UPDATED STANDARDIZED CATCH RATES IN BIOMASS FOR THE BLUE SHARK (*PRIONACE GLAUCA*) CAUGHT BY THE SPANISH SURFACE LONGLINE FLEET IN THE INDIAN OCEAN DURING THE 2001-2019 PERIOD

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ABSTRACT

*This paper provides an update of standardized catch rates in weight of blue shark using a Generalized Linear Model (GLM) from a total of 2,301 trips carried out by the Spanish surface longline fleet targeting swordfish in the Indian Ocean during the 2001-2019 period. The criteria used to define explanatory variables were similar to those used in previous papers. The main factors considered in the analysis were year, quarter, area, ratio, gear and the interaction quarter*area. The results indicate that the ratio factor (an indicator of target criteria of the skippers) defined as the ratio between the two most prevalent species caught -swordfish and blue shark- was the most important factor which explained the CPUE variability. The GLM results explained 80% of CPUE variability in weight. The index showed a stable trend over time.*

Key words: blue shark, sharks, CPUE, GLM, longline.

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1. Introduction

With the gradual introduction of on-board freezing systems in the 1980s, the Spanish surface longline fleet targeting swordfish was able to expand its activity toward more distant areas of the Atlantic, Indian and Pacific Oceans. The Spanish longline fleet targeting swordfish using night setting began to operate in western areas of the Indian Ocean in 1993 (Mejuto *et al.* 2006[a]; García-Cortés *et al.* 2008). Important changes in gear configuration took place in the early 2000's when the multifilament style traditionally used was replaced by the American-style monofilament gear, which continues to be the preferred gear of choice to date (García-Cortés and Mejuto 2000; García-Cortés *et al.* 2003, 2004, 2008; Mejuto *et al.* 2006[a], 2008; Ramos-Cartelle *et al*. 2011).

The geographical distribution of blue shark overlaps with the range of the fishing areas of surface longline fleet targeting tunas and/or swordfish. Blue shark is the most prevalent bycatch shark caught by these and other fleets in all oceans (García-Cortés and Mejuto 2001, 2005; Mejuto and García-Cortés 2005; Mejuto *et al.* 2006[a], 2006[b]; Ramos-Cartelle *et al*. 2008, 2009; Fernández-Costa *et al.* 2015, 2017; Coelho *et al.* 2017).

The target species of Spanish surface longline fleets was traditionally swordfish, but freezing systems introduced, changes in the market 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 with a combination of both swordfish and blue shark. The impact of these changes on the fishing strategy in several longline fleets targeting swordfish and other species has already been described in literature and considered in the recent standardized CPUE analysis of this fleet (e.g. Mejuto and De la Serna 2000, Ramos-Cartelle *et al.* 2011, 2020[a], 2020[b]; Fernández-Costa *et al.* 2014, 2015, 2017).

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 may give rise to bias in the index. Catch-per-unit-effort (CPUE) data from fishery-dependent data (commercial fishing operations) have traditionally been used as a source of information 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 change in abundance over time (Maunder and Punt 2004).

This document updates the standardized blue shark CPUE index of the Spanish longline fleet previously provided for the Indian Ocean blue shark stock (Fernández-Costa *et al.* 2015, 2017).

2. Material and methods

In the analysis the data used was that gathered for scientific purposes from the Spanish longline fleet's trips targeting swordfish in the Indian Ocean during the period 2001-2019. The standardized CPUE analysis was carried out with a Generalized Linear Model (GLM) with a log-normal error using SAS 9.4 software. The base case model was defined with the same explanatory variables to be compared with previous analyses.

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

where: u = overall mean, Y = *year* effect, Q = *quarter* effect (1: January-March; 2: April-June; 3: July-September; 4: 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), G = *gear* effect (1: traditional multifilament; 3: American-style monofilament) and e = logarithm of the normally distributed error term. The symbol * represents the interactions between factors. The methodology used in this paper is based on previous research carried out by the Spanish longline fleet in the Indian Ocean (Mejuto *et al.* 2008; Ramos-Cartelle *et al.* 2011 2020[a], 2020[b]; Fernández-Costa *et al*. 2014, 2015, 2017).

The response variable - CPUE - was measured as biomass (gutted weight in kg) per fishing effort (thousands of hooks). Standardized residuals by year were plotted.

An alternative-sensitivity MIXED was performed to allow some of the parameters in the linear prediction to be considered as random variables (Maunder and Punt 2004).

3. Results and discussion

A total of 2,301 trip records were available from the 2001-2019 period. The spatial-temporal coverage was appropriate for blue shark catches and the fishing activity of this fleet over time. **Figure 1** show the areas defined in the Indian Ocean used in the CPUE standardization and a summary of the Spanish longline fleet fishing activity (nominal CPUEw and total effort) during the 2001-2019 period. In this analysis no activity was observed in area 56, so finally only 7 areas were considered on the GLM runs.

Table 1 provides the ANOVA summary obtained from the GLM base case analysis, including R-square, mean square error (root), F statistics and significance level, as well as the Type III SS for each factor used.

The base case GLM model explained 80% of the CPUE variability in biomass of the Indian stock. All the explanatory variables tested contributed significantly to explaining part of the deviance. As with the case of the previous blue shark CPUE analyses (Mejuto *et al.* 2009, Fernández-Costa 2015, 2017), the CPUE variability (Type III SS) may be primarily attributed to the targeting criteria (*ratio*). This ratio provides a good approximation of the skipper's priority by trip and the targeting criteria. The use of these ratios was found to perform best among the different proxy methods simulated and it was considered to be the preferred proxy (Anon. 2001). The *year*, *area, gear* and the interaction *quarter*area* were also significant, although less important.

Table 2 provides information on estimated base case parameters (Lsmean), their standard error, CV%, standard CPUE in biomass and upper and lower 95% confidence limits. **Figure 2** provides distribution of standardized residuals and the normal probability *qq*-plot over the 2001-2019 period. The box-plot of the standardized residuals obtained, by main factor, is shown in **Figure 3**. The fit of the model seems not to be biased and residuals are normally distributed.

The analysis results showed a stable overall trend of the standardized CPUE between 2004 and 2019, with peaks of values in 2010 and 2016.

A sensitivity analysis using a GLMM procedure was run taking into account the factors and interactions that contributed more than 5% to the deviance explanation. Only the fixed factors contributed significantly to explain part of the deviance. The results obtained were very similar to the base case GLM model.

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References

Anonymous. 2001. Report of the ICCAT working group on stock assessment methods (Madrid, Spain - May 8 to 11, 2000). Collect. Vol. Sci. Pap. ICCAT, 52(5): 1569-1662.

Coelho, R., Mejuto, J., Domingo, A., Yokawa, K., Liu, K.M., Cortés, E., Romanov, E.V., Da Silva, C., Hazin, F., Arocha,F., Mwilima, A.M., Bach, P., Ortíz de Zárate, V., Roche, W., Lino, P.G., García-Cortés, B., Ramos-Cartelle, A., Forselledo, R., Mas, F., Ohshimo, S., Courtney, D., Sabarros, P.S., Pérez, B., Wogerbauer, C., Tsai, W.P., Carvalho, F. and Santos, M.N. 2017. Distribution patterns and population structure of the blue shark (*Prionace glauca*) in the Atlantic and Indian Oceans. Fish and Fisheries 2017: 1–17.

Fernández-Costa, J., Ramos-Cartelle, A., García-Cortés, B. and Mejuto, J. 2014. Standardized catch rates for the swordfish (*Xiphias gladius*) caught by the Spanish longline in the Indian Ocean during the 2001-2012 period. IOTC-2014-WPB12-20: 16pp.

Fernández-Costa, J., Ramos-Cartelle, A., García-Cortés, B. and Mejuto, J. 2015. Standardized catch rates for the blue shark caught by the Spanish surface longline in the Indian Ocean during the 2001-2013 period. IOTC-2015-WPBE11-25: 10pp.

Fernández-Costa, J., Ramos-Cartelle, A., García-Cortés, B. and Mejuto, J. 2017. Standardized catch rates in biomass for the blue shark (*Prionace glauca*) caught by the Spanish surface longline fleet in the Indian ocean during the 2001-2015 period. IOTC-2017-WPEB13-25: 11pp.

García-Cortés, B. and Mejuto, J. 2000. A general overview on the activity of the Spanish surface longline fleet targeting swordfish (*Xiphias gladius)* in the Indian Ocean for the period 1993-1999. IOTC-2000-WPB00-01. IOTC Proceedings no.3 (2000): 140-153.

García-Cortés, B. and Mejuto, J. 2001. Preliminary scientific estimations of by-catches landed by the Spanish surface longline fleet targeting swordfish (*Xiphias gladius)* in the Indian Ocean: years 1993-2000. IOTC-2001-WPDCS01-02. IOTC Proceedings no.4 (2001): 19-23.

García-Cortés, B. and Mejuto, J. 2005. Scientific estimations of bycatch landed by the Spanish surface longline fleet targeting swordfish (X*iphias gladius*) in the Indian Ocean: 2001–2003 period**.** IOTC-2005-WPBy-14: 9pp.

García-Cortés, B., Mejuto, J. and Ramos-Cartelle, A. 2003. A description of the activity of the Spanish surface longline fleet targeting swordfish (*Xiphias gladius*) in the Indian Ocean with special reference to the year 2001. IOTC WPB-2003 IOTC Proceedings no.6 (2003): 280-286.

García-Cortés, B., Mejuto, J. and Ramos-Cartelle, A. 2004. A general overview of the activity of the Spanish surface longline fleet targeting swordfish (*Xiphias gladius*) in the Indian Ocean during the year 2002. IOTC-2004-WPB-05: 5pp.

García-Cortés, B., Ramos-Cartelle, A. and Mejuto, J. 2008. Activity of the Spanish surface longline fleet targeting swordfish (*Xiphias gladius*) in the Indian Ocean during the period 2003-2006. IOTC-2008-WPB-05: 12pp.

Gavaris, S. 1980. Use of a multiplicative model to estimate catch rate and effort from commercial data. Can. J. Fish. Aquat. Sci. 37: 2272-2275.

Kimura, D.K. 1981. Standardized measures of relative abundance based on modeling log (CPUE) and their application to Pacific Ocean Perch. J. Cons. Int. Explor. Mer. 39: 211-218.

Maunder, M. and Punt, A.E. 2004. Standardizing catch and effort data: A review of recent approaches. Fisheries Research 70: 141-159.

Mejuto, J. and De la Serna, J.M. 2000. Standardized catch rates by age and biomass for the North Atlantic swordfish (*Xiphias gladius*) from the Spanish longline fleet for the period 1983-1998 and bias produced by changes in the fishing strategy. Collect. Vol. Sci. Pap. ICCAT, 51(5): 1387-1410.

Mejuto, J. and García-Cortés, B. 2005. Reproductive and reproduction parameters of the blue shark *Prionace glauca*, on the basis of on-board observations at sea in the Atlantic, Indian and Pacific Oceans. Collect. Vol. Sci. Pap. ICCAT, 58(3): 951-973.

Mejuto, J., García-Cortés, B. and Ramos-Cartelle, A. 2006[a]. An overview of research activities on swordfish (*Xiphias gladius*) and the by-catch species, caught by the Spanish longline fleet in the Indian ocean. IOTC 2006-WPB-2006-11: 23pp.

Mejuto, J., García-Cortés, B. and Ramos-Cartelle, A. 2006[b]. Annex an overview of research activities on swordfish (*Xiphias gladius*) and the by-catch species, caught by the Spanish longline fleet in the Indian Ocean. IOTC 2006-WPB-2006-11-ANNEX: 21pp.

Mejuto, J., García-Cortés, B. and Ramos-Cartelle, A. 2008. Standardized catch rates in biomass for the swordfish (*Xiphias gladius*) caught by the Spanish longline fleet in the Indian ocean for the period 1993-2007. IOTC-2008-WPB-06: 17pp.

Mejuto, J., García-Cortés, B., Ramos-Cartelle, A. and De la Serna, J.M. 2009. Standardized catch rates for the blue shark (*Prionace glauca*) and shortfin mako (*Isurus oxyrinchus*) caught by the Spanish surface longline fleet in the Atlantic Ocean during the period 1990-2007. Collect. Vol. Sci. Pap. ICCAT, 64(5): 1509-1521.

Ramos-Cartelle, A., Fernández-Costa, J. and Mejuto, J. 2020[a]. Standardized catch rates of shortfin mako (*Isurus oxyrinchus*) caught by the Spanish surface longline fishery targeting swordfish in the Indian ocean during the period 2001-2018. IOTC-2020-WPEB16-16: 14pp.

Ramos-Cartelle, A., Fernández-Costa, J. and Mejuto, J. 2020[b]. Updated standardized catch rates of swordfish (*Xiphias gladius*) caught by the Spanish surface longline fleet in the Indian Ocean during the 2001-2018 period. IOTC-2020-WPB18-12: 12pp.

Ramos-Cartelle, A., García-Cortés, B., Fernández, J. and Mejuto, J. 2009. Scientific catch estimations of bycatch species landed by the Spanish surface longline fleet targeting swordfish (*Xiphias gladius*) in the Indian Ocean with special reference to the years 2007 and 2008. IOTC-2009-WPEB-03: 7pp.

Ramos-Cartelle, A., García-Cortés, B., Fernández, J. and Mejuto, J. 2011. Standardized catch rates for the swordfish (*Xiphias gladius*) caught by the Spanish longline in the Indian Ocean during the period 2001-2010. IOTC-2011-WPB09-23: 19pp.

Ramos-Cartelle, A., García-Cortés, B. and Mejuto, J. 2008. Scientific estimates of bycatch landed by the Spanish surface longline fleet targeting swordfish (*Xiphias gladius*) in the Indian Ocean with special reference to the 2004-2006 period. IOTC-2008-WPEB-03: 9pp.

Robson, D.S. 1966. Estimation of relative fishing power of individual ships. Res. Bull. Int. Comm. N.W. Atl. Fish, 3: 5-14.

Table 1. Summary of ANOVA for base case CPUE analysis in biomass (gutted weight -GW) for blue shark in the Indian Ocean: R-square, mean square error (root) and F statistics. Dependent variable: ln (CPUEw).

Indian Ocean. BSH CPUE in weight (GW)

Dependent variable: ln (CPUEw)

Source	DF	Sum of Squares	Mean Square	F Value	Pr > F
Model	55	1083.343738	19.697159	164.1	<.0001
Error	2245	269.472838	0.120032		
Corrected Total	2300	1352.816577			

R-Square	Coeff Var	Root MSE	cpue1 Mean
0.800806	5.498128	0.346457	6.301363

Source	DF	Type III SS	Mean Square	F Value	Pr > F
year	18	27.3644654	1.5202481	12.67	<.0001
quarter	3	2.0755039	0.6918346	5.76	0.0006
area	6	21.9916931	3.6652822	30.54	<.0001
ratio	9	621.3540091	69.0393343	575.17	<.0001
gear	1	9.7127393	9.7127393	80.92	<.0001
quarter*area	18	10.8734542	0.6040808	5.03	<.0001

Table 2. Estimated parameters (LSMEAN), standard error (STDERR), CV%, base case standardized CPUE in biomass (CPUEw) of blue shark and upper and lower 95% confidence limits for the Spanish longline fleet in the Indian Ocean during the period analyzed, 2001-2019.

YEAR	LSMEAN	STDERR	CV%	95%UCPUEw	CPUEw	95%LCPUEw
2001	5.798630	0.075424	1.300721	383.487	330.787	285.330
2002	5.706950	0.067929	1.190286	344.606	301.648	264.045
2003	5.783770	0.066384	1.147763	370.958	325.700	285.964
2004	5.659140	0.067176	1.187035	328.015	287.549	252.076
2005	5.537370	0.068129	1.230349	290.972	254.600	222.774
2006	5.458000	0.064993	1.190784	267.066	235.123	207.000
2007	5.504490	0.069961	1.270981	282.609	246.396	214.824
2008	5.598880	0.070666	1.262145	311.027	270.798	235.773
2009	5.693360	0.070397	1.236475	341.662	297.627	259.269
2010	5.796920	0.076686	1.322875	383.816	330.252	284.164
2011	5.724700	0.074167	1.295561	355.250	307.186	265.626
2012	5.761640	0.071425	1.239664	366.569	318.682	277.051
2013	5.566540	0.069874	1.255250	300.648	262.168	228.613
2014	5.440200	0.069958	1.285945	265.008	231.052	201.447
2015	5.594060	0.075320	1.346428	312.474	269.588	232.587
2016	5.727190	0.077734	1.357280	358.732	308.036	264.504
2017	5.687060	0.078072	1.372801	344.856	295.924	253.936
2018	5.645830	0.080540	1.426540	332.597	284.028	242.552
2019	5.621440	0.074617	1.327365	320.690	277.057	239.361

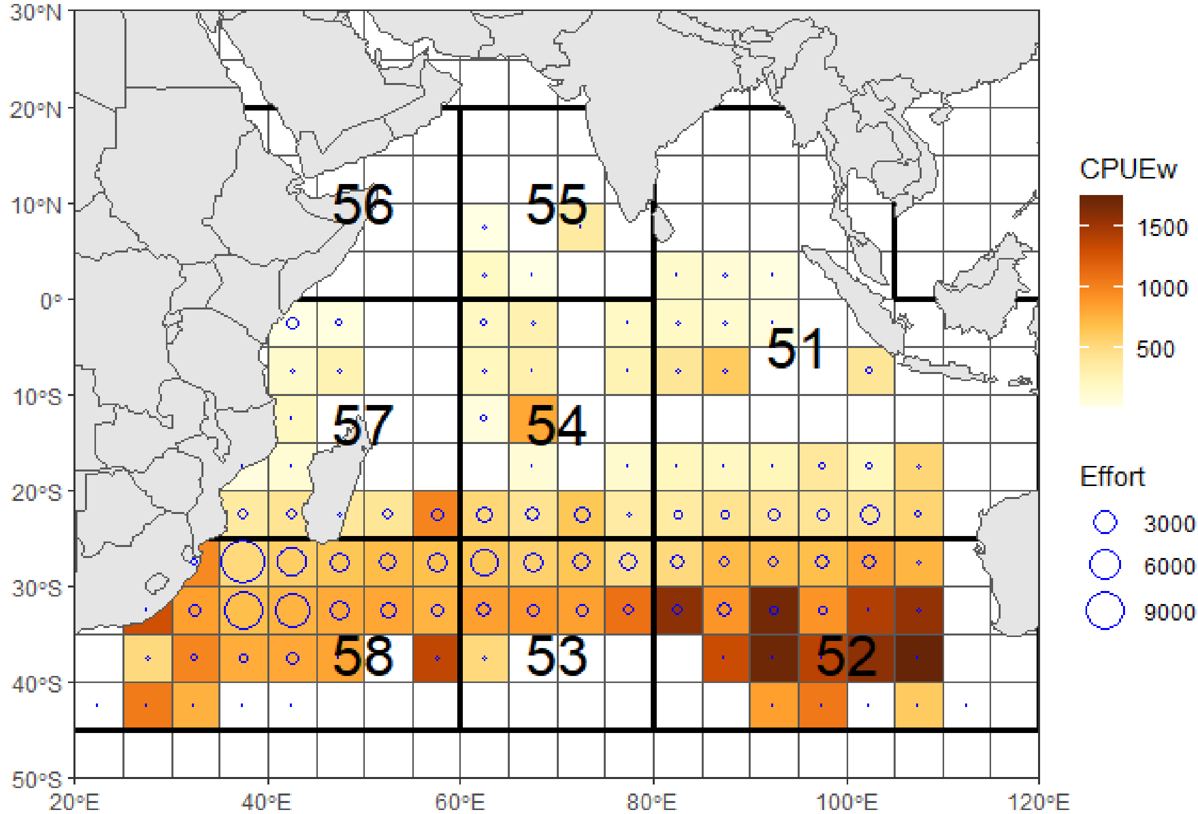

Figure 1. Geographical area definition used in GLM runs for the CPUE standardization of the Spanish surface longline fleet in the Indian Ocean during the period 2001-2019. The color scale represents the nominal CPUEw (kg GW/1000 hooks) per 5ºx5º square and circle scale represents the total effort (thousands of hooks) per 5ºx5º square for all years combined during the 2001-2019 period.

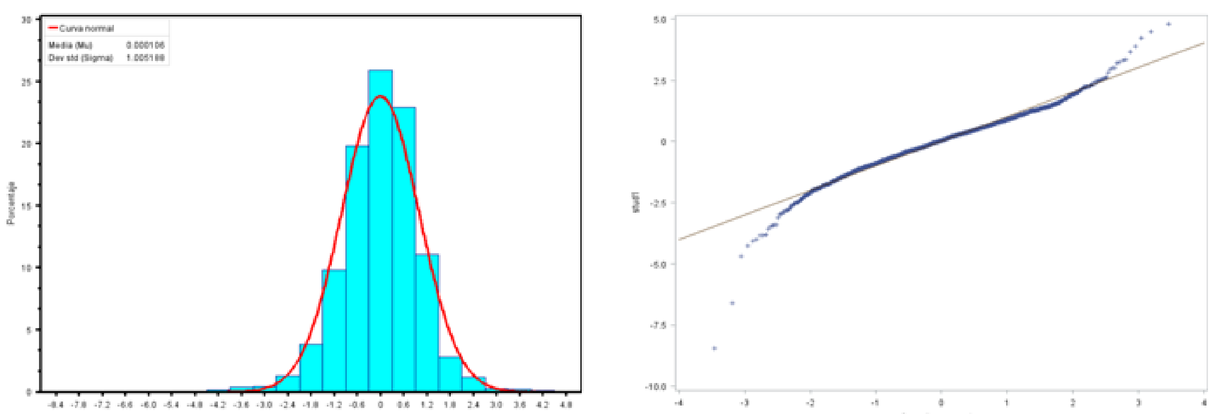

Figure 2. Frequency distribution of the standardized residuals in weight (left) and normal probability *qq*-plots (right), in the Indian Ocean for the 2001-2019 period.

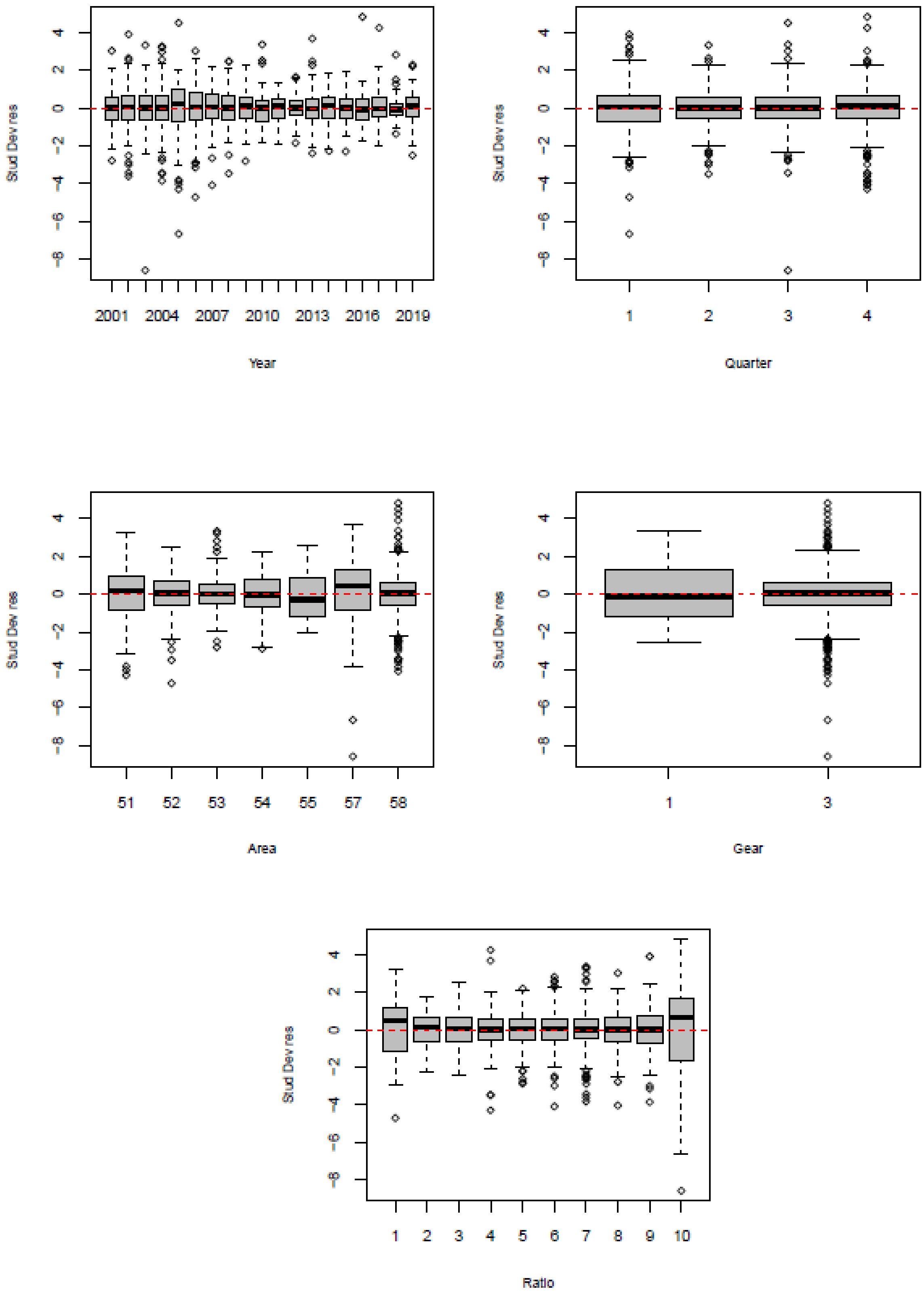

Figure 3. Box-plots of the standardized deviance residuals *versus* explanatory variables, obtained from the GLM analysis in weight for the Indian Ocean stock of the blue shark during the 2001-2019 period.

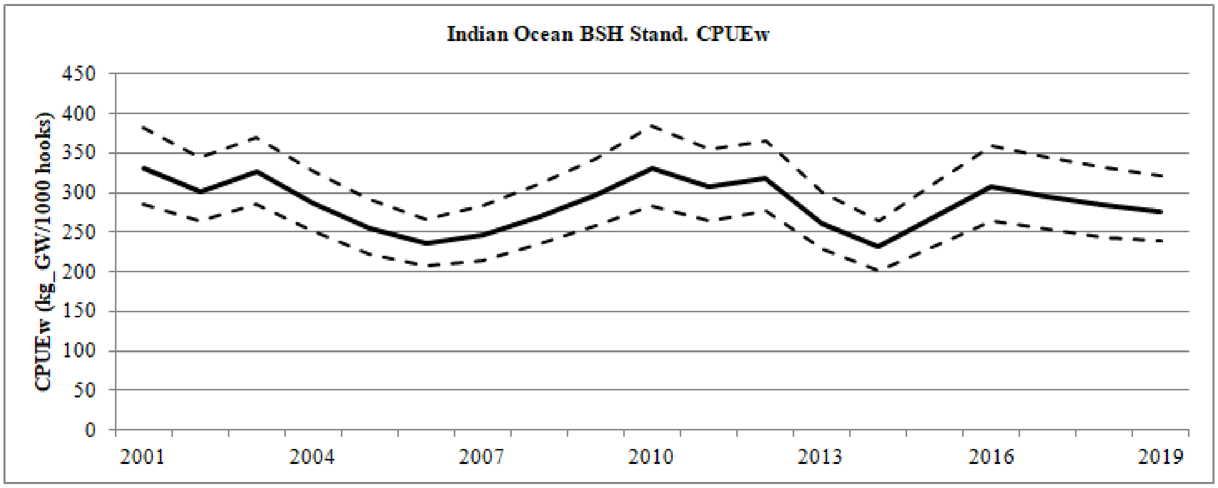

Figure 4. Standardized CPUE in gutted weight by year and confidence intervals (95%) of the Indian Ocean stock of the blue shark during the 2001-2019 period.