forthcoming stock assessment.

2. MATERIAL AND METHODS

The standardized log-normal CPUE analyses were performed using GLM procedures (*SAS 9.4*) for the period 2001-2021 assuming a log-normal distribution of catch rates as in a previous paper (Fernández-Costa *et al.* 2014, 2017, Ramos-Cartelle *et al*. 2020[a]). 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-, *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-

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September; Q4 = October-December), A= *area* effect, R= *ratio* effect (defined in order to categorize the targeting criteria of the skippers 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, squid, and others), Q*A= *quarter*area* interaction and e = normally distributed error term.

The response variable for the model (CPUE) is measured in number of fish and in kg of round weight per fishing effort (defined by thousands of hooks). 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 be treated as random variables (Maunder and Punt 2004).

It was also explored as a sensitivity analysis, the reduction of the categories for the ratio factor (targeting criteria of the skipper) in which the ratio was divided into five categories (20% intervals) instead of ten categories as in the base case.

3. RESULTS AND DISCUSSION

A total number of 2,832 trip observations were available. The effort covered by this set of data is representing the 90% of the total fishing effort of this fleet during that period. The number of observations per spatial-temporal strata may be considered satisfactory except for area 56, where few observations were available because the commercial fishing was very rare or sporadic. The final runs thus considered 7 areas (area 56 was joined to area 57). **Figure 1** shows the geographical area distribution used in the analysis for the period analyzed 2001-2021.

Table 1 provides a summary of the ANOVA results from GLM base case analysis. The base case model explains the 54% and 57% of the CPUE variability in number and weight, respectively. The explanatory variables tested were significant. The CPUE variability (Type III SS) could be mainly attributed to the targeting criteria of the skippers (*ratio* factor) highly significant, followed by the year factor although less significant.

Tables 2 and **3** provide information on estimated parameters (lsmeans), their standard error, coefficient of variation, standardized CPUE in number and in biomass respectively (kg round weight) and upper and lower 95% confidence intervals.

Figure 2 shows the frequency distribution of standardized residuals and normal probability qq-plot in number of fishes and in weight for the years 2001 to 2021 combined. **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.

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. The standardized CPUE shows a slight decrease until 2005 followed by a stable trend since then until 2021. In the case of the standardized mean weight, this shows a stable trend since 2005with an average weight of 43 kg since 2005 to 2021. It is important to note that these indices include all ages-sizes combined, as regularly reported in catch as sizes (CAS) data. Any comparison of these results with CPUE indices obtained for other fleets should take into consideration the respective age-fractions included.

The deviance table analyses of the factors tested in the GLMM procedure is presented in **Table 4**. The factors and interactions with ≥ 5.0% of deviance explained were considered in the sensitivity analysis. The final GLMM model was:

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

Figure 6 shows a comparative between standardized CPUE performed in the base case and the sensitivity analyzes. The CPUE were scaled to their respective average values to be compared. The trends obtained were similar when the targeting criterion of skippers was broken down into ten or five categories, but the five categories produces lower fit and broader confidence intervals. Small differences between base case and the GLMM for some years analyzed being the base case a bit more optimistic in recent years. The updated index is consistent with that given in 2020 (Ramos-Cartelle *et al*. 2020[a]).

The targeting practices of many tuna and tuna-like fisheries have often changed over the years due to changes in regulations, species targeted, market trends and/or in improvements of the scientific knowledge. Important changes in the fishing strategy have occurred in the Spanish surface longline fisheries since mid of 1980´s with the gradually introduction of on-board freezing systems together with other factors such as the quota allocation for the Atlantic swordfish and the increased economic importance in the market of blue shark allowed and encouraged skippers to retain on board and landing the swordfish and all blue shark caught as well as their derivatives. Details on the activity of this fleet can be found in previous papers (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, 2020[a], 2020[b]). An important change in the gear configuration took place in the early 2000's when the multifilament style traditionally used was replaced by the American-style monofilament, broadly introduced in the Spanish fleet and most vessels have been fishing with this new monofilament style since then (García-Cortés *et al.* 2016, Mejuto and De la Serna 2000, Mejuto *et al.* 2001[a], 2001[b], 2009).

Some scientists have expressed concern about how different *proxies of the targeting* may affect the representativeness of the standardized catch rate series as indicators of the relative abundance of the stock, or how the different data sets used from a fleet can affect the results of the standardization (Walter *et al.* 2014). Ideally, the detailed targeting information should be collected on board and/or recorded in the logbooks. However, such information is rarely known or is highly uncertain. In each fleet, the methodology used is probably adapted to their specific case in terms of the target and by-catch species, changes over time, among other factors considering the respective particularities of their fishing patterns over time.

The issue of *targeting* has been specifically assessed by the ICCAT Methods Working Group in year 2000 using simulations for five different fishery-scenarios and several alternatives for each scenario (Anon. 2001). One of the scenarios tested was to change the target species from swordfish only to both swordfish (original target species) and blue shark (secondary main or target species). The results of the evaluations performed by Methods Working Group in 2000 suggested that there is no clearly "best" method that could be generally applied to all cases-scenarios and that any one proxy, even if it performs best relative to the others, can still produce some biased results. But main conclusions achieved were: "*Of the proxy methods evaluated, the use of the ratio of catch of the target species to total catch, performed best on average and remains the preferred proxy, although this method may not provide the best performance in all cases".* Moreover, the working group pointed out *"the benefits of applying proxies for targeting relative to ignoring targeting effects*.

The *targeting criteria of the skipper* (ratio factor) was in the present case categorized as the percentage in weight of swordfish landed per trip in relation to the amount of the two species swordfish and blue shark landed per trip. Considering the information obtained from skippers, observers and other sources, this ratio factor fairly captures the intent or species prioritization that the skipper followed during each trip. After analyzing the behaviour of this fleet over time, testing several methodological approaches of categorization of the targeting and assessing the impact of this variable within the CPUE and standardized models, it was concluded that the ratio between these species is the best available *proxy* indicator for the skipper's targeting criteria belonging to this fleet over time to categorize the trips (Mejuto and De la Serna 2000, Ortiz *et al.* 2010). Similar findings were described in other fleets (e.g. Carvalho *et al.* 2010, Coelho and Rosa 2020, Santos *et al*. 2012, 2013). Taking into consideration previous analyses, the best fit was achieved in the present case broken down the targeting into ten categories at 10% intervals for modelling the type of trip, although other type of categorization was also tested (five categories at 20% intervals).

The "*targeting strategy*" was identified in several previous studies as one of the main explanatory variables for standardized swordfish catch rates and, along with other factors that are known to influence catchability, it may be included in the standardization of the CPUE series using Generalized Linear Models (Gulland 1983). The possible presence of collinearity among some factors it was considered as a less of a problem if the goal of the analysis to generate an index of relative abundance for use in a stock assessment because additional variables that are correlated tend not to add much explanatory power beyond the first variables selected (Maunder and Punt 2004).

It has also been in some cases hypothesized that the introduction of the *targeting* as an explanatory variable within the GLM models could cause a false vision of *hyper-stability* in the standardized CPUE trends. But the truth is that in the case of this fleet and its history compile over time, it has been seen and previously described that the non-inclusion of the change in targeting could produces a fake and systematic inter-annual *hyper-instability* predicting false changes in the relative abundance throughout the years. The omission of the targeting factor in the present case would falsely adjudicate a part of the variability in CPUE observed to the year effect, but it was mainly due to changes in targeting among both species with subsequent effects on the respective CPUE of swordfish and blue shark (Mejuto 2007). Lower coefficients of variation (CV) do not necessarily means that they better represent the abundance of the stock it doesn't mean either the opposite. A more detailed discussion of some of these issues has been included in previous papers and summarized in a recent paper on standardizing of blue shark catch rates in the Atlantic Ocean (Mejuto *et al.* 2023-in press). The evaluation of each index and the weights taken into account in the stock assessment models should be evaluated case by case based on the qualitative, quantitative merits and the credibility of the data used, the spatial coverage of each fleet in relation to the stock distribution, as well as the biological plausibility of the inter-annual CPUE variability obtained in the analyses since abrupt changes in the total abundance should not be biologically plausible in this type of species during short time scenarios (Ramos-Cartelle *et al.* 2011).

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

CPUEn (in number of fish):

Source	DF	Sum of Squares	Mean squared	F value	Pr>F
Model	59	414.2024433	7.0203804	55.73	<.0001
Error	2772	349.1638194	0.125961		
Corrected Total	2831	763.3662628			

R-Squared	Coeff Var	Root MSE	Mean CPUEn
0.5426	13.69341	0.35491	2.591829

Source	DF	Type III SS	Mean squared	F value	Pr>F
year	20	22.0500409	1.102502	8.75	<.0001
quarter	3	0.8754945	0.2918315	2.32	0.0737
area	6	1.5174658	0.252911	2.01	0.0613
gear	1	3.3925789	3.3925789	26.93	<.0001
bait	2	0.5628589	0.2814295	2.23	0.1073
ratio	9	254.6609258	28.2956584	224.64	<.0001
quarter*area	18	5.6052658	0.3114037	2.47	0.0005

CPUEw (in weight):

Source	DF	Sum of Squares	Mean squared	F value	Pr>F
Model	59	456.8423997	7.7430915	62.27	<.0001
Error	2772	344.6987707	0.1243502		
Corrected Total	2831	801.5411704			

R-Squared	Coeff Var	Root MSE	Mean CPUEw
0.569955	5.417689	0.352633	6.508924

Source	DF	Type III SS	Mean squared	F value	Pr>F
year	20	36.9858345	1.8492917	14.87	<.0001
quarter	3	0.2402883	0.0800961	0.64	0.5866
area	6	16.8933909	2.8155652	22.64	<.0001
gear	1	8.1638597	8.1638597	65.65	<.0001
bait	2	1.4076564	0.7038282	5.66	0.0035
ratio	9	254.6787649	28.2976405	227.56	<.0001
quarter*area	18	9.524	0.5291111	4.26	<.0001

Table 2. Estimated parameters (lsmean), standard error (stderr), the coefficient of variation (CV%), standardized CPUEn in number of swordfish and upper and lower 95% confidence limits and for the Spanish longline fleet in the Indian Ocean during the period analyzed 2001-2021.

YEAR	LSMEAN	STDERR	CV%	UCPUEn	CPUEn	LCPUEn
2001	2.0230	0.0878	8.7935	9.015	7.590	6.391
2002	1.9302	0.0807	8.0846	8.098	6.913	5.902
2003	2.0904	0.0797	7.9815	9.485	8.114	6.940
2004	2.0380	0.0804	8.0557	9.015	7.700	6.577
2005	2.0012	0.0813	8.1470	8.705	7.423	6.329
2006	1.9153	0.0785	7.8573	7.942	6.810	5.840
2007	1.9195	0.0828	8.2906	8.046	6.841	5.817
2008	1.9977	0.0833	8.3480	8.710	7.397	6.283
2009	2.1263	0.0832	8.3382	9.904	8.413	7.147
2010	2.1471	0.0888	8.9010	10.228	8.594	7.220
2011	2.1537	0.0863	8.6503	10.244	8.649	7.303
2012	2.1287	0.0840	8.4136	9.943	8.434	7.154
2013	1.9257	0.0826	8.2779	8.094	6.883	5.854
2014	1.8506	0.0824	8.2575	7.505	6.385	5.433
2015	2.0202	0.0874	8.7517	8.982	7.568	6.378
2016	2.0818	0.0896	8.9815	9.597	8.051	6.754
2017	2.0933	0.0899	9.0078	9.714	8.145	6.829
2018	2.0151	0.0921	9.2295	9.024	7.534	6.289
2019	1.9632	0.0868	8.6968	8.475	7.149	6.030
2020	1.8661	0.0791	7.9208	7.570	6.483	5.552
2021	2.0538	0.0803	8.0468	9.156	7.822	6.683

Table 3. Estimated parameters (lsmean), standard error (stderr), the coefficient of variation (CV%), standardized CPUEw in round weight of swordfish and upper and lower 95% confidence limits for the Spanish longline fleet in the Indian Ocean during the period analyzed 2001-2021.

YEAR	LSMEAN	STDERR	CV%	UCPUEw	CPUEw	LCPUEw
2001	5.7673	0.0872	8.7369	380.690	320.880	270.467
2002	5.7041	0.0802	8.0325	352.315	301.070	257.278
2003	5.8453	0.0792	7.9301	404.879	346.680	296.847
2004	5.7517	0.0799	8.0039	369.247	315.715	269.944
2005	5.5683	0.0808	8.0946	307.958	262.846	224.343
2006	5.4852	0.0779	7.8068	281.741	241.824	207.562
2007	5.5276	0.0822	8.2372	296.536	252.394	214.823
2008	5.6180	0.0828	8.2943	324.979	276.296	234.905
2009	5.7030	0.0827	8.2846	353.723	300.790	255.779
2010	5.7790	0.0883	8.8436	386.023	324.700	273.118
2011	5.7435	0.0858	8.5946	370.689	313.318	264.827
2012	5.7703	0.0834	8.3594	378.939	321.763	273.214
2013	5.5644	0.0821	8.2247	307.569	261.849	222.925
2014	5.4489	0.0819	8.2045	273.911	233.286	198.687
2015	5.6313	0.0868	8.6954	332.023	280.086	236.273
2016	5.7566	0.0891	8.9237	378.089	317.530	266.671
2017	5.6999	0.0893	8.9498	357.444	300.039	251.853
2018	5.6182	0.0915	9.1700	330.870	276.544	231.138
2019	5.5867	0.0862	8.6408	317.181	267.850	226.192
2020	5.4703	0.0786	7.8698	277.941	238.268	204.259
2021	5.6502	0.0798	7.9950	333.563	285.254	243.941

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	_	801.5412				
Year	20	672.5849	128.9563	26.7%	< 0.001	6.12E-18
Year Quarter	3	652.5876	19.9973	4.1%	< 0.001	1.70E-04
Year Quarter Area	6	642.0943	10.4933	2.2%	0.10535	1.05E-01
Year Quarter Area Gear	1	622.0496	20.0447	4.1%	< 0.001	7.57E-06
Year Quarter Area Gear Bait	2	621.3598	0.6898	0.1%	0.708	7.08E-01
Year Quarter Area Gear Bait Ratio	9	354.2228	267.1370	55.3%	< 0.001	2.39E-52
Year Quarter Area Gear Bait Ratio Gear*Ratio	4	353.8997	0.3231	0.1%	0.988	9.88E-01
Year Quarter Area Gear Bait Ratio Quarter*Gear	2	353.2426	0.9802	0.2%	0.613	6.13E-01
Year Quarter Area Gear Bait Ratio Year*Gear	1	353.1567	1.0661	0.2%	0.302	3.02E-01
Year Quarter Area Gear Bait Ratio Area*Gear	4	351.7997	2.4231	0.5%	0.658	6.58E-01
Year Quarter Area Gear Bait Ratio Area*Bait	7	350.5275	3.6953	0.8%	0.814	8.14E-01
Year Quarter Area Gear Bait Ratio Quarter*Bait	4	350.047	4.1758	0.9%	0.383	3.83E-01
Year Quarter Area Gear Bait Ratio Year*Bait	18	348.1765	6.0463	1.3%	0.996	9.96E-01
Year Quarter Area Gear Bait Ratio Quarter*Ratio	26	347.3511	6.8717	1.4%	1.000	1.00E+00
Year Quarter Area Gear Bait Ratio Bait*Ratio	13	345.322	8.9008	1.8%	0.780	7.80E-01
Year Quarter Area Gear Bait Ratio Quarter*Area	18	344.6988	9.5240	2.0%	0.946	9.46E-01
Year Quarter Area Gear Bait Ratio Area*Ratio	45	340.571	13.6518	2.8%	1.000	1.00E+00
Year Quarter Area Gear Bait Ratio Year*Quarter	60	322.9132	31.3096	6.5%	0.999	9.99E-01
Year Quarter Area Gear Bait Ratio Year*Area	82	320.5106	33.7122	7.0%	1.000	1.00E+00
Year Quarter Area Gear Bait Ratio Year*Ratio	143	318.1227	36.1001	7.5%	1.000	1.00E+00

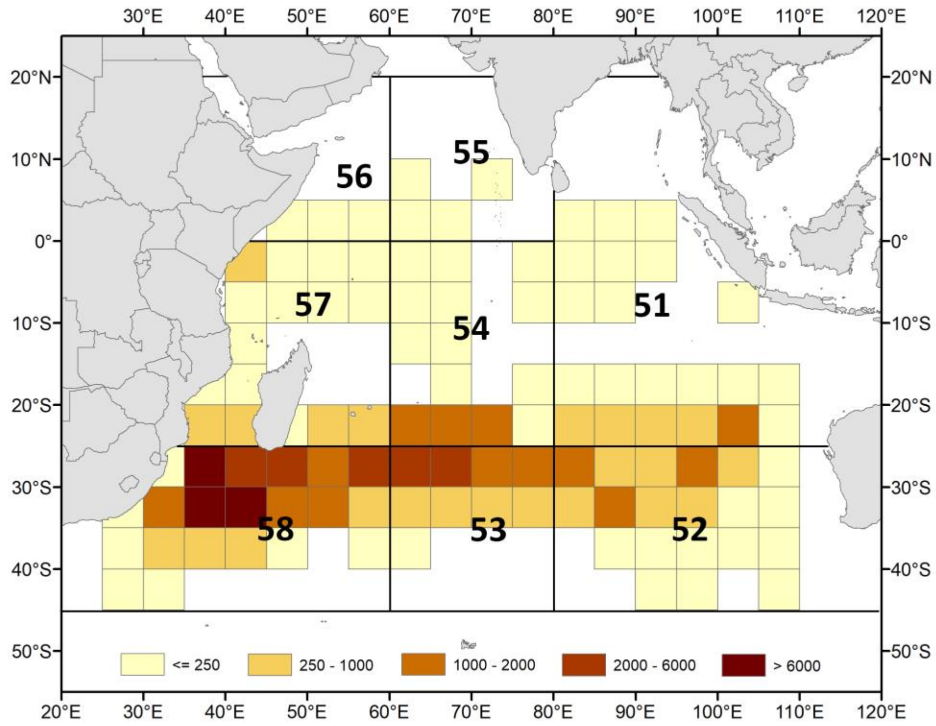

Figure 1. Geographical areas stratification used in the GLM for swordfish. Color scale represents the total nominal effort of this fleet (thousands of hooks) per 5x5 squares during the combined period 2001-2021.

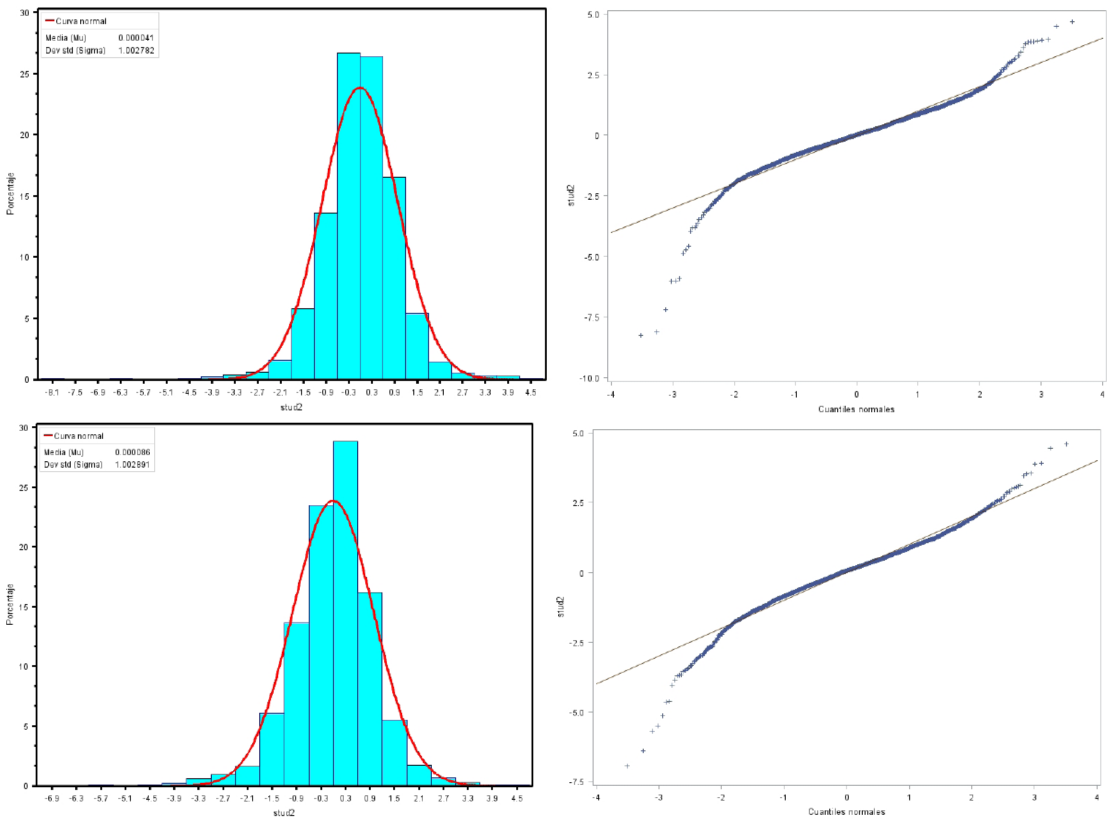

Figure 2. Distribution of the standardized residuals and normal probability qq-plot of swordfish in the Indian Ocean for years 2001-2021 combined. Upper the graphs in number and lower the graphs in weight.

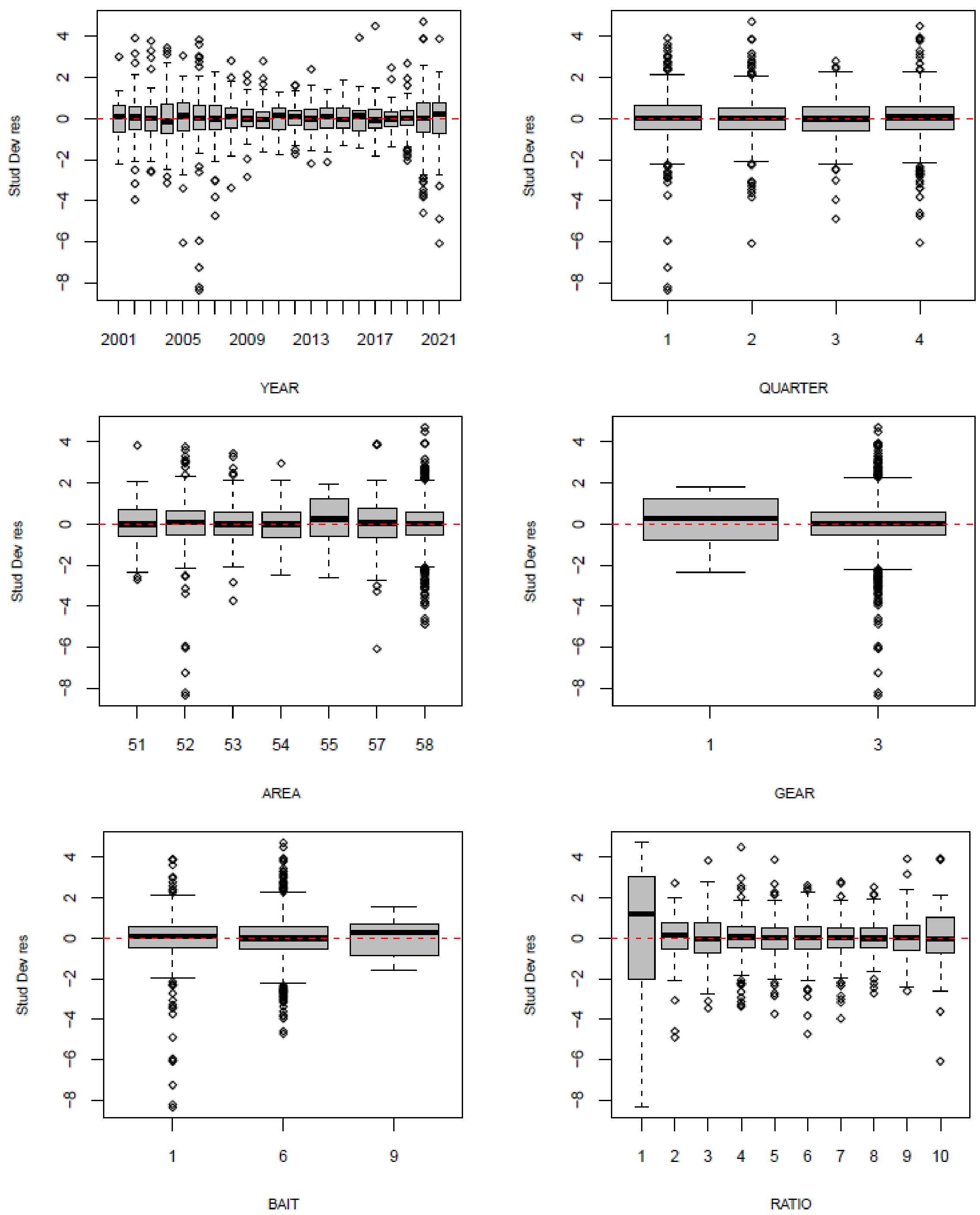

Figure 3. Box-plots of the standardized deviance residuals by explanatory variables obtained from the GLM base case in number of swordfish for the Indian Ocean.

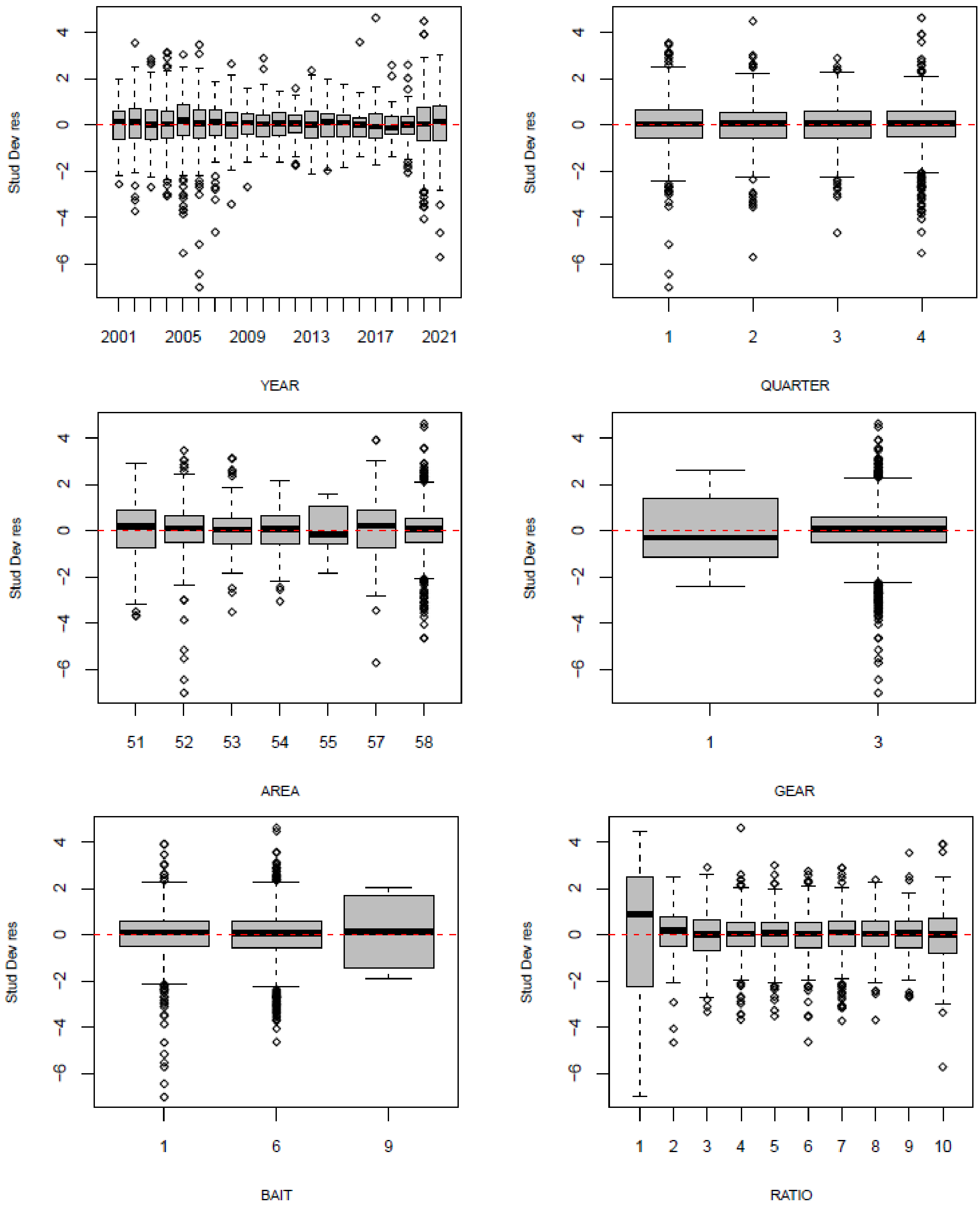

Figure 4. Box-plots of the standardized deviance residuals by explanatory variables obtained from the GLM base case in round weight of swordfish for the Indian Ocean.

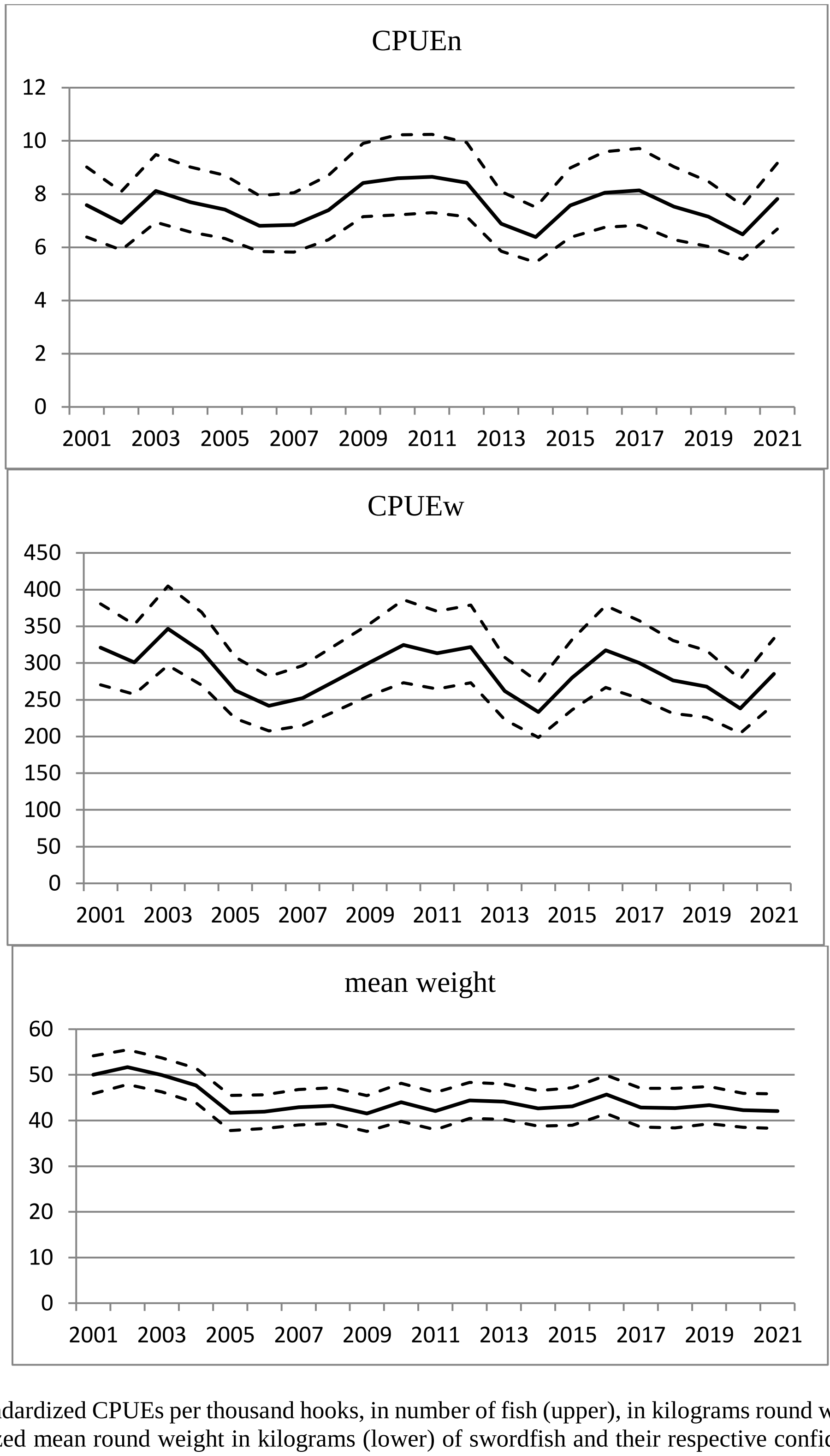

Figure 5. Standardized CPUEs per thousand hooks, in number of fish (upper), in kilograms round weight (middle) and standardized mean round weight in kilograms (lower) of swordfish and their respective confidence intervals (95%) observed in the Spanish surface longline fleet during the period analyzed (2001-2021) in the Indian Ocean.

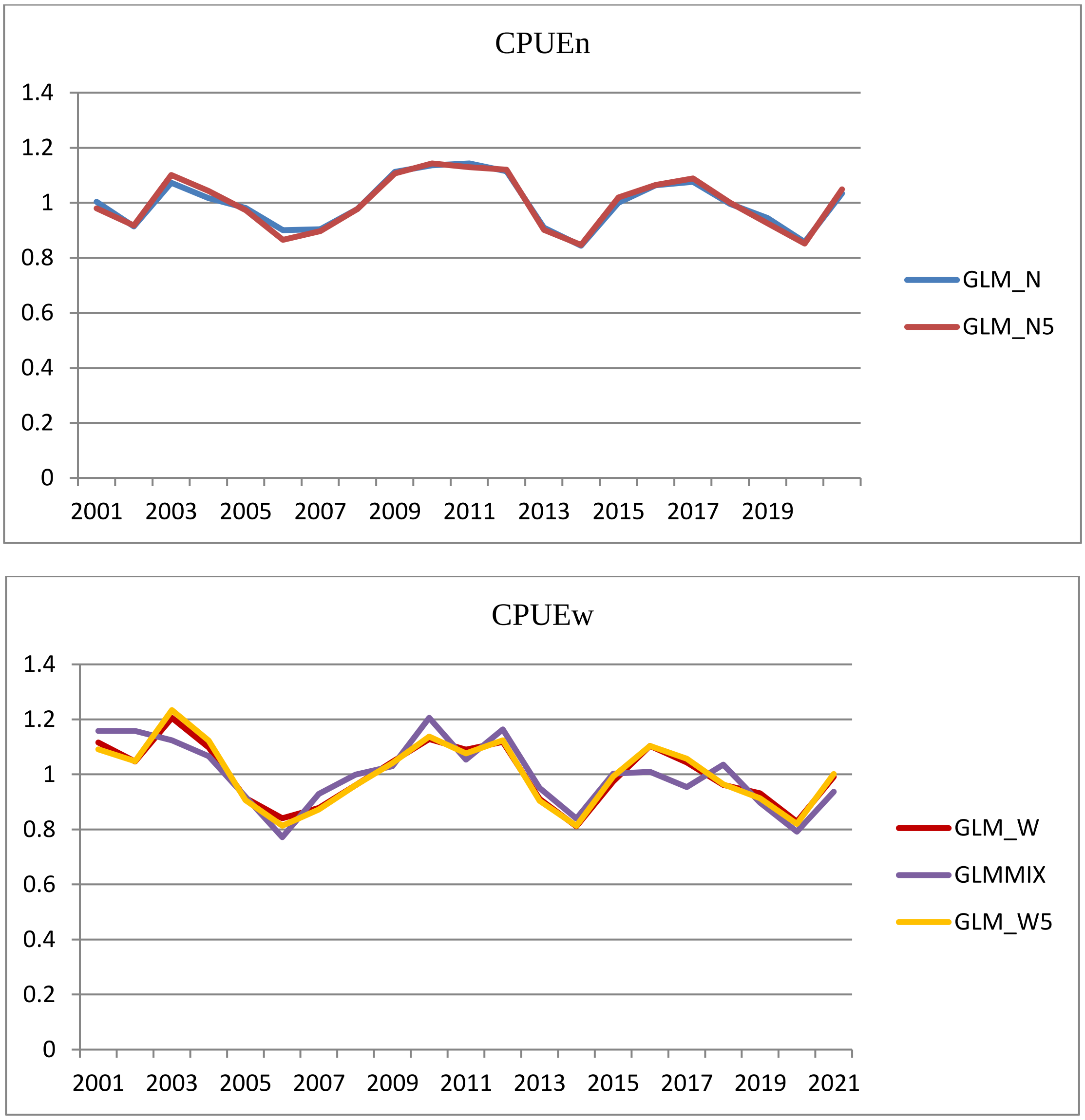

Figure 6. Comparative scaled standardized CPUE in number (upper panel) and in kg round weight (lower panel) for swordfish in the Indian Ocean for the period 2001-2021. Both series are scaled from their respective mean value. GLM_N/GLM_W: the base case in number/weight, GLM_N5/GLM_W5: the base case in number/weight with 5 categories of ratio factor, GLMMIX: the GLMM procedure in weight.