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UPDATED STANDARDIZED CATCH RATES OF SWORDFISH (*XIPHIAS GLADIUS*) CAUGHT BY THE SPANISH SURFACE LONGLINE FLEET IN THE INDIAN OCEAN DURING THE 2001-2024 PERIOD

J. FERNÁNDEZ-COSTA AND A. RAMOS-CARTELLE

Purpose, expectation and action intended.

Discussions (for information and open discussion):

The purpose of this document is to inform meeting participants that the standardized catch rates per unit of effort (CPUE), expressed both in number and biomass, for the Spanish longline fleet targeting swordfish in the Indian Ocean have been updated for the 2001-2024 period.

The resulting standardized swordfish CPUE series are presented for consideration by the Group and for inclusion in the swordfish stock assessment at the 24th Working Party on Billfish (WPB24) meeting in September.

Feedback (to collect input and suggestions)

Conclusion (to record a concluded position or summary)

Recommendation (to ask the meeting to endorse a recommendation)

Decisions (to request formal approval of actions)

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 3,504 trips, representing 91% of coverage of the Spanish surface longline fleet targeting swordfish, are analyzed for the period 2001-2024. The main factors considered in the analysis were year, quarter, area, gear, targeting criteria of skippers and the interaction quarter-area. The results indicate that the skipper's target criteria was the most important factor explaining CPUE variability, followed by year and, to a lesser extent, the other factors considered. The model explained 53% and 56% of CPUE variability in number and weight, respectively. The standardized CPUE show a stable trend until 2021 followed by a slight increase afterward.

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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 3,504 trips, representing 91% of coverage of the Spanish surface longline fleet targeting swordfish, are analyzed for the period 2001-2024. The main factors considered in the analysis were year, quarter, area, gear, targeting criteria of skippers and the interaction quarter-area. The results indicate that the skipper's target criteria was the most important factor explaining CPUE variability, followed by year and, to a lesser extent, the other factors considered. The model explained 53% and 56% of CPUE variability in number and weight, respectively. The standardized CPUE show a stable trend until 2021 followed by a slight increase afterward.

Keywords: swordfish, CPUE, GLM, longline.

1. INTRODUCTION

The Spanish surface longline fishery targeting mainly swordfish (*Xiphias gladius*) began operating in the Indian Ocean in 1993 with a fleet already adapted to retain and land both swordfish and blue shark, following the introduction of on-board freezing systems in the mid-1980s and the increasing market value of blue shark (Fernandez-Costa *et al.* 2023, García-Cortés and Mejuto 2000, García-Cortés *et al.* 2003, 2004, 2008, 2010; Ramos-Cartelle *et al.* 2011, 2020).

A further change in gear configuration occurred in the early 2000s, when the traditional multifilament gear was replaced by the American-style monofilament configuration. This gear was widely adopted throughout the Spanish fleet, and most vessels have operated with this monofilament configuration since then (Fernandez-Costa *et al.* 2023, Mejuto *et al.* 2011).

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 need 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 over time, could be a good alternative to be considered in some cases.

The document updates the standardized CPUE series of the swordfish in the Indian Ocean stock previously presented (Ramos-Cartelle *et al.* 2020, Fernández-Costa *et al.* 2023) to be considered in the forthcoming assessment.

2. MATERIAL AND METHODS

The standardized CPUE analyses were performed using GLM procedures (*SAS 9.4*) for the period 2001-2024 assuming a log-normal distribution of catch rates as in a previous paper (Fernández-Costa *et al.* 2014, 2017, Ramos-Cartelle *et al.* 2020). Data records were obtained per trip. To maintain consistency with previous studies, the model was defined as follows:

$$Ln\ (CPUE) = u + Y + Q + A + G + B + R + Q*A + e$$

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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)**, G = *gear* effect (traditional multifilament or American-monofilament style and modified American-style monofilament), B = *bait* type (mackerel, squid, and others), 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), 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. As a sensitivity analysis, an alternative model was fitted using a generalized linear mixed model (GLMM), which allows some parameters to be treated as random effects (Maunder and Punt 2004). An additional sensitivity analysis was also conducted without including the *ratio* factor.

3. RESULTS AND DISCUSSION

A total number of 3,504 trip observations were available. The effort covered by this set of data is representing the 91% 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).

Table 1 provides a summary of the ANOVA results from GLM base case analysis. The base case model explains the 53% and 56% of the CPUE variability in number and weight, respectively. Most of the explanatory variables tested were statistically significant, except for the *quarter* factor, depending on whether the analysis was based on number or weight. 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.

The estimated model parameters (least-squares mean), along with the standardized CPUE, the corresponding 95% confidence intervals, and coefficient of variation (CV) are reported in **Table 2** for the CPUE in number and in **Table 3** for the CPUE in biomass (kg round weight).

Figure 2 presents the frequency distributions and normal Q–Q plots of the standardized residuals for abundance (number of individuals and biomass), based on the combined data for the period 2001–2024. **Figures 3 and 4** show box plots of the standardized residuals by the main factors included in the base case for number of individuals and biomass, respectively.

Figure 5 shows the base case standardized CPUE in number of individuals and biomass (kg round weight) as well as the standardized mean round weight obtained by year and the corresponding 95% confidence intervals (lower and upper limits). The standardized CPUE trends in terms of abundance in number of individuals and in biomass are similar. Standardized CPUE decreased slightly until 2005, followed by a relatively stable period with interannual fluctuations through 2021. A slight increase was then observed until 2023, followed by a shift in the final year. The updated index is consistent with that given in previous assessment (Ramos-Cartelle *et al.* 2020, Fernández-Costa *et al.* 2023).

In the case of the standardized mean weight, this shows a stable trend since 2005 with an average weight of 48 kg since 2005 to 2024. It is important to note that these indices include all ages and size class combined. Therefore, any comparison with CPUE indices derived from other fleets should consider the age and size composition represented in the respective indices.

Sensitivity analyses were performed and compared with the base case in biomass. The first sensitivity analysis involved comparing the biomass base case (GLM-based) with an alternative model using a GLMM approach. 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:

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

The second sensitivity analysis compared the base-case biomass estimates with those obtained from a model excluding the *ratio* factor.

To facilitate comparison, the different standardized CPUE indices were scaled to their respective mean values. Overall, similar trends were observed across the base case and both sensitivity analyses (**Figures 6 and 7**). The GLMM showed differences in some years of the time series, particularly at the beginning of the series and during the 2015–2018 period. Excluding the ratio factor also resulted in differences in the magnitude of the estimated indices for some years, although the overall temporal pattern remained consistent with the base case.

The ratio factor was categorized according the percentage of swordfish landed (by weight) per fishing trip relative to the combined weight of swordfish and blue shark landed during the same trip. Based on information collected from skippers and onboard observers, together with an analysis of fleet behavior over time and the evaluation of alternative approaches, this ratio factor was considered an appropriate proxy for identifying the targeting criteria applied by Spanish skippers during each fishing trip (Mejuto and De la Serna 2000, Ortiz et al. 2010). Similar findings were described in other fleets and Oceans (Carvalho et al. 2010, Coelho and Rosa 2020, Coelho *et al*. 2023, Santos et al. 2012, 2013).

The second sensitivity analysis was conducted because some scientists have expressed concern regarding the inclusion of this *ratio* as factor in the GLM as a proxy for the skipper´s targeting strategy. However, excluding the targeting factor from the model would incorrectly attribute part of the observed CPUE variability to the year effect, whereas this variability is largely explained by temporal changes in targeting practices, thereby biasing the estimation of annual CPUE indices. For further discussion on the *ratio* factor see Fernandez-Costa et al (2023).

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

CPUEn (in number of fish):

Source	DF	Sum of Squares	Mean squared	F value	Pr>F
Model	63	498.736380	7.9164505	61.53	<.0001
Error	3440	442.604966	0.1286642		
Corrected Total	3503	941.341346			

R-Squared	Coeff Var	Root MSE	Mean CPUE
0.529815	13.6293	0.358698	2.631814

Source	DF	Type III SS	Mean squared	F value	Pr>F
year	23	42.8949577	1.8649982	14.5	<.0001
quarter	3	0.8703728	0.2901243	2.25	0.08
area	6	0.8575415	0.1429236	1.11	0.3532
gear	2	2.9644470	1.4822235	11.52	<.0001
bait	2	1.2915906	0.6457953	5.02	0.0067
ratio	9	317.3324480	35.2591609	274.04	<.0001
quarter*area	18	6.4677364	0.3593187	2.79	<.0001

CPUEw (in weight):

Source	DF	Sum of Squares	Mean squared	F value	Pr>F
Model	63	547.894918	8.6967447	68.98	<.0001
Error	3440	433.733215	0.1260852		
Corrected Total	3503	981.628133			

R-Squared	Coeff Var	Root MSE	Mean CPUE
0.558149	5.422183	0.355085	6.548744

Source	DF	Type III SS	Mean squared	F value	Pr>F
year	23	56.1437023	2.4410305	19.36	<.0001
quarter	3	0.3706340	0.1235447	0.98	0.4012
area	6	18.0362965	3.0060494	23.84	<.0001
gear	2	7.0240547	3.5120273	27.85	<.0001
bait	2	1.1420305	0.5710153	4.53	0.0109
ratio	9	318.6462870	35.4051430	280.80	<.0001
quarter*area	18	11.7759347	0.6542186	5.19	<.0001

Table 2. Estimated parameters (lsmean), standard error (stderr), standardized CPUEn in number of swordfish, the upper and lower 95% confidence limits and the coefficient of variation (CV%) for the Spanish longline fleet in the Indian Ocean during the period analyzed 2001-2024.

YEAR	LSMEAN	STDERR	UCPUEn	CPUEn	LCPUEn	CV%
2001	2.1591	0.0671	9.9037	8.6828	7.6124	6.7201
2002	2.0813	0.0582	8.9984	8.0287	7.1636	5.8223
2003	2.2457	0.0577	10.5963	9.4630	8.4510	5.7758
2004	2.1916	0.0585	10.0537	8.9650	7.9942	5.8527
2005	2.1446	0.0592	9.6058	8.5533	7.6161	5.9263
2006	2.0610	0.0557	8.7739	7.8659	7.0519	5.5782
2007	2.0650	0.0612	8.9064	7.9000	7.0073	6.1236
2008	2.1461	0.0620	9.6758	8.5682	7.5873	6.2090
2009	2.2783	0.0618	11.0384	9.7787	8.6627	6.1884
2010	2.2867	0.0690	11.2943	9.8656	8.6177	6.9085
2011	2.2944	0.0656	11.3031	9.9396	8.7407	6.5654
2012	2.2656	0.0624	10.9106	9.6552	8.5444	6.2423
2013	2.0709	0.0607	8.9515	7.9469	7.0550	6.0791
2014	1.9970	0.0606	8.3106	7.3801	6.5538	6.0640
2015	2.1744	0.0676	10.0658	8.8167	7.7225	6.7680
2016	2.2273	0.0700	10.6632	9.2970	8.1059	7.0036
2017	2.2388	0.0705	10.7995	9.4057	8.1918	7.0590
2018	2.1523	0.0729	9.9532	8.6279	7.4790	7.3006
2019	2.1006	0.0659	9.3169	8.1886	7.1969	6.5931
2020	2.0045	0.0550	8.2800	7.4336	6.6737	5.5059
2021	2.1819	0.0608	10.0035	8.8794	7.8817	6.0868
2022	2.2744	0.0622	11.0035	9.7410	8.6234	6.2236
2023	2.3938	0.0567	12.2616	10.9724	9.8189	5.6721
2024	2.3338	0.0552	11.5135	10.3329	9.2734	5.5239

Table 3. Estimated parameters (lsmean), standard error (stderr), standardized CPUEw in round weight of swordfish, the upper and lower 95% confidence limits and the coefficient of variation (CV%) for the Spanish longline fleet in the Indian Ocean during the period analyzed 2001-2024.

YEAR	LSMEAN	STDERR	UCPUEw	CPUEw	LCPUEw	CV%
2001	6.0641	0.0664	491.0430	431.0790	378.4370	6.6522
2002	6.0078	0.0576	455.9150	407.2530	363.7840	5.7636
2003	6.1508	0.0571	525.5290	469.8590	420.0870	5.7175
2004	6.0550	0.0579	478.2530	426.9560	381.1600	5.7937
2005	5.8670	0.0586	396.8510	353.7810	315.3850	5.8665
2006	5.7847	0.0552	362.9860	325.7790	292.3850	5.5219
2007	5.8279	0.0606	383.1440	340.2590	302.1750	6.0619
2008	5.9202	0.0614	420.9180	373.1890	330.8720	6.1463
2009	6.0077	0.0612	459.2240	407.3130	361.2700	6.1259
2010	6.0759	0.0683	498.7470	436.2510	381.5850	6.8388
2011	6.0413	0.0649	478.5100	421.3350	370.9930	6.4990
2012	6.0652	0.0617	486.9340	431.4410	382.2720	6.1793
2013	5.8654	0.0601	397.4570	353.2750	314.0040	6.0177
2014	5.7500	0.0600	354.0110	314.7500	279.8440	6.0028
2015	5.9375	0.0669	433.0600	379.8250	333.1330	6.6997
2016	6.0562	0.0692	489.9500	427.7680	373.4780	6.9329
2017	5.9995	0.0698	463.4510	404.2000	352.5230	6.9877
2018	5.9131	0.0722	427.1420	370.7960	321.8840	7.2269
2019	5.8839	0.0652	409.0380	359.9700	316.7890	6.5266
2020	5.7678	0.0545	356.3930	320.3100	287.8790	5.4503
2021	5.9181	0.0602	419.0250	372.3890	330.9430	6.0255
2022	6.0623	0.0616	485.3380	430.1820	381.2940	6.1608
2023	6.1544	0.0561	526.3450	471.5350	422.4320	5.6148
2024	6.1071	0.0546	500.5540	449.7170	404.0440	5.4682

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
Intercept		981.6281				
year	23	827.1229	154.5052	26.8%	< 0.001	1.82E-21
year quarter	3	806.1870	20.9359	3.6%	< 0.001	1.09E-04
year quarter area	6	796.2864	9.9006	1.7%	0.129	1.29E-01
year quarter area gear	2	778.0230	18.2634	3.2%	< 0.001	1.08E-04
year quarter area gear bait	2	777.3391	0.6839	0.1%	0.710	7.10E-01
year quarter area gear bait ratio	9	445.5091	331.8300	57.6%	< 0.001	4.54E-66
year quarter area gear bait ratio gear*ratio	12	444.0421	1.4670	0.3%	1.000	1.00E+00
year quarter area gear bait ratio year*gear	3	442.4092	3.0999	0.5%	0.376	3.76E-01
year quarter area gear bait ratio quarter*gear	5	442.0567	3.4524	0.6%	0.631	6.31E-01
year quarter area gear bait ratio gear*bait	3	441.7057	3.8034	0.7%	0.283	2.83E-01
year quarter area gear bait ratio quarter*bait	4	440.5867	4.9224	0.9%	0.295	2.95E-01
year quarter area gear bait ratio area*gear	8	440.0091	5.5000	1.0%	0.703	7.03E-01
year quarter area gear bait ratio area*bait	10	438.3782	7.1309	1.2%	0.713	7.13E-01
year quarter area gear bait ratio quarter*ratio	26	438.2879	7.2212	1.3%	1.000	1.00E+00
year quarter area gear bait ratio year*bait	22	435.6914	9.8177	1.7%	0.988	9.88E-01
year quarter area gear bait ratio bait*ratio	14	435.3930	10.1161	1.8%	0.754	7.54E-01
year quarter area gear bait ratio quarter*area	18	433.7332	11.7759	2.0%	0.859	8.59E-01
year quarter area gear bait ratio area*ratio	45	430.2305	15.2786	2.7%	1.000	1.00E+00
year quarter area gear bait ratio year*quarter	69	411.9234	33.5857	5.8%	1.000	1.00E+00
year quarter area gear bait ratio year*area	93	409.4018	36.1073	6.3%	1.000	1.00E+00
year quarter area gear bait ratio year*ratio	167	405.5115	39.9976	6.9%	1.000	1.00E+00

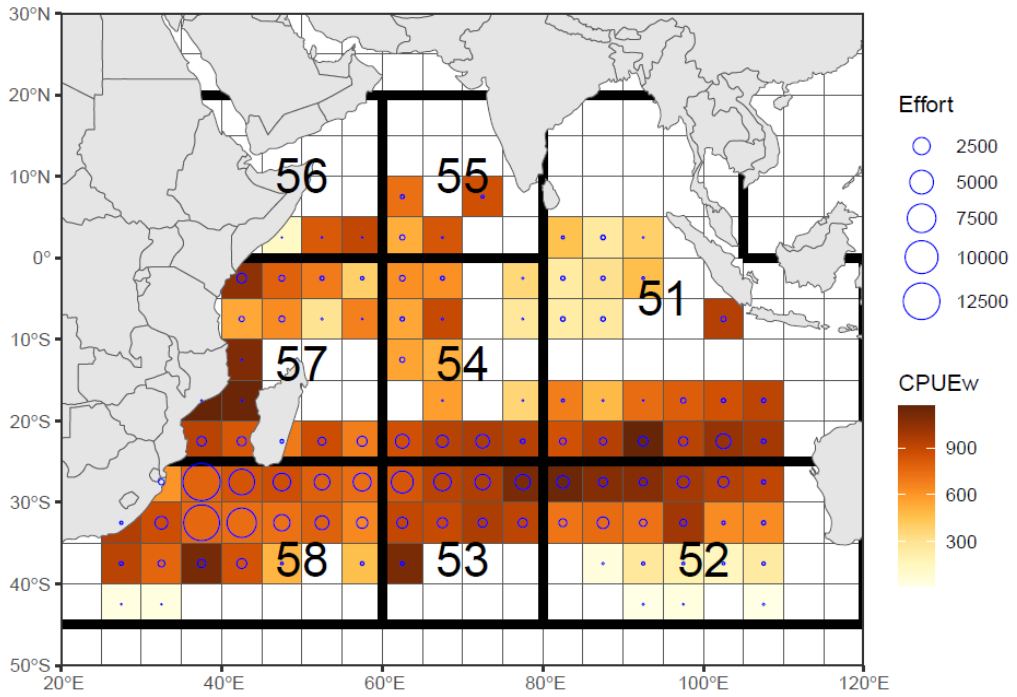

Figure 1. Geographical areas stratification used in the GLM for swordfish. Color scale represents the total nominal CPUE in kg round weight and circles represent the total effort (thousands of hooks) per 5x5 squares during the combined period 2001-2024.

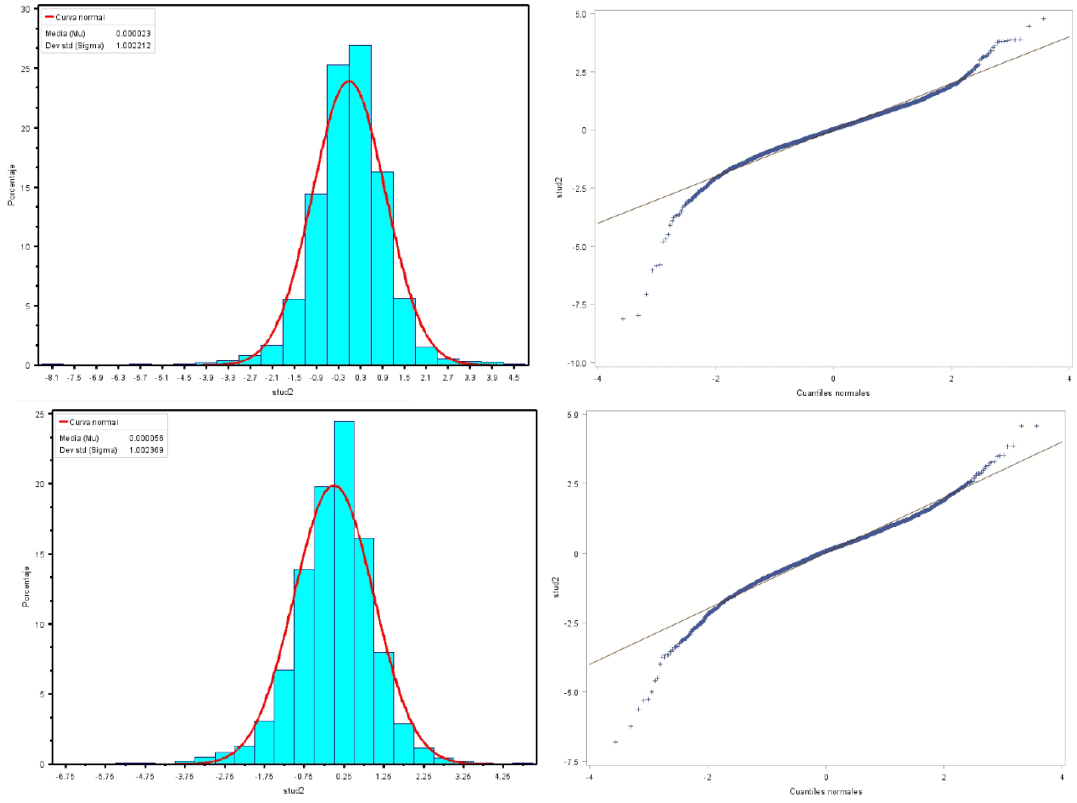

Figure 2. Distribution of the standardized residuals and normal probability qq-plot of swordfish in the Indian Ocean for years 2001-2024 combined. Upper in number and lower in weight.

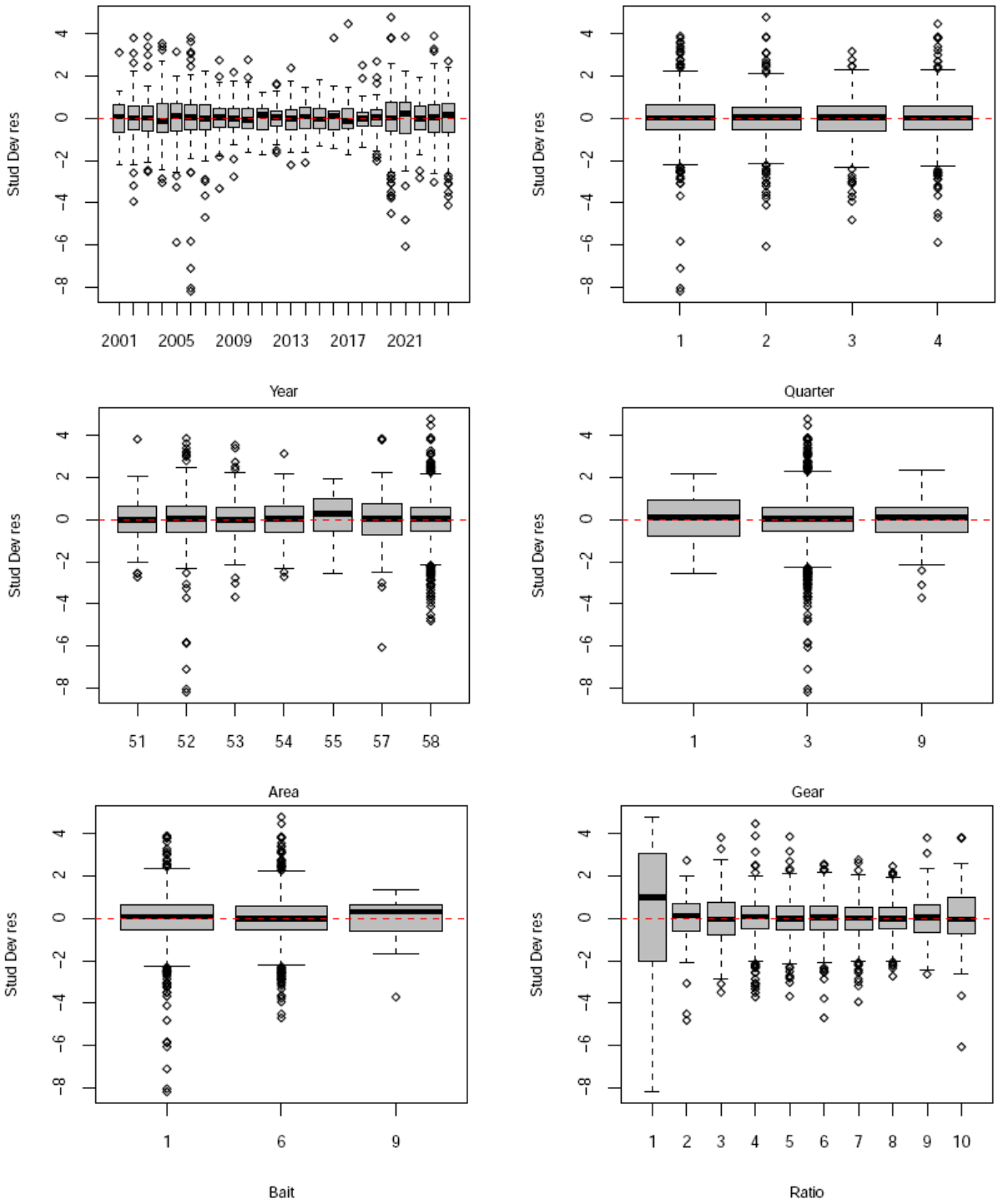

Figure 3. Box plots of standardized deviance residuals by explanatory variable from the GLM base case model for swordfish abundance (number of individuals) in the Indian Ocean.

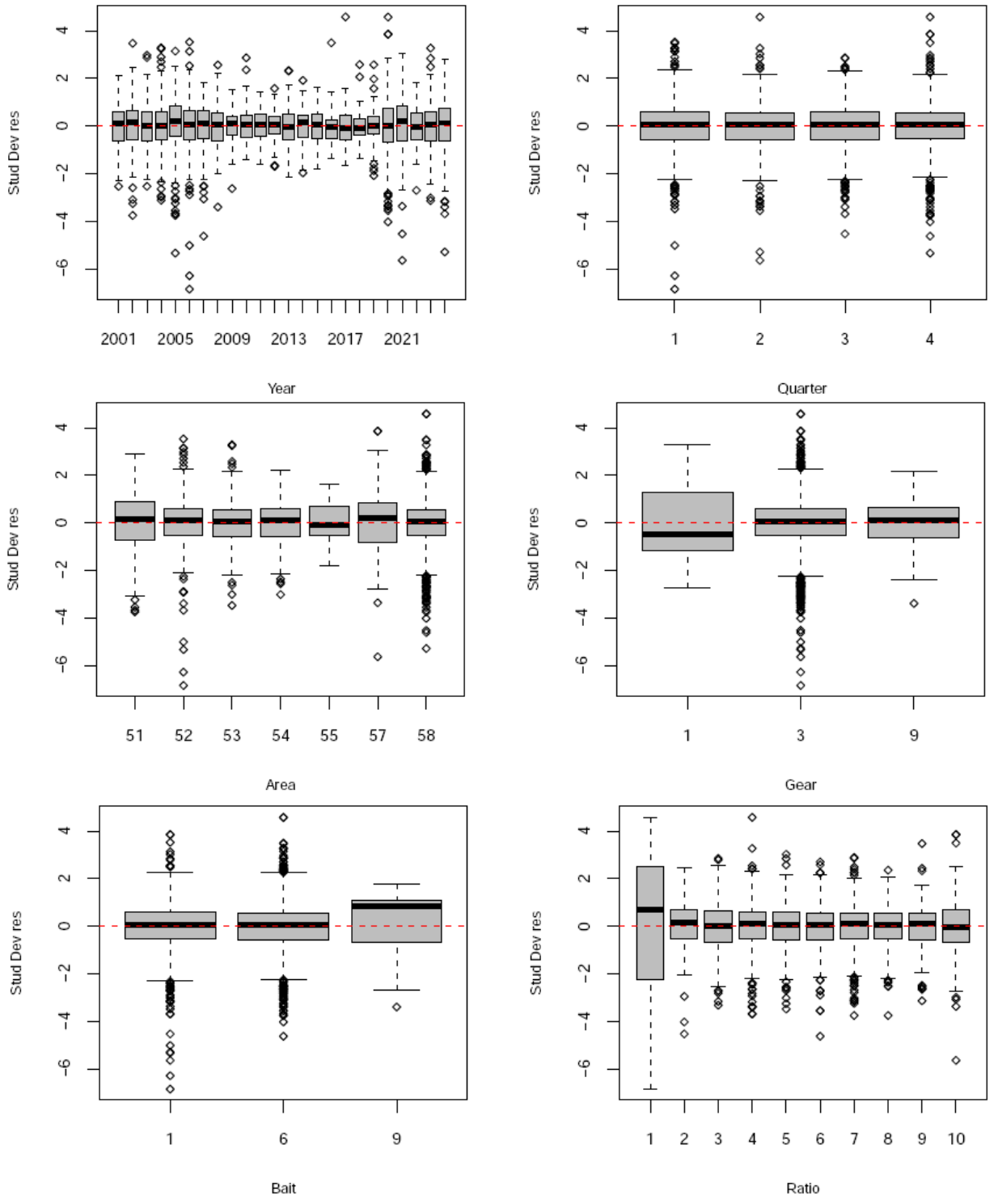

Figure 4. Box plots of standardized deviance residuals by explanatory variable from the GLM base case model for swordfish abundance (kg round weight) in the Indian Ocean.

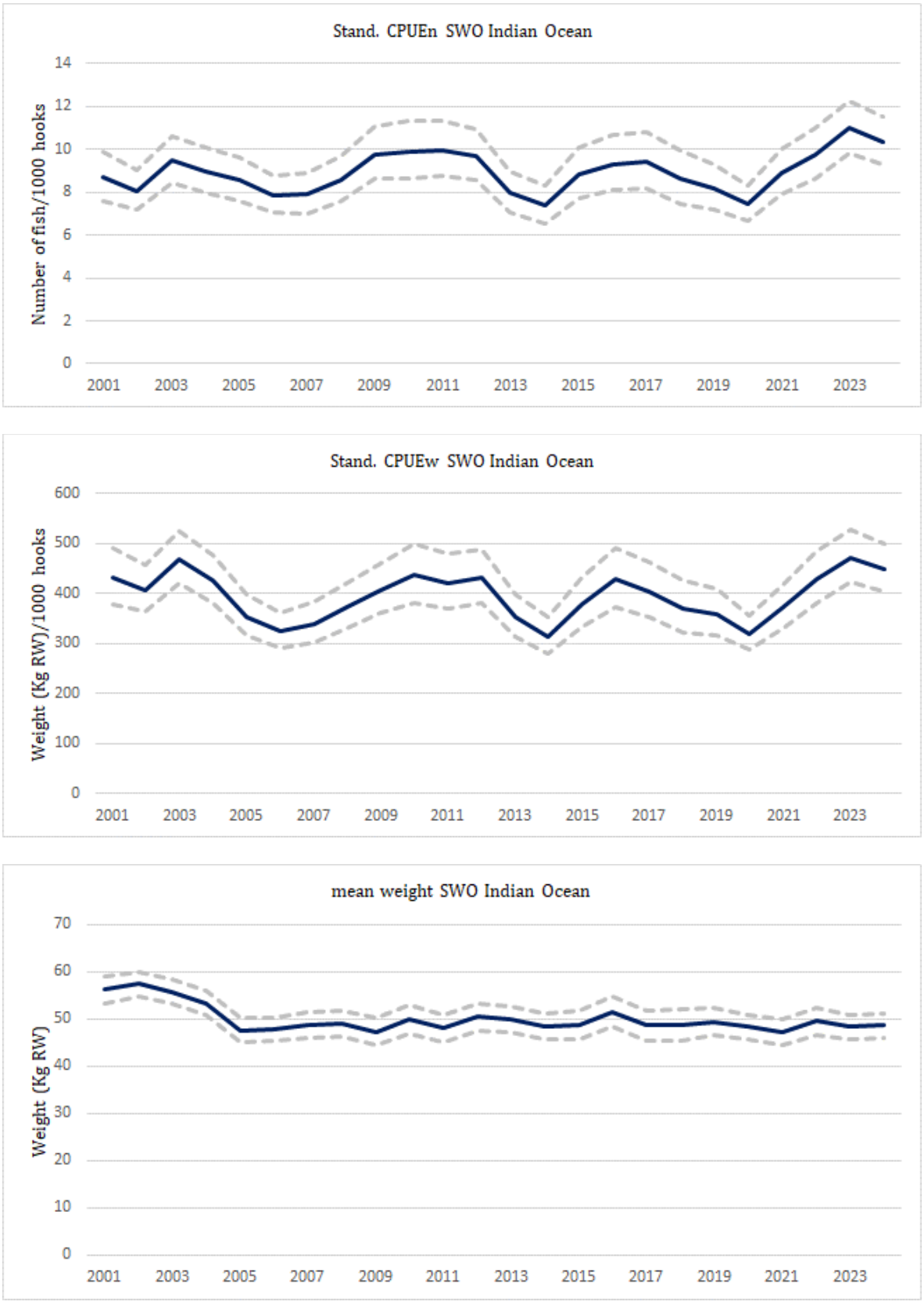

Figure 5. Standardized CPUEs per thousand hooks, in number of fish (upper), in kilograms round weight (middle) and standardized mean round weight in kilograms (lower) of swordfish and their respective confidence intervals (95%) observed in the Spanish surface longline fleet during the period analyzed (2001-2024) in the Indian Ocean.

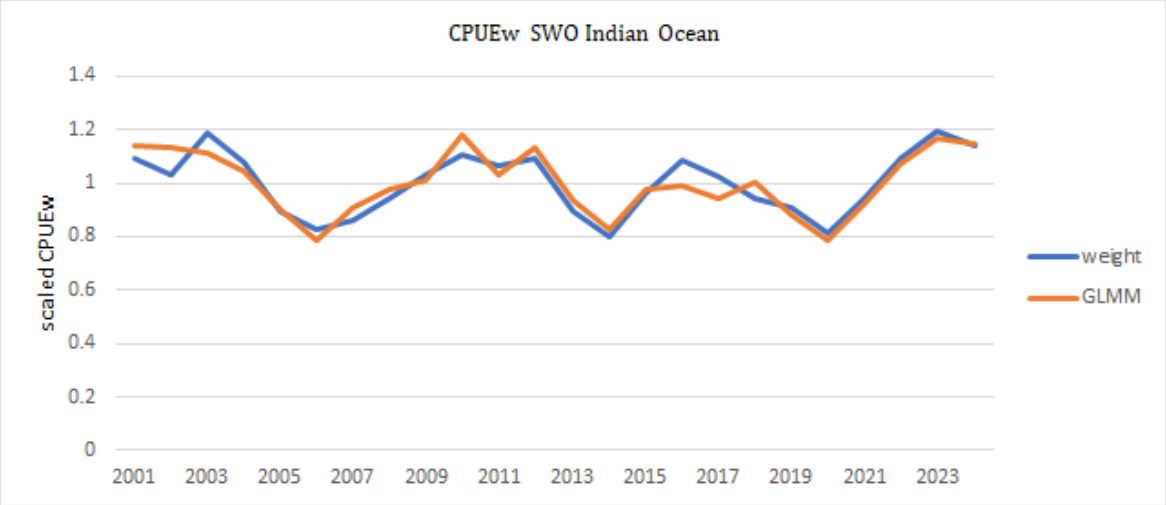

Figure 6. Comparison of scaled standardized swordfish CPUE (kg round weight) in the Indian Ocean estimated using the GLM and GLMM approaches for the period 2001–2024.

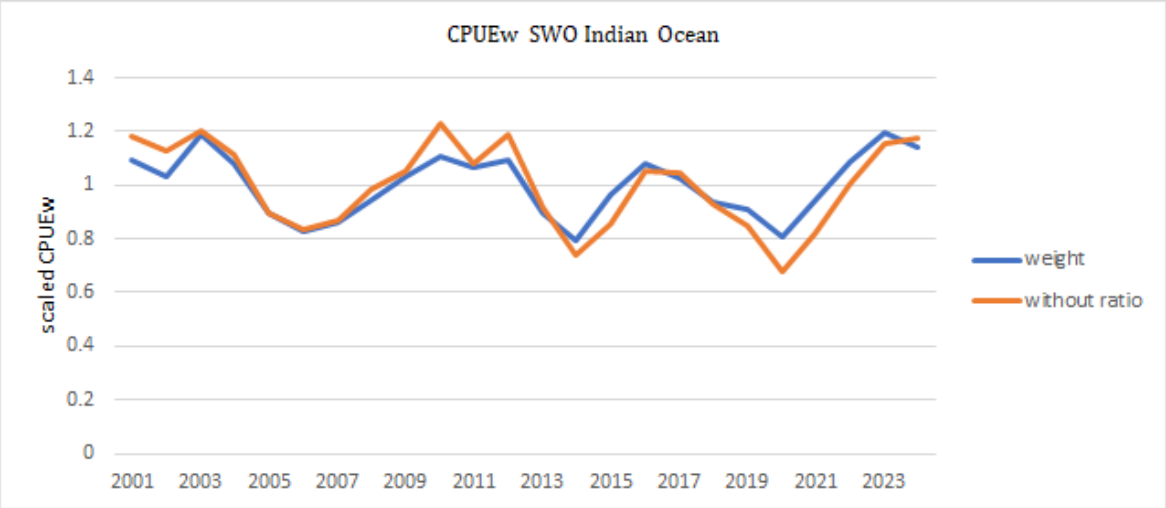

Figure 7. Comparative of scaled standardized swordfish CPUE (kg round weight) in the Indian Ocean for the period 2001-2024, with and without inclusion of the *ratio* factor.