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UPDATED STANDARDIZED CATCH RATES FOR SOUTH ATLANTIC STOCK OF SWORDFISH (*XIPHIAS GLADIUS*) FROM THE SPANISH LONGLINE FLEET FOR THE PERIOD 1989-2015

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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 fishing the South Atlantic swordfish stock during the period 1989-2015. The criteria used to define factors were similar to those used in previous papers as were the models applied. 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, with a slight increase of abundance in the last year analyzed. The statistical diagnoses were highly satisfactory.

RÉSUMÉ

Les taux de capture standardisés mis à jour en nombre et en poids ont été obtenus à l'aide de procédures de modèle linéaire généralisé (GLM) à partir de sorties réalisées par la flottille palangrière de surface espagnole qui pêchait le stock d'espadon de l'Atlantique Sud pendant la période allant de 1989 à 2015. Les critères utilisés pour définir les facteurs étaient similaires à ceux utilisés dans les documents précédents, tout comme les modèles appliqués. Les résultats expliquent respectivement 65% et 71% de la variabilité de la CPUE en nombre et en poids, indiquant des tendances de CPUE standardisées et de poids moyen très stables dans le temps, avec une légère augmentation de l'abondance au cours de la dernière année analysée. Les diagnostics statistiques étaient extrêmement 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 sobre el stock de pez espada del Atlántico Sur para el período 1989-2015. El modelo usado explicó el 65% y 71% de la variabilidad de la CPUE en número y peso, respectivamente. Los resultados sugieren tendencias estables de la CPUE y del peso medio estandarizado a lo largo de la serie analizada, con un ligero incremento de la abundancia en el año 2015. Los diagnósticos estadísticos resultaron altamente satisfactorios.

KEYWORDS

Swordfish, CPUE, GLM, Longline

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1. Introduction

Spanish distant water longline vessels targeting swordfish started their activity in the South Atlantic stock in 1986 with traditional multifilament gear. At the end of the last century a new monofilament surface longline was introduced -the American style- which continues to be the preferred gear at present (Mejuto *et al*. 1997, 1998, 1999, 2000, 2001, 2002; Mejuto and De la Serna 1995, 1997, 2000; García-Cortés *et al*. in press).

The target species of this fleet was traditionally swordfish, but this strategy has moved towards a combination of swordfish and blue shark as the most valuable species during more recent periods. The impact of some of these changes on the fishing strategy of this fleet has already been described and considered in recent papers and compared with the results obtained using traditional approaches (Mejuto and De la Serna 2000, Mejuto *et al*. 2000, 2011, García-Cortés *et al*. 2010, in press).

Stock assessments commonly require at least indices of abundance and a catch data series. The Generalized Linear Modeling technique (GLM) (Robson 1966, Gavaris 1980, Kimura, 1981) was used as a routine instrument in the estimation of standardized catch rates based on data from commercial longline fleets. The aim of this document is to update the standardized CPUE series previously provided for this swordfish stock. The present GLM study was applied to trip data for the period between 1989 and 2015.

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 1989-2015.

The standardized CPUE in number of fish caught and in weight (kg round weight) for the period 1989-2015 was updated using GLM 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):

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

Where: u = overall mean, Y = *year* effect, Q =time effect (*quarters*), A = *area* effect, R = type of trip (*ratio*), G= *gear* style effect, B= *bait* type. The definition of *Quarters* was as follows: Q1 = January, February, March; Q2 = April, May, June; Q3 = July, August, September; Q4 = October, November and December, e = logarithm of the normally distributed error term. The variable type of trip or *ratio* was defined for each available trip record as the percentage of swordfish in weight related to swordfish and blue shark combined classified in 10% intervals to reflect the criteria of the skippers regarding the two potentially desirable main species (Mejuto and De la Serna 2000, Mejuto *et al.* 2000, 2001, 2002, 2010). Two levels of *gear* type were identified: 1 = traditional multifilament main line and 3 = new monofilament, American style. Three *bait* types were considered: 1 = mackerel, 6 = squid and 9 = other types or combinations. The interaction *area***quarter* was also included, as in previous analyses. The final runs were done considering 5 areas (**Figure 1**).

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).

To allow some of the parameters in the linear prediction to be considered as random variables (Maunder and Punt 2004), a sensitivity analysis was also performed as a further and more fundamental extension of the GLM technique using MIXED procedure: Ln (CPUE) = u + Y + Q + A + R + G + e.

3. Results and discussion

A total number of 7,028 trip observations were available for the period 1989-2015. Spatial and temporal coverage of the observations is sufficiently representative. However, 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 the South Atlantic stock.

Table 1 provides a summary of the ANOVA results from GLM procedures. The significant 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, expressed as a *ratio* factor, as would be expected and as observed in previous results from North and South Atlantic analyses of different 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.

Table 2 provides 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, shows a normal shape. 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 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 analysis shows an overall stable trend of CPUE in both number and weight with an almost identical trend for both during the whole period observed, there being a slight increase in abundance in the last year analyzed. In the standardized mean weights important multi-annual phases were not initially detected.

The factors and interactions with >= 5.0% of deviance explained were considered in the sensitivity analysis (**Table 3**). The MIXED model run was similar to the GLM model, although it was not necessary to introduce the bait factor or any interaction. Any significant difference was observed between both runs (GLM *vs* MIXED). The standardized CPUE obtained from the sensitivity analysis 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 ANOVAs for each CPUE analysis, in number (upper) and in weight (lower).

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

Source	DF	Sum of Squares	Mean Square	F Value	Pr > F
Model	57	2105.142850	36.93231	231.19	<.0001
Error	6970	1113.455172	0.15975		
Corrected Total	7027	3218.598022			

R-Square	Coeff Var	Root MSE	cpue1 Mean
0.654056	18.45879	0.399687	2.165294

Source	DF	Type III SS	Mean Square	F Value	Pr > F
year	26	56.307105	2.165658	13.56	<.0001
quarter	3	1.474704	1.390568	8.70	<.0001
area	4	17.014543	4.253636	26.63	<.0001
gear	1	153.702923	153.702923	962.15	<.0001
bait	2	1.636624	0.818312	5.12	0.0060
ratio	9	1013.126624	112.569633	704.66	<.0001
quarter*area	12	17.074541	1.422878	8.91	<.0001

South Atl. CPUE in weight
Dependent variable: ln (CPUEw)

Source	DF	Sum of Squares	Mean Square	F Value	Pr > F
Model	57	2471.395781	43.357820	297.23	<.0001
Error	6970	1016.738340	0.145874		
Corrected Total	7027	3488.134105			

R-Square	Coeff Var	Root MSE	cpue1 Mean
0.708515	6.305403	0.381934	6.057248

Source	DF	Type III SS	Mean Square	F Value	Pr > F
year	26	54.595169	2.099814	14.39	<.0001
quarter	3	6.432817	2.144272	14.70	<.0001
area	4	79.289492	19.822373	135.89	<.0001
gear	1	143.691733	143.691733	985.04	<.0001
bait	2	0.616470	0.308235	2.11	0.1209
ratio	9	1177.290314	130.810035	896.74	<.0001
quarter*area	12	17.669522	1.472460	10.09	<.0001

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

Year	Lsmean	Stderr.	CV%	UcpueN	Mean CPUEN	LcpueN
1989	2.26734	0.054253	2.392804	10.753	9.668	8.693
1990	1.95317	0.037855	1.938131	7.599	7.056	6.551
1991	1.95904	0.034913	1.782148	7.995	7.097	6.627
1992	1.86091	0.031571	1.696536	6.434	6.432	6.047
1993	1.76126	0.026581	1.509204	6.332	5.821	5.526
1994	1.95442	0.027481	1.406095	7.533	7.062	6.692
1995	2.12002	0.027119	1.279186	8.894	8.334	7.903
1996	1.99708	0.025923	1.298045	7.754	7.370	7.005
1997	1.95106	0.022716	1.164290	7.358	7.038	6.731
1998	1.94413	0.025060	1.289008	7.342	6.990	6.655
1999	1.97279	0.026110	1.323506	7.571	7.193	6.834
2000	2.17649	0.027974	1.285280	9.319	8.819	8.348
2001	2.01597	0.024151	1.197984	7.874	7.510	7.163
2002	1.95830	0.024900	1.271511	7.444	7.089	6.752
2003	1.86672	0.027096	1.451530	6.822	6.469	6.135
2004	1.89214	0.034479	1.822222	7.101	6.637	6.204
2005	2.06093	0.033324	1.616940	8.388	7.858	7.361
2006	2.06324	0.032521	1.576210	8.394	7.876	7.389
2007	2.02033	0.033314	1.648938	8.054	7.545	7.068
2008	1.96186	0.030004	1.529365	7.547	7.116	6.709
2009	2.04547	0.028621	1.399238	8.182	7.736	7.314
2010	2.05433	0.030011	1.460866	8.278	7.805	7.359
2011	2.01358	0.029116	1.445982	7.933	7.493	7.078
2012	2.07478	0.032049	1.544694	8.483	7.967	7.482
2013	2.05250	0.033224	1.618709	8.316	7.792	7.300
2014	2.05535	0.034239	1.665848	8.356	7.814	7.307
2015	2.15535	0.035258	1.635836	9.254	8.636	8.060

Year	Lsmean	Stderr.	CV%	UcpueW	Mean CPUEW	LcpueW
1989	628.262	0.051843	0.825181	593.228	535.910	484.129
1990	600.054	0.036174	0.602845	433.586	403.909	376.264
1991	596.679	0.033362	0.559128	416.853	390.467	365.751
1992	587.099	0.030169	0.513865	376.371	354.761	334.392
1993	572.923	0.025400	0.443340	323.544	307.831	292.881
1994	586.444	0.026260	0.447783	371.018	352.405	334.725
1995	599.660	0.025914	0.432145	423.149	402.194	382.276
1996	589.294	0.024772	0.420367	380.620	362.581	345.397
1997	582.881	0.021707	0.372408	354.814	340.035	325.872
1998	580.311	0.023947	0.412658	347.348	331.422	316.226
1999	587.531	0.024950	0.424658	374.099	356.245	339.243
2000	606.395	0.026731	0.440818	453.365	430.224	408.263
2001	594.132	0.023078	0.388432	398.146	380.538	363.708
2002	589.698	0.023794	0.403495	381.421	364.041	347.453
2003	576.663	0.025893	0.449014	336.202	319.566	303.753
2004	574.891	0.032948	0.573117	334.968	314.020	294.382
2005	593.675	0.031843	0.536379	403.295	378.894	355.969
2006	594.654	0.031076	0.522590	406.642	382.613	360.003
2007	591.147	0.031834	0.538512	393.222	369.436	347.090
2008	587.530	0.028671	0.487992	376.871	356.277	336.808
2009	596.436	0.027350	0.458557	410.895	389.449	369.122
2010	593.839	0.028678	0.482926	401.420	379.479	358.737
2011	590.628	0.027822	0.471058	388.076	367.480	347.977
2012	597.168	0.030625	0.512837	416.618	392.346	369.488
2013	597.360	0.031748	0.531472	418.355	393.116	369.400
2014	602.247	0.032718	0.543265	440.158	412.817	387.175
2015	610.287	0.033692	0.552068	477.936	447.395	418.805

Table 3. Deviance table analyses of the factors tested in the MIXED model. 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	-	3488.1341				
Year	26	3146.3489	341.7852	13.6%	< 0.001	8.43E-57
Year Quarter	3	2934.4779	211.8710	8.4%	< 0.001	1.15E-45
Year Quarter Area	4	2698.3799	236.0980	9.4%	< 0.001	6.42E-50
Year Quarter Area Gear	1	2304.9471	393.4328	15.6%	< 0.001	1.48E-87
Year Quarter Area Gear Bait	2	2298.0840	6.8631	0.3%	0.032	3.23E-02
Year Quarter Area Gear Bait Ratio	9	1034.4079	1263.6761	50.1%	< 0.001	2.16E-266
Year Quarter Area Gear Bait Ratio Gear*Bait	2	1033.5418	0.8661	0.0%	0.649	6.49E-01
Year Quarter Area Gear Bait Ratio Area*Bait	8	1031.7918	2.6161	0.1%	0.956	9.56E-01
Year Quarter Area Gear Bait Ratio Quarter*Gear	3	1031.4195	2.9884	0.1%	0.393	3.93E-01
Year Quarter Area Gear Bait Ratio Area*Gear	4	1031.2306	3.1773	0.1%	0.529	5.29E-01
Year Quarter Area Gear Bait Ratio Quarter*Bait	6	1031.0082	3.3997	0.1%	0.757	7.57E-01
Year Quarter Area Gear Bait Ratio Gear*Ratio	9	1024.1982	10.2097	0.4%	0.334	3.34E-01
Year Quarter Area Gear Bait Ratio Quarter*Ratio	27	1022.7388	11.6691	0.5%	0.995	9.95E-01
Year Quarter Area Gear Bait Ratio Bait*Ratio	18	1022.2376	12.1703	0.5%	0.838	8.38E-01
Year Quarter Area Gear Bait Ratio Year*Gear	10	1020.2845	14.1234	0.6%	0.167	1.67E-01
Year Quarter Area Gear Bait Ratio Quarter*Area	12	1016.7383	17.6696	0.7%	0.126	1.26E-01
Year Quarter Area Gear Bait Ratio Year*Bait	38	1014.2938	20.1141	0.8%	0.992	9.92E-01
Year Quarter Area Gear Bait Ratio Area*Ratio	36	1000.5302	33.8777	1.3%	0.570	5.70E-01
Year Quarter Area Gear Bait Ratio Year*Area	95	981.3529	53.0550	2.1%	1.000	1.00E+00
Year Quarter Area Gear Bait Ratio Year*Quarter	78	981.3350	53.0729	2.1%	0.986	9.86E-01
Year Quarter Area Gear Bait Ratio Year*Ratio	220	967.5945	66.8134	2.7%	1.000	1.00E+00

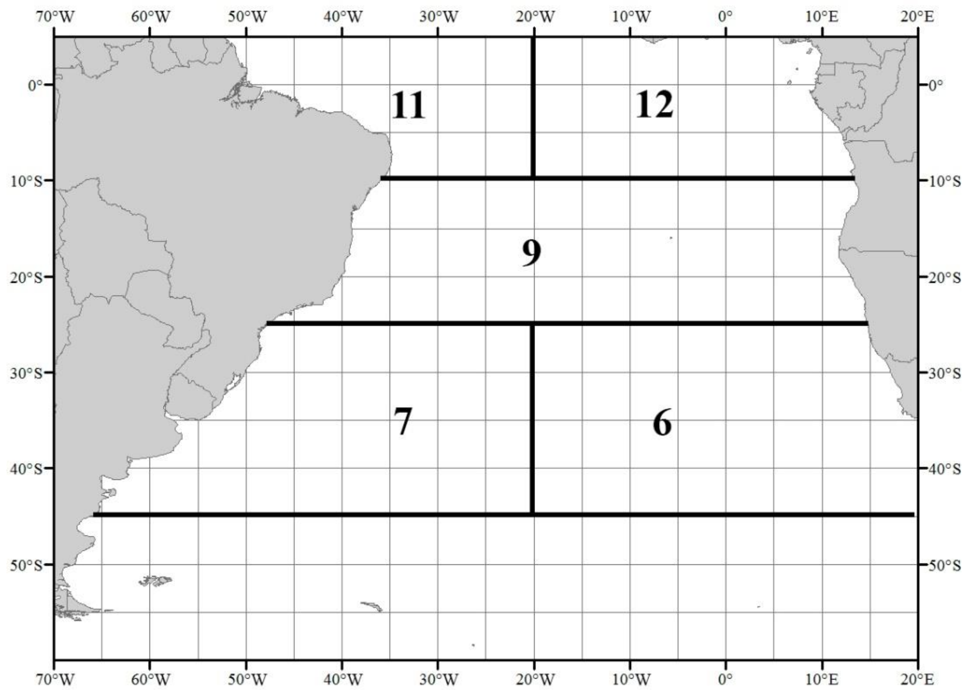


Figure 1. Area definition used for the CPUE standardization of the Spanish surface longline fleet in the South Atlantic, during the whole period 1989-2015.

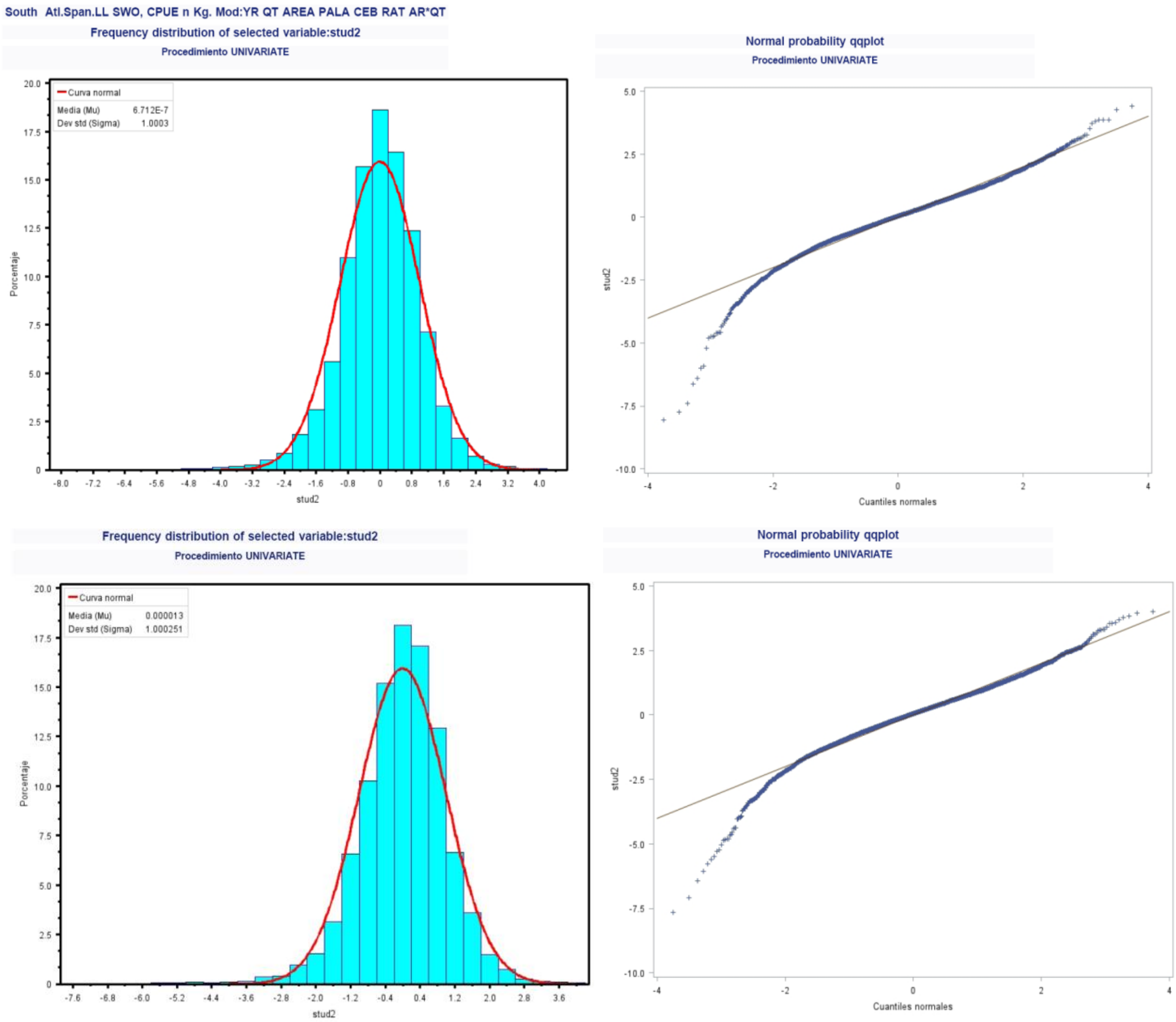


Figure 2. Frequency distribution of the standardized residuals, years combined, and normal probability qq-plot in number (upper) and in weight (lower).

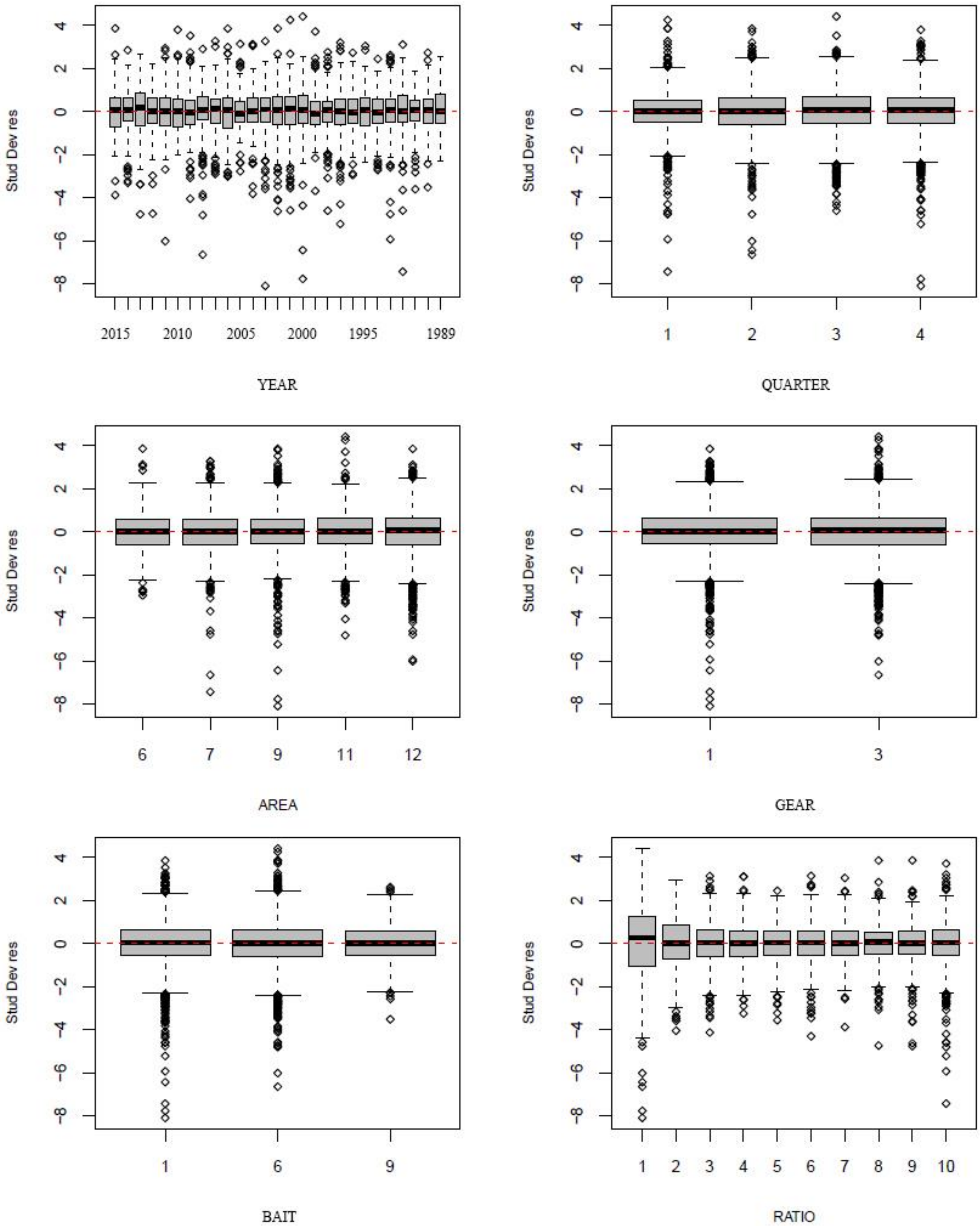


Figure 3. Standardized deviance residuals vs. explanatory variables obtained for GLM of the standardized CPUE in number of fish.

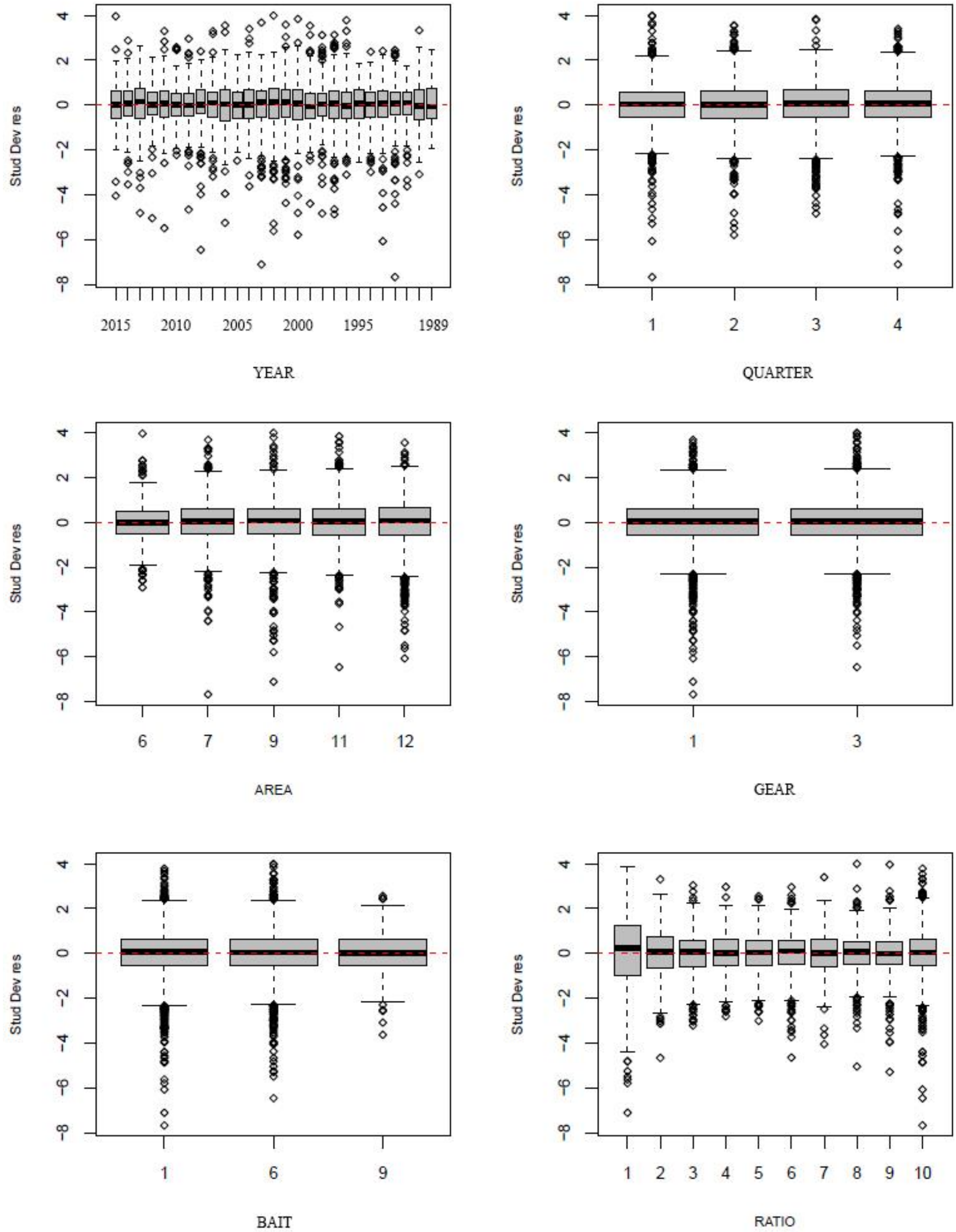
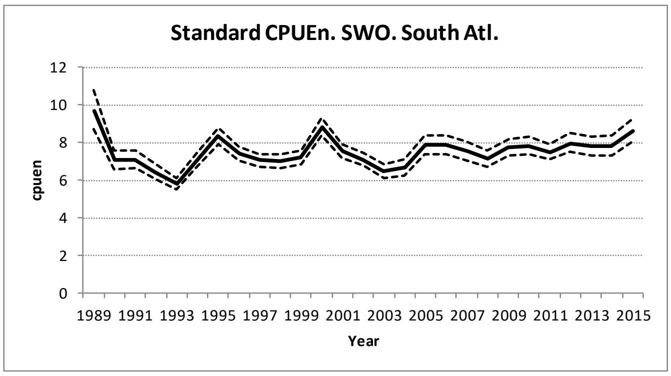
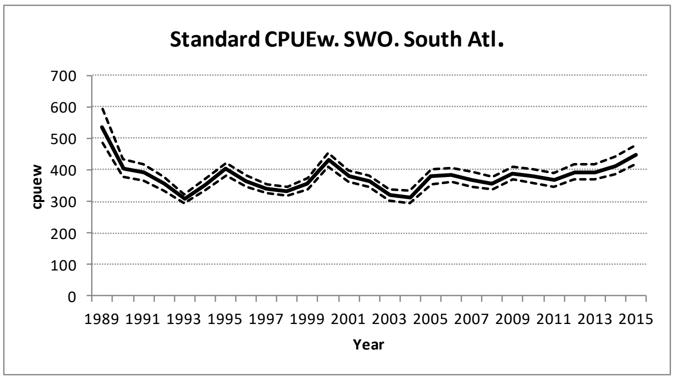


Figure 4. Standardized deviance residuals vs. explanatory variables obtained for the GLM of the standardized CPUE in weight.





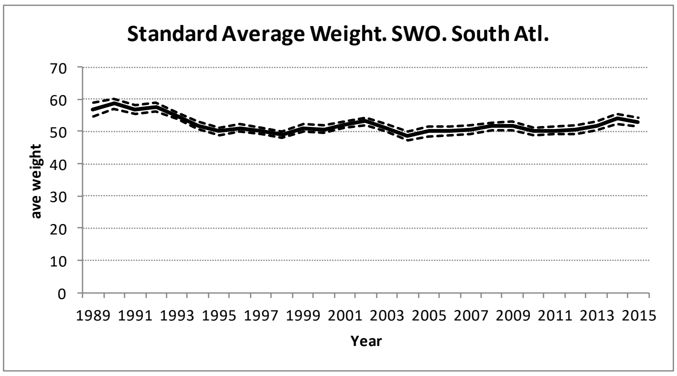


Figure 5. Standardized CPUEs per thousand hooks and 95% CIs: in number of fish (upper), in kilograms round weight (middle). Standardized mean round weight in kilograms and 95% CIs (lower).

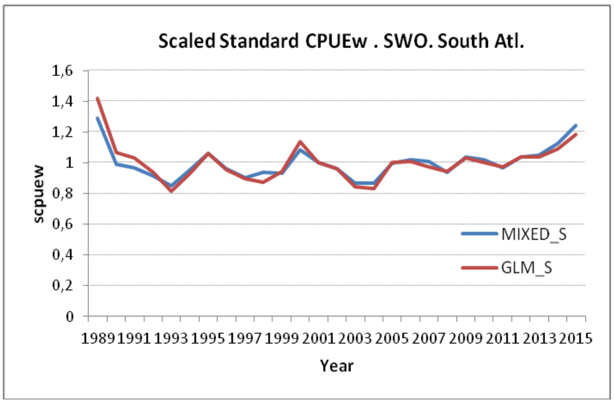


Figure 6. Comparative scaled standardized CPUEw GLM *versus* MIXED obtained in the South Atlantic stock for the 1989-2015 period. Both series are scaled from their respective mean values.