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UPDATED STANDARDIZED CATCH RATES FOR SOUTH ATLANTIC STOCK OF SWORDFISH (*Xiphias gladius*) FROM THE SPANISH LONGLINE FLEET FOR THE PERIOD 1989-2019

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SUMMARY

Updated standardized catch rates in number and in weight were obtained using General Linear Modeling (GLM) procedures from trips carried out by the Spanish surface longline fleet targeting swordfish in the South Atlantic stock during the period 1989-2019. The criteria used to define factors were similar to those used in previous contributions. The results explained 65% and 71% of CPUE variability in number and weight, respectively, pointing to very stable standardized CPUE and mean weight trends over time. The statistical diagnoses were highly satisfactory.

RÉSUMÉ

Les taux de capture standardisés actualisés en nombre et en poids ont été obtenus à l'aide de procédures de modélisation linéaire généralisée (GLM) à partir de marées réalisées par la flottille palangrière de surface espagnole ciblant l'espadon du stock de l'Atlantique Sud pendant la période 1989-2019. Les critères utilisés pour définir les facteurs étaient similaires à ceux utilisés dans les contributions antérieures. Les résultats expliquaient 65% et 71% de la variabilité de la CPUE en nombre et en poids, respectivement, indiquant des tendances de la CPUE standardisée et du poids moyen très stables au fil du temps. Les diagnostics statistiques ont été hautement satisfaisants.

RESUMEN

Se actualizan tasas de captura normalizadas usando técnicas de Modelo Lineal Generalizado (GLM) a partir de mareas realizadas por la flota española de palangre de superficie dirigida a pez espada en el stock del Atlántico Sur durante el período 1989-2019. El modelo usado explicó el 65% y 71% de la variabilidad de la CPUE en número y en peso, respectivamente. Los resultados sugieren tendencias estables de la CPUE y del peso medio estandarizado a lo largo de la serie analizada. Los diagnósticos estadísticos resultaron altamente satisfactorios.

KEYWORDS

Swordfish, CPUE, GLM, Abundance, Longline

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1. Introduction

With the gradual introduction of on-board freezing systems in the 1980s, the surface longline fleet targeting swordfish was able to expand its activity to warm and more distant areas in the Atlantic. This fleet targeting swordfish started its activity in areas of the South Atlantic stock in 1986. At the beginning, the gear configuration of this fleet was relatively stable and remained so for several decades using the multifilament-traditional mainline style, but an important change occurred in the early 2000s when the multifilament surface longline was rapidly replaced by the American-style monofilament, which continues to be the preferred choice of gear at present (Mejuto *et al.* 1997, 1998, 1999, 2000, 2001, 2002, 2011; Mejuto and De la Serna 1995, 1997, 2000; Garcia-Cortés *et al* 2010).

The target species of this fleet was traditionally swordfish but the new freezing systems introduced, changes in market´s value of the two most abundant species (swordfish and blue shark) and other factors have allowed the skippers to move towards full retention on board of a combination of swordfish and blue shark. This change in fishing strategy has taken place in recent periods of the activity. The impact of these changes on the fishing strategy in several longline fleets targeting swordfish and other species has already been described in abundant literature and also considered in the recent standardized CPUE analysis of this fleet (e.g. Mejuto and De la Serna 2000, Mejuto *et al* 2000, 2011, García-Cortés *et al* 2010, 2017, Ramos-Cartelle *et al* 2014, 2017) as well as it has been assessed by the SCRS Methods Working Group (Anon. 2001).

The most common method for standardizing catch and effort data from commercial longline fleets 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. Catch-per-unit-effort (CPUE) data from fishery-dependent data (commercial fishing operations) have traditionally been used as the main source of information in order to obtain the relative index of abundance used in the fish stock assessment. This index may be considered in some cases to be an indicator of changes in abundance over time (Maunder and Punt 2004, Maunder *et al.* 2006).

The aim of the present document is to update the standardized CPUE series previously provided for the assessment of South Atlantic swordfish stock.

2. Material and methods

The trip records used were voluntarily provided by the Spanish surface longline fleet targeting swordfish in the South Atlantic stock during 1989-2019 period. The standardized CPUE in number of fish caught and in weight (kg round weight) for the period 1989-2019 was updated using GLM and MIXED procedures (*SAS 9.4*) assuming in the analysis the same approach, factors and the combination of factors already employed in previous analyses (Ramos-Cartelle *et al.* 2014, 2017):

$$\text{GLM: } Ln\,(CPUE) = u + Y + Q + A + R + G + B + A*Q + e.$$
$$\text{MIXED: } Ln\,(CPUEw) = u + Y + Q + A + R + G + e$$

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 for each available trip record as an indicator of the target criteria of the skipper, expressed as the percentage of swordfish by weight related to the catches in weight of swordfish and blue shark combined, classified in ten categories at 10% intervals (Mejuto and De la Serna 2000, Anon 2001), G = *gear* effect (1: traditional multifilament, 3: American-style monofilament), B= *bait* type (1: mackerel, 6: squid and 9: other types or combinations) and e = logarithm of the normally distributed error term. The symbol * represents the interactions between factors.

The standardized mean weight of swordfish per year and the confidence intervals were also obtained using GLM. The methods and specifications were consistent with previous analyses (e.g. Mejuto *et al.* 2000, 2001, 2010; Ramos-Cartelle *et al.* 2014, 2017).

3. Results and discussion

A total number of 7,768 trip observations (323.2 x 10^6 hooks) were available for the period 1989-2019. Spatial and temporal coverage of the observations is sufficiently representative. Some spatial-temporal cells were scarcely represented at the beginning of the time series due to the progressive geographical entry and expansion of this fleet in areas of the South Atlantic stock. **Figure 1** shows the geographical definition of the *area* factor used in the present analysis and a summary of the area-coverage (5ºx5º) of the information considered for the whole period.

Table 1 provides a summary of the ANOVA results from GLM procedures. These significantly defined models explained 65% and 71% of CPUE variability in number and weight, respectively. Most CPUE variability (Type III SS) may be attributed to the type of trip categorized, expressed as a *ratio* factor, as would be expected and described in previous results from North and South Atlantic analyses of different longline fleets. Other factors considered, such as *gear*, *year* or *area*, were also quite important but much less significant. The *year* and *area* factors seem to be qualitatively different in terms of explaining the variability of CPUE in number or weight.

Tables 2 and 3 provide information on estimated parameters (lsmean), their standard error, CV (%), standard CPUE and upper and lower 95% confidence limits, in number of fish and in weight. The frequency distribution of the standardized residuals, years combined, follows a normal pattern. The fit of the model seems not to be biased and residuals are normally distributed. The qq-plots were highly satisfactory (**Figure 2**). **Figures 3** and **4** show the variability box-plot of the main factors for standardized CPUE in number and in weight respectively.

The standardized CPUEs obtained per year were also plotted as well as the standardized mean weight and their respective confidence intervals (**Figure 5**). The analyses are consistent in number and in weight showing a stable trend of CPUE between 1993 and 2004. After 2004 the overall outlook of relative abundance indices shows a slight but sustained upward trend in both series. The standardized mean round weight shows a stable trend from the beginning of the nineties onwards.

The MIXED model was run as a sensitivity analysis. The standardized CPUE in kg round weight obtained from the MIXED procedure was scaled to compare it with the scaled standardized CPUE base case, both trends being very similar (**Figure 6**).

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Table 1. Summary of ANOVA for each CPUE analysis, in number (upper) and in weight (lower).

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

Source	DF	Sum of Squares	Mean Square	F Value	Pr > F
Model	61	2418.851874	39.653309	234.79	<.0001
Error	7706	1301.449900	0.168888		
Corrected Total	7767	3720.301775			

R-Square	Coeff Var	Root MSE	cpue1 Mean
0.650176	18.8756	0.41096	2.177201

Source	DF	Type III SS	Mean Square	F Value	Pr > F
year	30	65.965519	2.198851	13.02	<.0001
quarter	3	2.325935	0.775312	4.59	0.0032
area	4	22.327672	5.581918	33.05	<.0001
gear	1	161.270769	161.270769	954.90	<.0001
bait	2	0.776211	0.388105	2.30	0.1005
ratio	9	1246.734562	138.526062	820.23	<.0001
quarter*area	12	15.883557	1.323630	7.84	<.0001

South Atlantic stock CPUE in weight
Dependent variable: ln (CPUEw)

Source	DF	Sum of Squares	Mean Square	F Value	Pr > F
Model	61	2845.779504	46.652123	304.12	<.0001
Error	7706	1182.108508	0.153401		
Corrected Total	7767	4027.888012			

R-Square	Coeff Var	Root MSE	cpue1 Mean
0.706519	6.44852	0.391664	6.073711

Source	DF	Type III SS	Mean Square	F Value	Pr > F
year	30	73.139589	2.437986	15.89	<.0001
quarter	3	6.021854	2.007285	13.09	<.0001
area	4	84.640880	21.160220	137.94	<.0001
gear	1	150.027277	150.027277	978.01	<.0001
bait	2	0.183437	0.091718	0.60	0.5500
ratio	9	1442.656731	160.295192	1044.94	<.0001
quarter*area	12	16.595318	1.382943	9.02	<.0001

Table 2. Estimated parameters (Lsmean), standard error (Stderr), CV%, standardized CPUE in number (CPUEn) of swordfish and upper and lower 95% confidence limits.

Year	Lsmean	Stderr.	CV%	UCPUEn	Mean CPUEn	LCPUEn
1989	2.245410	0.055592	2.475806	10.54780	9.45886	8.48238
1990	1.937580	0.038693	1.996976	7.49450	6.94712	6.43974
1991	1.947930	0.035654	1.830353	7.52660	7.01862	6.54489
1992	1.846750	0.032241	1.745824	6.75620	6.34249	5.95409
1993	1.742990	0.027085	1.553939	6.02820	5.71652	5.42096
1994	1.935660	0.028041	1.448653	7.32290	6.93133	6.56065
1995	2.102490	0.027656	1.315393	8.64580	8.18962	7.75751
1996	1.976260	0.026436	1.337678	7.60210	7.21820	6.85371
1997	1.945140	0.023198	1.192613	7.32190	6.99647	6.68548
1998	1.936420	0.025591	1.321562	7.29290	6.93616	6.59684
1999	1.973310	0.026712	1.353665	7.58390	7.19703	6.82993
2000	2.177970	0.028669	1.316317	9.34250	8.83201	8.34941
2001	2.016090	0.024770	1.228616	7.88490	7.51125	7.15529
2002	1.959090	0.025526	1.302952	7.45920	7.09518	6.74894
2003	1.871600	0.027795	1.485093	6.86520	6.50121	6.15651
2004	1.886100	0.035355	1.874503	7.07120	6.59776	6.15604
2005	2.058470	0.034216	1.662205	8.38230	7.83856	7.33012
2006	2.060450	0.033368	1.619452	8.38470	7.85386	7.35665
2007	2.025000	0.034206	1.689185	8.10620	7.58056	7.08899
2008	1.969090	0.030749	1.561584	7.61280	7.16753	6.74831
2009	2.053440	0.029334	1.428530	8.25950	7.79802	7.36232
2010	2.058990	0.030777	1.494762	8.32940	7.84180	7.38275
2011	2.018900	0.029822	1.477141	7.98680	7.53339	7.10568
2012	2.078750	0.032855	1.580517	8.53090	7.99881	7.49994
2013	2.063420	0.034088	1.652015	8.42170	7.87743	7.36830
2014	2.064940	0.035130	1.701260	8.45210	7.88971	7.36474
2015	2.159650	0.036186	1.675549	9.31130	8.67378	8.07991
2016	2.223440	0.039153	1.760920	9.98370	9.24617	8.56317
2017	2.202910	0.038061	1.727760	9.75940	9.05783	8.40671
2018	2.076030	0.034454	1.659610	8.53480	7.97747	7.45654
2019	2.097100	0.029885	1.425063	8.63750	8.14614	7.68270

Table 3. Estimated parameters (Lsmean), standard error (Stderr), CV%, standardized CPUE in kg round weight (CPUEw) of swordfish and upper and lower 95% confidence limits.

Year	Lsmean	Stderr.	CV%	UCPUEw	Mean CPUEw	LCPUEw
1989	6.257910	0.052982	0.846640	580.073	522.857	471.286
1990	5.981550	0.036876	0.616496	426.030	396.324	368.689
1991	5.952270	0.033980	0.570875	411.353	384.849	360.053
1992	5.855400	0.030728	0.524781	370.962	349.279	328.865
1993	5.710190	0.025814	0.452069	317.704	302.030	287.129
1994	5.846020	0.026725	0.457149	364.583	345.977	328.321
1995	5.980030	0.026358	0.440767	416.562	395.588	375.670
1996	5.872770	0.025195	0.429014	373.332	355.344	338.223
1997	5.822230	0.022109	0.379734	352.768	337.808	323.483
1998	5.794340	0.024389	0.420911	344.619	328.532	313.197
1999	5.873330	0.025458	0.433451	373.736	355.546	338.241
2000	6.063220	0.027323	0.450635	453.569	429.918	407.500
2001	5.941230	0.023607	0.397342	398.530	380.510	363.305
2002	5.898490	0.024327	0.412428	382.402	364.596	347.620
2003	5.770800	0.026490	0.459035	338.010	320.908	304.672
2004	5.743760	0.033695	0.586637	333.741	312.412	292.446
2005	5.937430	0.032610	0.549228	404.187	379.162	355.686
2006	5.945550	0.031801	0.534871	406.827	382.244	359.146
2007	5.917170	0.032600	0.550939	396.073	371.557	348.559
2008	5.883850	0.029306	0.498075	380.590	359.345	339.287
2009	5.973540	0.027957	0.468014	415.185	393.047	372.089
2010	5.944550	0.029332	0.493427	404.427	381.832	360.500
2011	5.912940	0.028421	0.480658	391.133	369.940	349.896
2012	5.976900	0.031313	0.523900	419.375	394.411	370.932
2013	5.985280	0.032488	0.542798	423.894	397.743	373.206
2014	6.032160	0.033481	0.555042	445.119	416.847	390.371
2015	6.109180	0.034487	0.564511	481.723	450.238	420.810
2016	6.196190	0.037315	0.602225	528.489	491.217	456.573
2017	6.171610	0.036274	0.587756	514.585	479.270	446.378
2018	6.042650	0.032836	0.543404	449.235	421.234	394.977
2019	6.037800	0.028482	0.471728	443.203	419.139	396.382

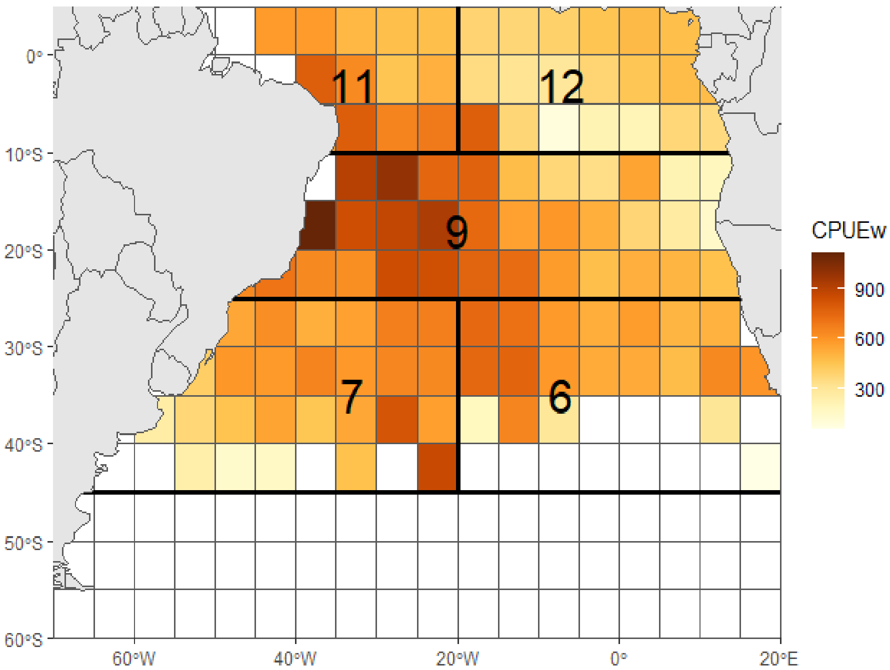

Figure 1. Area-definition used for the CPUE standardization of the Spanish surface longline fleet in the South Atlantic, during the whole period 1989-2019. Scale color represents a summary of the squares observed over time and the observed nominal CPUEw (kg RW/1000 hooks) per 5ºx5º square years combined.

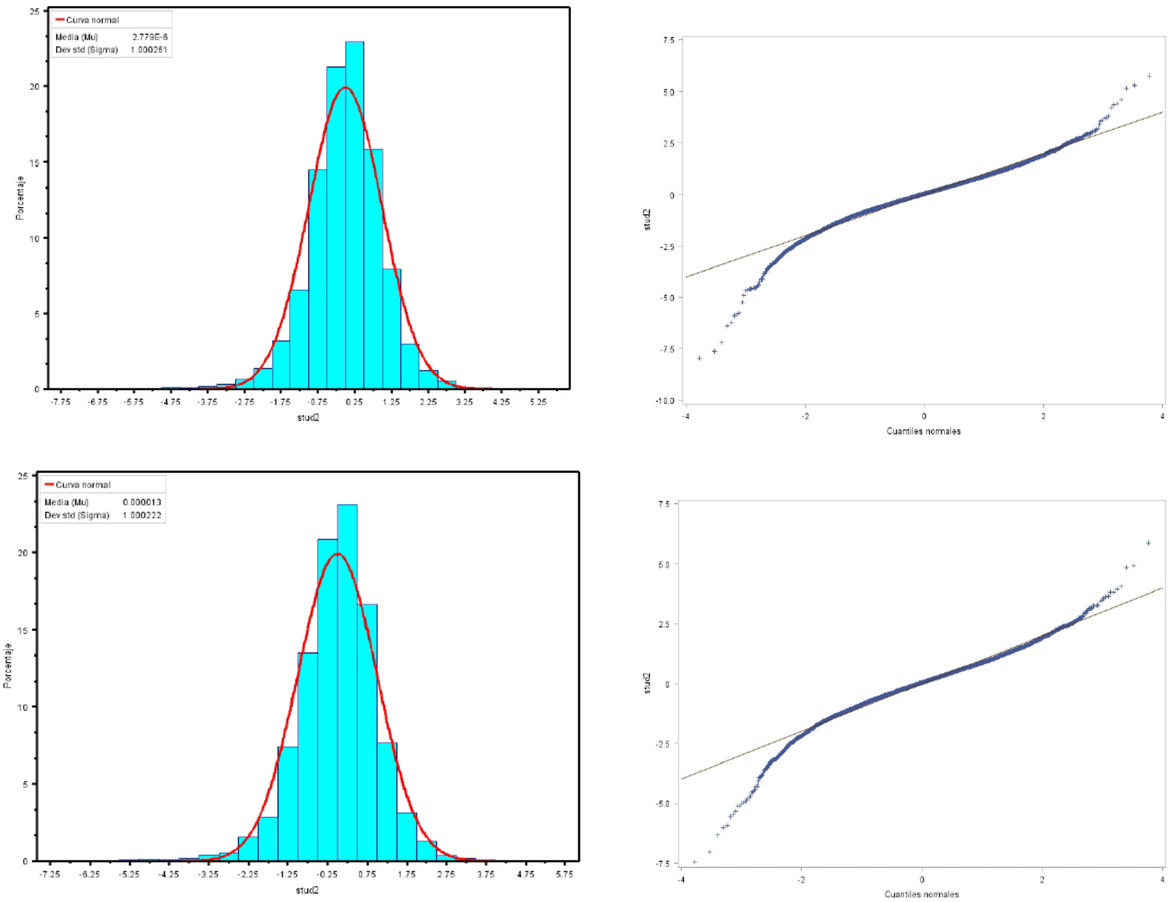

Figure 2. Frequency distribution of the standardized residuals, years combined, and normal probability qq-plot in number (upper) and in weight (lower).

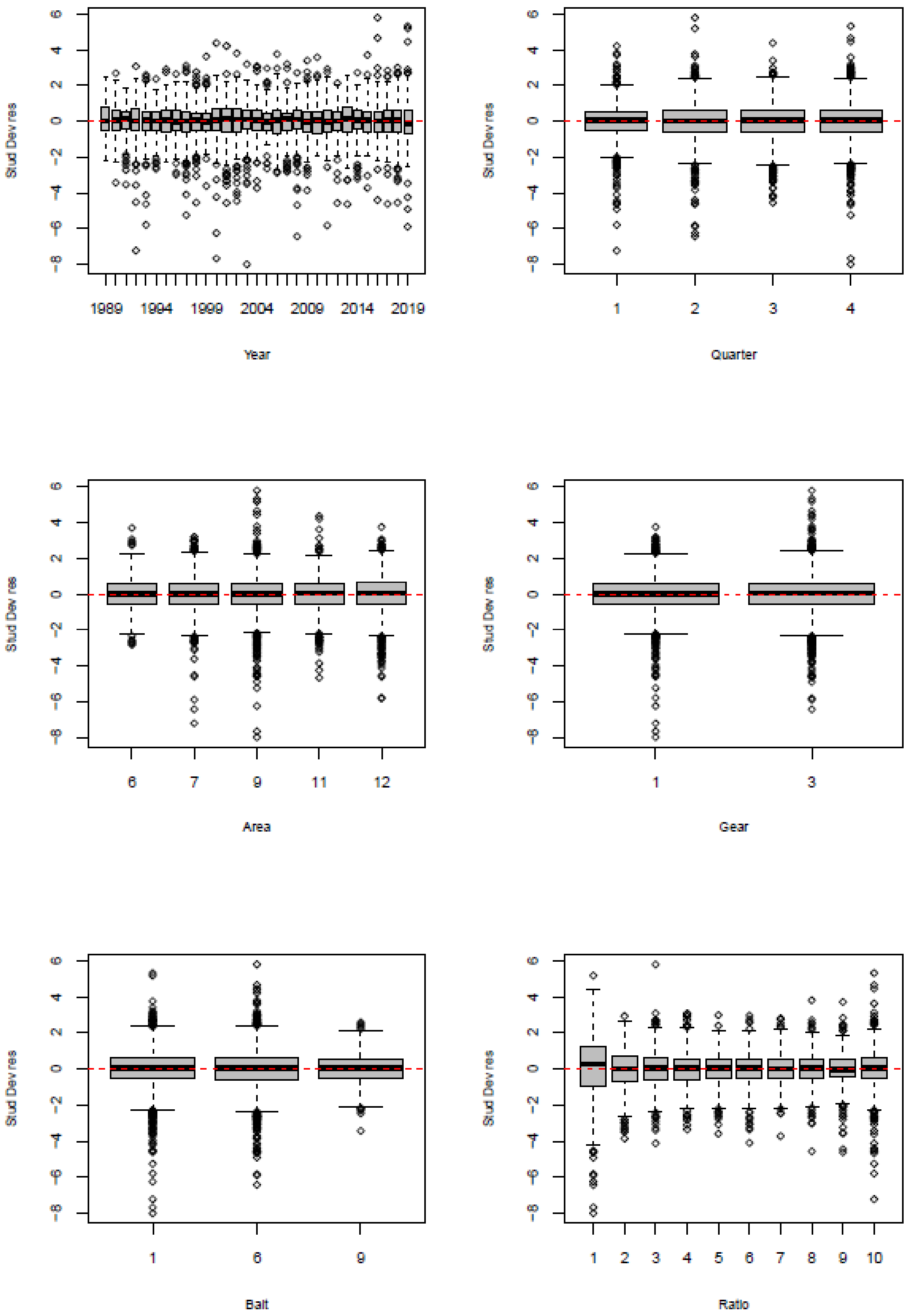

Figure 3. Standardized deviance residuals *versus* explanatory variables obtained for GLM of the standardized CPUE in number of fish.

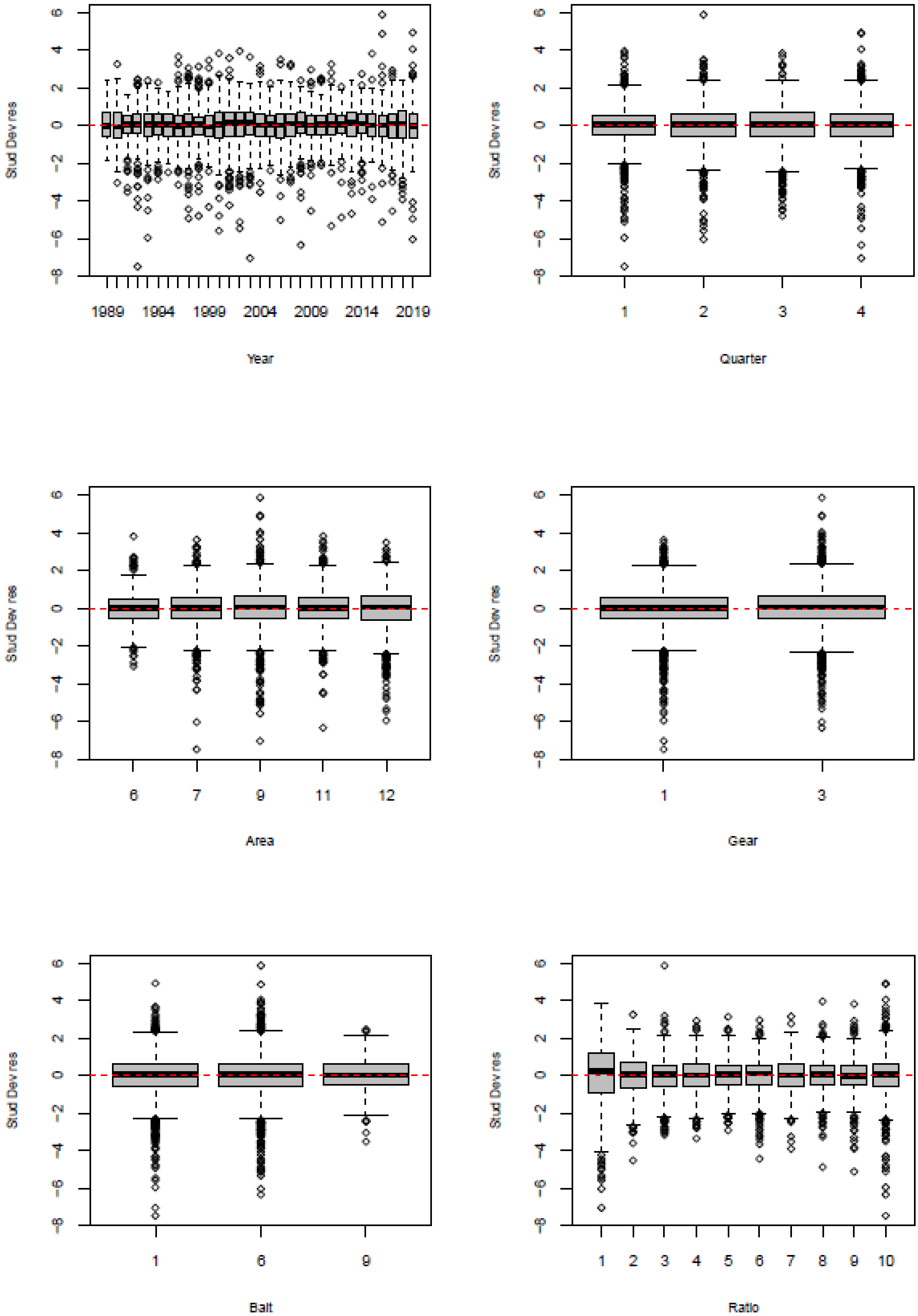

Figure 4. Standardized deviance residuals *versus* explanatory variables obtained for the GLM of the standardized CPUE in weight.

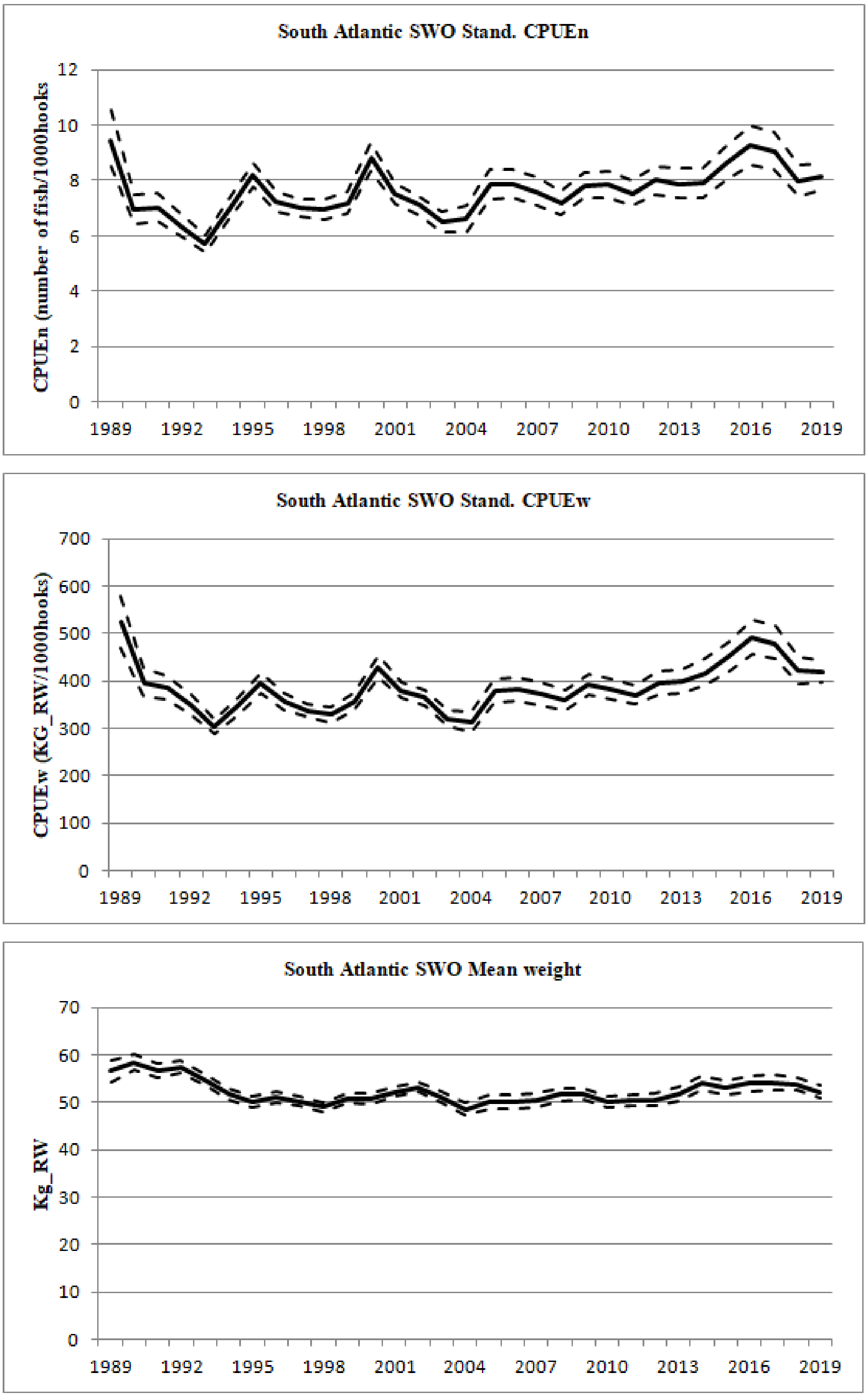

Figure 5. Standardized CPUEs per thousand hooks and 95% CIs: in number of fish (upper), in kilograms round weight (middle). Standardized mean round weight in kilograms and 95% CIs (lower).

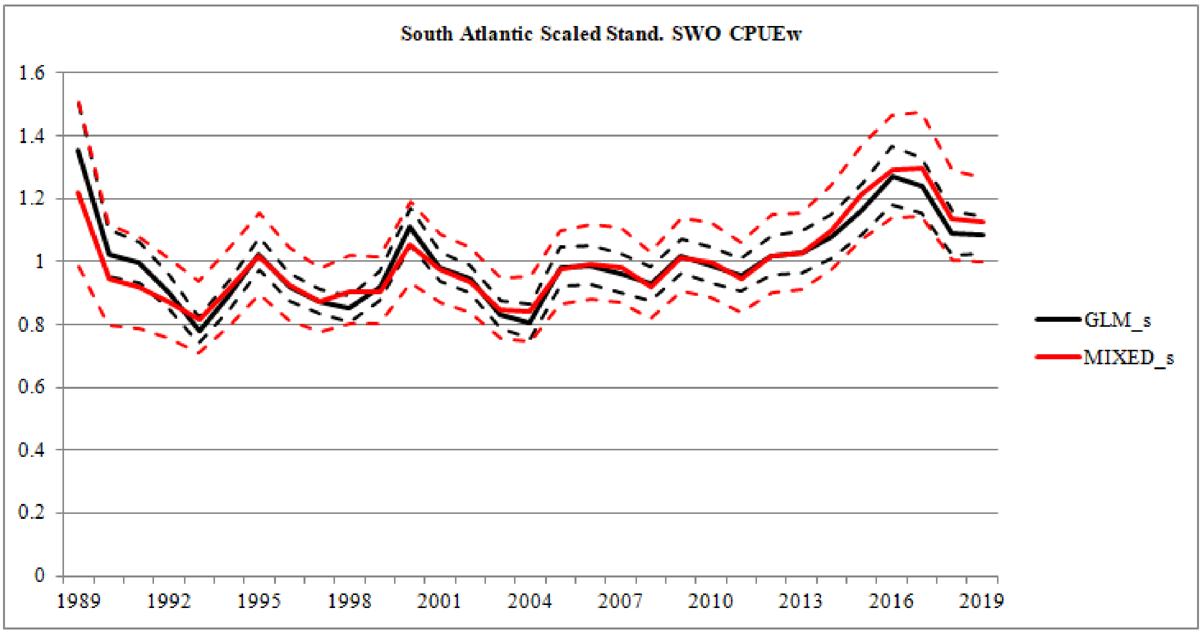

Figure 6. Comparative scaled standardized CPUEw GLM *versus* MIXED (and their respective confidence intervals) obtained in the South Atlantic stock for the 1989-2019 period. Both series are scaled from their respective mean values.