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

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ABSTRACT

*Based on 2,049 trips by vessels in the Spanish surface longline fleet in the Indian Ocean during the period 2001-2015, standardised CPUE catch rates were obtained for the blue shark (Prionace glauca) using General Linear Modelling. The main factors considered were year, quarter, area, ratio, gear and the interaction quarter*area. The basic significant model obtained explained 81% of CPUE variability observed and suggests a stable trend for this blue shark stock in the Indian Ocean. Most of the variability in CPUE was explained by the targeting factor, as represented by the ratio between catch levels for the two most valued and prevalent species landed: swordfish and blue shark. Other significant factors were identified but these were less important. The MIXED model used to analyse sensitivity showed the same trend as that obtained using the basic case.*

RESUMEN

*A partir de 2,049 mareas realizadas por la flota española de palangre de superficie en el océano Índico durante el período 2001-2015, se obtuvieron tasas estandarizadas de captura por unidad de esfuerzo para la tintorera (Prionace glauca) usando Modelos Lineales Generalizados. Los principales factores considerados fueron año, trimestre, área, ratio, arte y la interacción trimestre*área. El modelo básico significativo obtenido explicó el 81% de la variabilidad de la CPUE observada y sugiere una tendencia estable para este stock de tintorera del océano Índico. La mayor parte de esta variabilidad de la CPUE fue explicada por el factor de direccionamiento el cual está representado por el ratio entre los niveles de captura de las dos especies más deseadas y prevalentes en los desembarcos, el pez espada y la tintorera. Otros factores fueron también identificados como significativos pero menos importantes. El modelo MIXED aplicado como análisis de sensibilidad mostró idéntica tendencia a la obtenida con el caso básico.*

Key words: blue shark, sharks, CPUE, GLM, longline, Spanish fleet, Indian Ocean.

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1. Introduction

Blue shark is one of the most prevalent fish species in the oceanic-epipelagic layers. The biomass of blue shark in these layers is regularly higher than that of many highly migratory-teleost species. The very broad geographical distribution of this shark is within the range of the fishing areas targeting tuna and/or swordfish, which is why blue shark was historically a very prevalent bycatch species caught by several types of fishing gear targeting tuna and tuna-like species around the world (García-Cortés and Mejuto 2001, 2005; Ramos-Cartelle *et al.* 2008, 2009). Size-sex segregation of this species has been described related to their respective biological processes (Mejuto and García-Cortés 2005, Nakano and Stevens 2008).

The activity of the Spanish fleet targeting swordfish (*Xiphias gladius*) in the Indian Ocean commenced in 1993 and it was mostly restricted to western regions (García-Cortés *et al.* 2008). Important changes in the fishing strategy of the Spanish fleet took place in the short period 1998-2001, when the multifilament style traditionally used was replaced by the American-style monofilament gear in most vessels (García-Cortés *et al.* 2003, 2004, 2008; Ramos-Cartelle *et al.* 2011). These changes in fishing methods have an important impact on the nominal CPUE obtained for swordfish (Mejuto and De la Serna 2000, Ortiz *et al.* 2010).

Standardized catch rates (CPUE) are frequently considered as an abundance indicator in a great number of large pelagic fisheries because of the lack of direct indicators. Generalized Linear Modelling (GLM) (Robson 1966, Gavaris 1980, Kimura 1981), which removes the effect of factors that bias the index, has been used to estimate standardized catch rates, based on data from commercial fleets with unbalanced spatial and temporal activity. It might also be useful to consider indirect factors such as operational changes and technological advances, including changes in the target species or the criteria of the skippers, in some cases.

This document updates the standardized CPUE series previously provided for the Indian Ocean blue shark stock, covering a 15-year period in this case.

2. Material and methods

The records used for these analyses were from trips by the Spanish surface longline fleet targeting swordfish in the Indian Ocean during the period 2001-2015. The response variable for the model is catch per unit of effort (CPUE) per trip measured as biomass (total gutted weight in kg) per fishing effort (thousands of hooks). Two runs were conducted.

The standardized CPUE analysis was done using the GLM procedure (*SAS 9.4*). The methodology used in this paper is based on previous research carried out on the Spanish longline fleet in the Indian Ocean (Mejuto *et al.* 2009, Ramos-Cartelle *et al.* 2011, Fernández-Costa *et al*. 2014, 2015). The GLM model defined included *year*, *quarter*, *area*, *ratio, gear* and the interaction *quarter*area,* as main factors: ln (CPUE) = u + Y + Q + A + R +G + Q * A + e. Where, u= overall mean, Y = *year* effect, Q = *quarter* effect, A = *area* effect, R = *ratio* effect (as an indicator of the type of trip or target criteria of the skipper regarding swordfish and/or blue shark during the fishing activity), G = *gear* effect, Q * A = *quarter*area* interaction and e = logarithm of the normally distributed error term. The *quarter* definition used for GLM runs was the same as that previously used in the Atlantic and Indian oceans for swordfish, blue shark and shortfin mako (Mejuto *et al.* 1999, 2000, 2001, 2002, 2008, 2009, 2013; Mejuto and De la Serna 2000, Ortiz *et al.* 2007, Fernández-Costa *et al.* 2014, 2015). The *area* factor initially included 8 areas. The *ratio* factor, defined for each available trip record as the percentage of swordfish in weight related to the catches of swordfish and blue shark combined, was categorized into ten levels at 10% intervals in order to classify the type of trip. Two main types-styles of factor *gear* were clearly identified: the Spanish traditional multifilament gear and the monofilament gear widely introduced around the end of the 20th century (Mejuto *et al.* 2006 [a,b]).

Trends over time of the standardized CPUE as well as the standardized residuals by year were plotted for the index of abundance to evaluate the extent of serial autocorrelation in the residuals. The methods and specifications were consistent with previous analyses (e.g. Mejuto *et al.* 2009, Fernández-Costa *et al.* 2015).

An alternative-sensitivity MIXED procedure was performed to allow some of the parameters in the linear prediction to be considered as random variables (Maunder and Punt 2004). The standardized CPUE in weight obtained from this sensitivity analysis was scaled to compare it with the scaled standardized CPUE in weight obtained by the base case GLM run. Both were scaled to their respective mean values.

3. Results and discussion

A total number of 2,049 trip records were available during the period 2001-2015. Spatial-temporal coverage was appropriate for blue shark catches and the fishing activity of this fleet over time, except for area 56, where no activity was observed, so that the final runs considered only 7 areas (**Figure 1**).

Table 1 provides the ANOVA summary obtained from the GLM base case analyses, 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 tested for the blue shark for the period 2001-2015 explained 81% of the CPUE variability in biomass of the Indian stock. All the explanatory factors tested contributed significantly to explaining part of the deviance. As was the case of the previous blue shark CPUE analyses (Mejuto *et al.* 2009, Fernández-Costa 2015), 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 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 (lsmeans), their standard error, CV%, standardized CPUE in biomass and upper and lower 95% confidence limits. **Figure 2** provides the aggregate standardized residuals distribution and the normal probability *qq*-plot for the run. 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 standardized CPUE in biomass shows a general stability of relative abundance with the highest values obtained in the years 2003, 2010, 2012 and 2015, the last year analyzed (**Figure 4**).

The factors and interactions with $\geq$ 5.0% of deviance explained were considered in the sensitivity analysis (**Table 3**). The MIXED model run, where ln (CPUE) = u + Y + Q + A + R + e produced a similar general trend over time to the base case model (without the *gear* and *bait* effects or any interaction).

The CPUE obtained from the sensitivity analysis was scaled to compare it with the scaled standardized CPUE base case (GLM *versus* MIXED). The two trends obtained were very similar (**Figure 5**). The updated index is consistent with that given in 2015 (Fernández-Costa *et al.* 2015).

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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 (CPUE).

Indian Ocean. BSH CPUE in weight (GW)

Dependent variable: ln (CPUEw)

Source	DF	Sum of Squares	Mean Square	F Value	Pr > F
Model	51	1048.858450	20.565852	167.19	<.0001
Error	97	245.654486	0.123012		
Corrected Total	2048	1294.512936			

R-Square	Coeff Var	Root MSE	cpue Mean
0.810234	5.587976	0.350730	6.276518

Source	DF	Type III SS	Mean Square	F Value	Pr > F
year	14	26.3941673	1.8852977	15.33	<.0001
quarter	3	1.6975467	0.5658489	4.60	0.0033
area	6	21.5251712	3.5875285	29.16	<.0001
ratio	9	599.1565082	66.5729454	541.19	<.0001
gear	1	9.5086115	9.5861150	77.30	<.0001
quarter*area	18	11.7846627	0.6547035	5.32	<.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, 2001-2015.

YEAR	LSMEAN	STDERR	CV%	UCPUEw	CPUEw	LCPUEw
2001	5.77352	0.077551	1.343219	375.602	322.637	277.141
2002	5.68435	0.069651	1.225312	338.082	294.940	257.304
2003	5.75331	0.068150	1.184536	361.120	315.966	276.459
2004	5.63973	0.068441	1.213551	322.538	282.047	246.640
2005	5.50247	0.070379	1.279044	282.277	245.906	214.221
2006	5.42723	0.067366	1.241259	260.222	228.035	199.829
2007	5.49529	0.071193	1.295528	280.723	244.161	212.361
2008	5.58345	0.072000	1.289525	307.098	266.679	231.580
2009	5.68168	0.071667	1.261370	338.564	294.196	255.643
2010	5.77970	0.078364	1.355849	378.554	324.656	278.432
2011	5.70825	0.076043	1.332160	350.789	302.215	260.368
2012	5.74204	0.073334	1.277142	360.851	312.540	270.696
2013	5.55224	0.071288	1.283950	297.229	258.469	224.764
2014	5.42241	0.071449	1.317661	261.126	227.003	197.339
2015	5.58239	0.076585	1.371903	309.646	266.486	229.342

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
1	_	1294.5129				
Year	14	1236.8350	57.6779	5.4%	< 0.001	2.98E-07
Year Quarter	3	1120.9081	115.9269	10.8%	< 0.001	5.81E-25
Year Quarter Area	6	918.6001	202.3080	18.8%	< 0.001	6.12E-41
Year Quarter Area Gear	1	914.0262	4.5739	0.4%	0.03246259	3.25E-02
Year Quarter Area Gear Bait	1	900.1875	13.8387	1.3%	< 0.001	1.99E-04
Year Quarter Area Gear Bait Ratio	9	256.1679	644.0196	59.8%	< 0.001	7.41E-133
Year Quarter Area Gear Bait Ratio Gear*Ratio	4	256.0215	0.1464	0.0%	0.997	9.97E-01
Year Quarter Area Gear Bait Ratio Quarter*Gear	2	254.8445	1.3234	0.1%	0.516	5.16E-01
Year Quarter Area Gear Bait Ratio Year*Gear	1	254.6029	1.5650	0.1%	0.211	2.11E-01
Year Quarter Area Gear Bait Ratio Area*Bait	6	254.0706	2.0973	0.2%	0.911	9.11E-01
Year Quarter Area Gear Bait Ratio Quarter*Bait	3	253.3913	2.7766	0.3%	0.427	4.27E-01
Year Quarter Area Gear Bait Ratio Bait*Ratio	9	252.1491	4.0188	0.4%	0.910	9.10E-01
Year Quarter Area Gear Bait Ratio Area*Gear	4	251.6390	4.5289	0.4%	0.339	3.39E-01
Year Quarter Area Gear Bait Ratio Year*Bait	12	250.4967	5.6712	0.5%	0.932	9.32E-01
Year Quarter Area Gear Bait Ratio Quarter*Ratio	26	246.7205	9.4474	0.9%	0.999	9.99E-01
Year Quarter Area Gear Bait Ratio Quarter*Area	18	244.7301	11.4378	1.1%	0.875	8.75E-01
Year Quarter Area Gear Bait Ratio Area*Ratio	42	237.2075	18.9604	1.8%	0.999	9.99E-01
Year Quarter Area Gear Bait Ratio Year*Quarter	42	230.4321	25.7358	2.4%	0.977	9.77E-01
Year Quarter Area Gear Bait Ratio Year*Ratio	105	224.2957	31.8722	3.0%	1.000	1.00E+00
Year Quarter Area Gear Bait Ratio Year*Area	66	218.2912	37.8767	3.5%	0.998	9.98E-01

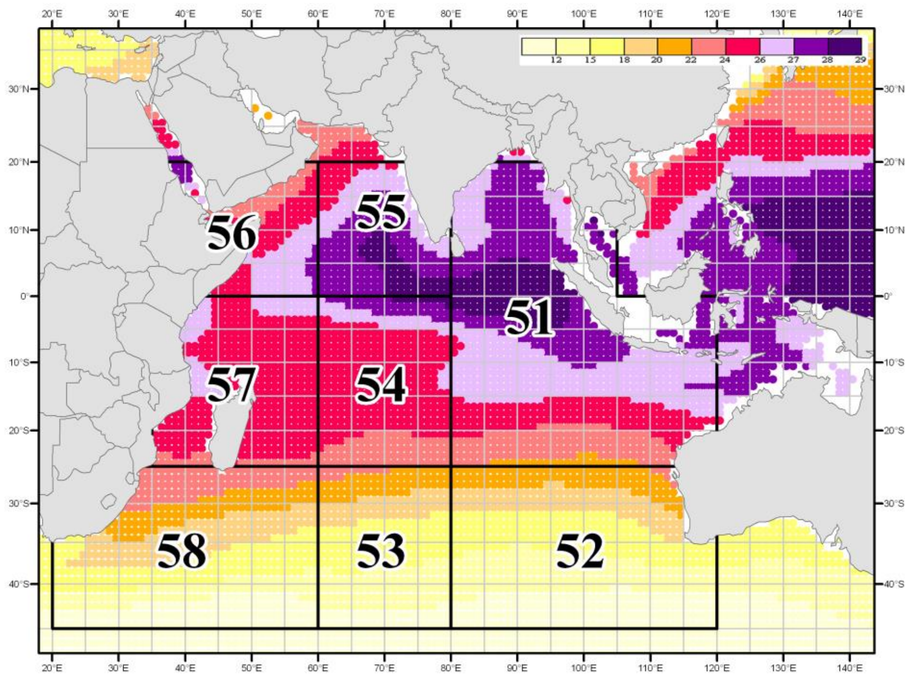

Figure 1. Geographical area stratification used for the GLM run of blue shark. Areas are superimposed on average sea temperature (ºC) at 50m depth.

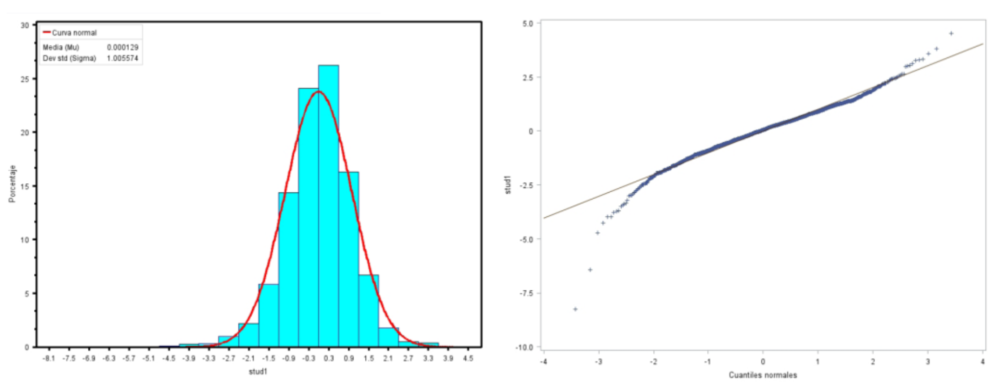

Figure 2. Distribution of the standardized residuals of blue shark in weight (left) and normal probability *qq*-plots (right), in the Indian Ocean for the years 2001-2015 combined.

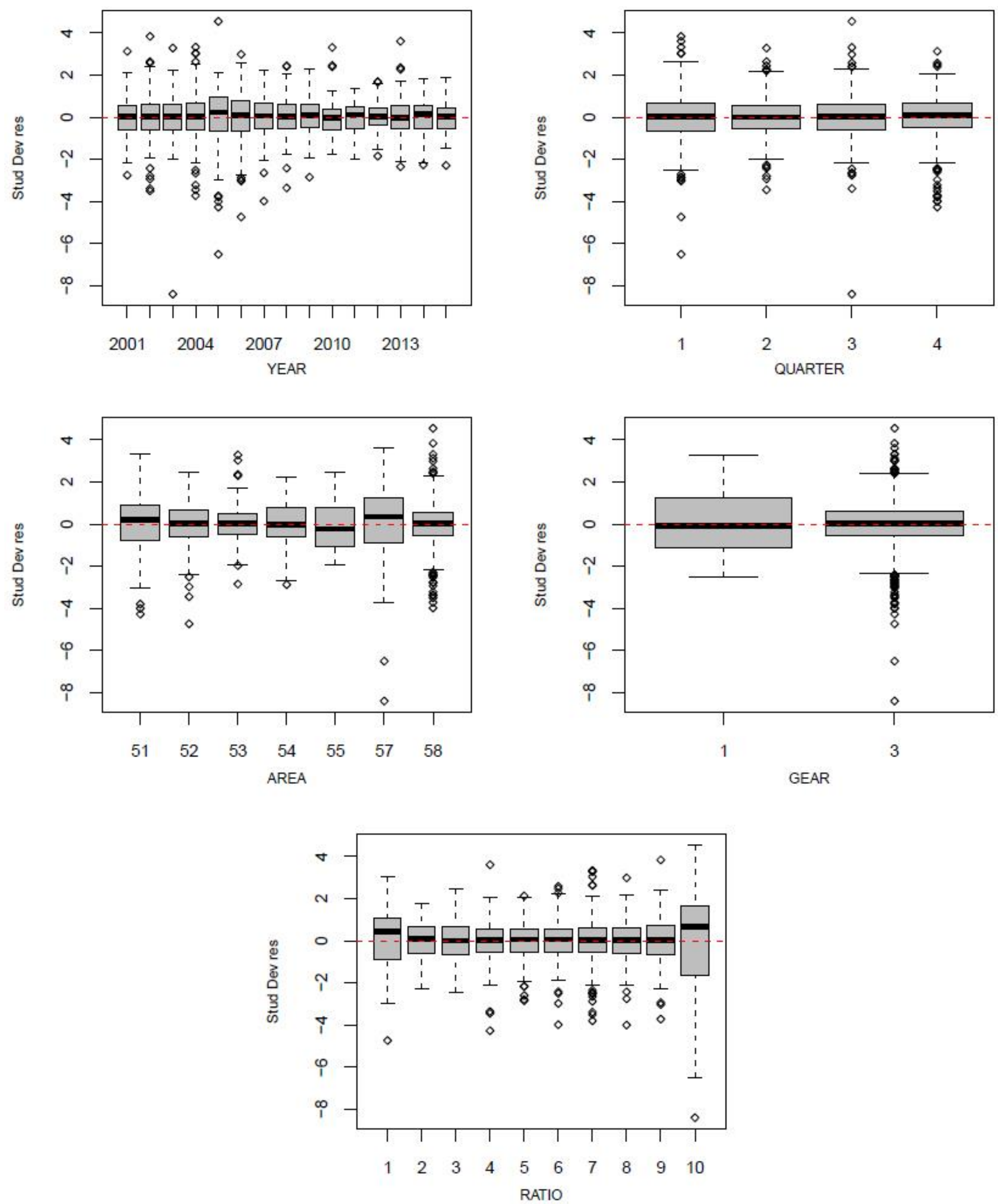

Figure 3. Box-plots of the standardized deviance residuals *versus* explanatory variables, obtained from the GLM analyses in weight for the Indian Ocean stock of the blue shark during the 2001-2015 period.

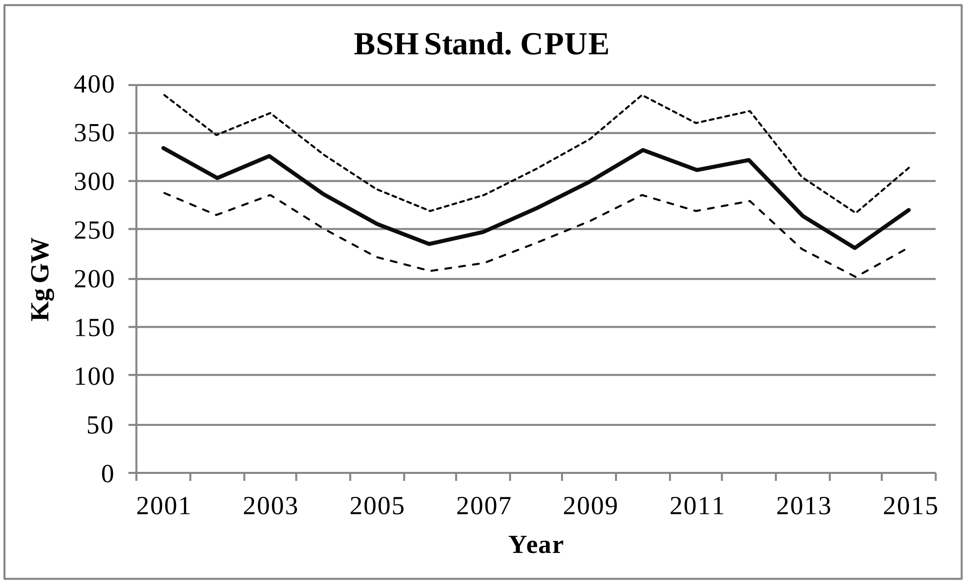

Figure 4. Standardized CPUE in gutted weight by year and confidence intervals (95%) of the Indian Ocean stock of the blue shark during the 2001-2015 period.

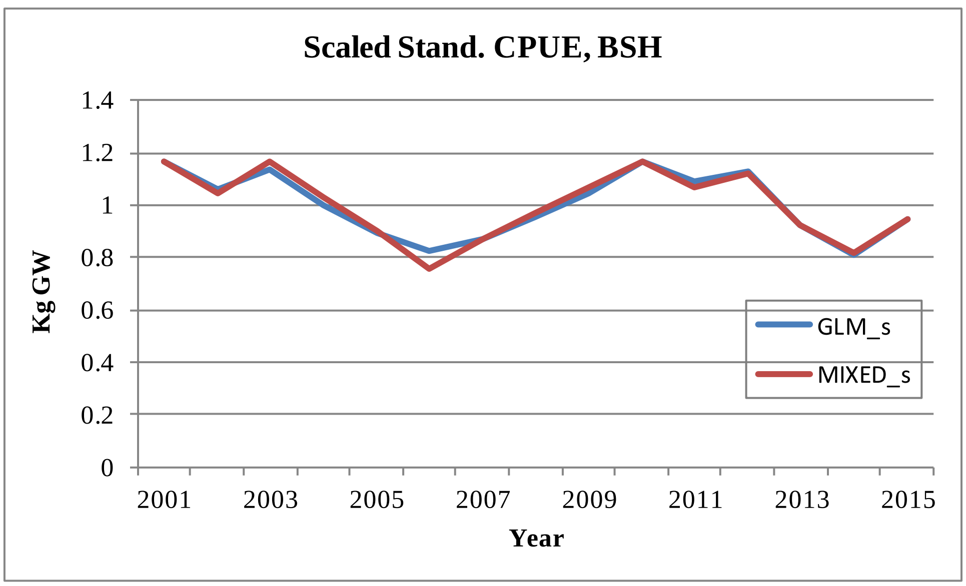

Figure 5. Comparative scaled standardized CPUE in weight by year (GLM *versus* MIXED) obtained for the blue shark in the Indian Ocean for the 2001-2015 period. Both series are scaled from their respective mean values.