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STANDARDIZED CATCH RATES FOR THE BLUE SHARK (*PRIONACE GLAUCA*) CAUGHT BY THE SPANISH SURFACE LONGLINE FLEET IN THE INDIAN OCEAN DURING THE 2001-2013 PERIOD

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SUMMARY

Standardized catch per unit of effort (CPUE) were obtained for the blue shark stock (Prionace glauca) of the Indian Ocean using General Lineal Models (GLM) from a total of 1838 trips of the Spanish surface longline fleet fishing swordfish during the 2001-2013 period. A base-case and two sensibility runs were conducted. The main factors considered into the base-case were year, area, quarter, gear and ratio between swordfish and blue shark catches. The significant base-case model explained the 82% of the CPUE variability of the blue shark. A major part of this variability was explained by the proxy of the targeting criteria defined as the ratio between the two more prevalent species caught during the trip, the swordfish and the blue shark. Other factors were also significant but less important. The standardized CPUE trend obtained in the base-case suggests a stable trend over time of the Indian Ocean blue shark stock. The sensitivity analyses showed similar trend as the base-case but in one of this runs the general trend obtained was slightly more optimistic when the ratio factor is excluded from the model.

RESUMEN

Tasas estandarizadas de captura por unidad de esfuerzo fueron obtenidas para la tintorera (Prionace glauca) usando Modelos Lineales Generalizados (GLM) a partir de 1838 mareas realizadas durante el periodo 2001-2013 por la flota española de palangre de superficie que captura pez espada en el océano Índico. Un caso-base y dos análisis de sensibilidad fueron realizados. Los principales factores considerados en el caso-base fueron año, área, trimestre, arte y el ratio entre la captura del pez espada y la tintorera. El modelo significativo obtenido explicó el 82% de la variabilidad de la CPUE observada. 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 entre las dos especies más deseadas y más prevalentes en los desembarcos, el pez espada y la tintorera. Otros factores fueron también identificados como significativos pero menos importantes. La CPUE estandarizada obtenida en el modelo básico sugiere una tendencia estable para este stock de tintorera del océano Índico. Los análisis de sensibilidad mostraron similar tendencia a la obtenida con el caso básico y en uno de ellos la tendencia fue ligeramente más optimista cuando se excluye el factor "ratio" del modelo.

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

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1. Introduction

Blue shark is a highly migratory, oceanic-epipelagic and wide-ranging circumglobal shark species distributed mostly -but not exclusively- between 50ºN-50ºS. Juveniles, recruits and in some cases adults of this species can also be found in fringe-littoral or coastal-nursery areas. However, the medium and large size individuals are mostly distributed in oceanic areas from temperate to tropical waters and size-sex segregation of this species has been described related to their respective biological processes (i.e. Mejuto and García-Cortés 2005, Nakano and Stevens 2008). The odd presence of some recruits was even described in some years as sporadic events very near of coastal areas, ports and marinas of the North Atlantic (Mejuto *et al*. 2014).

Blue shark is one of the most prevalent fish species in the oceanic-epipelagic layers because of its efficient viviparous reproductive strategy with an average of 37 pups per litter (Castro *et al.* 2000, Mejuto and García-Cortés 2005). Other authors indicate a litter average about 30 pups but up to 135 pups have been recorded (Nakano and Stevens 2008). The biomass of blue shark in the oceanic-epipelagic layers is regularly higher than that of many highly migratory-teleost species. The geographical distribution of this shark is within the range of the fishing areas targeting tunas and/or swordfish, which is why blue shark was historically a very prevalent species caught by several fishing gears targeting tunas and tuna-like species around the world.

The geographical distribution of blue shark in the Indian Ocean could be considered an exception in relation to other oceans. The environmental structure in the northern hemisphere of the Indian Ocean is different in relation to the Atlantic and Pacific oceans. In the Indian Ocean, there is a predominance of warm waters in the northern hemisphere and that may involve a different population structure and spatial-temporal segregation -with different migration patterns- in this stock relative to that described for the other two oceans cited.

The Spanish surface longline fishery targeting swordfish began operating in the Indian Ocean at the end of the last century. Several descriptions about this fishery covering from the initial to recent periods are available in literature, including catch estimations by species, reproductive parameters, etc. The most important bycatch of overall shark species in Indian areas was the blue shark. This species accounted for a yearly average of 85.8% (Std.= 4.8%) of all large-pelagic shark landings of this surface longline fleet during the 1995-2008 period (García-Cortés and Mejuto 2001, 2005; Ramos-Cartelle *et al*. 2008, 2009). This average remains similar in more recent years.

The standardized catch rates (CPUE) are frequently considered as an abundance indicator in a great number of large pelagic fisheries because the lack of direct indicators. The Generalized Linear Modeling (GLM) (Robson 1966, Gavaris 1980, Kimura 1981) has been used to estimate standardized catch rates based on data from commercial fleets with unbalanced spatial and temporal activity. This procedure has become a basic routine task in stock assessments because provides useful information on stock trends –or stock fractions- over time. Moreover, this standardized index is regularly required as key input data for tuning stock assessment models. However, the CPUE indicators as abundance indices must be evaluated based on the empirical knowledge of each fishery and the quality of the data used, the spatial-temporal coverage in relation to the stock distribution and taking into consideration the limits and risks involved in this assumption (Mejuto *et al*. 1999). Yearly changes in the predicted biomass indices should also be plausible from a biological point of view of these large-span species. The demographic structure and the biological characteristics of these species tend to buffer fluctuations in their total biomass even under scenarios of recruitment variability. The time-area distribution of the fleets and their fishing strategies over time are also important factors to be considered for said assumption. Consistency in fishing areas over time facilitates this interpretation and increases the reliability of the CPUE information (Carruthers *et al.* 2010). This paper sets out the blue shark biomass index obtained from the commercial Spanish longline fleet.

2. Material and methods

The records used for these analyses were voluntary reports of the Spanish surface longline fleet targeting swordfish in the Indian Ocean during the period 2001-2013. Data are mostly record per trip provided from different sources. Nominal effort was defined by thousands of hooks. The nominal catch per unit of effort (CPUE) was calculated as total kilograms of gutted weight (GW) caught per thousand hooks. Catch per unit of effort per trip -the response variable considered- was measured as biomass (total gutted weight in kg) per thousands hooks set. The standardized log (CPUE) analysis was done using the GLM procedure (SAS 9.2). The methodology used in this paper is based on previous research carried out on the Spanish longline fleet in the Atlantic (i.e. Mejuto and De la Serna 2000, Mejuto *et al.* 2000, 2001, 2002, 2009, 2013; Ortiz 2007, 2010; Ortiz *et al.* 2007, 2014; García-Cortés *et al.* 2014) and in the Indian Ocean (Mejuto *et al*. 2008, Ramos-Cartelle *et al.* 2011, Fernández-Costa *et al*. 2014).

Two runs were initially developed. In the first run (*base case*), the '*area*' factor used included 8 areas (figure **1**). A second run (*sensitivity 1*) included 4 areas as defined in Semba and Nishida (2008). A third run (*sensitivity 2*) was identical to the base case without considering the ratio effect. The *base case* and the *sensitivity 1* models defined included '*year*', '*quarter*', '*area*', '*ratio*' and '*gear*' as main factors, as well as the '*quarter***area*' interaction: LOG (CPUE) = u + Y + Q + A + R +G + Q * A + e. Where, u= overall mean, Y= effect year, Q= effect quarter, A= effect area, R= effect ratio, G= effect gear, e= logarithm of the normally distributed error term. The '*quarter*' definition used for GLM runs were the same as that previously used in the Atlantic and Indian ocean for swordfish, blue shark and shortfin mako (Mejuto *et al.* 1999, 2008, 2009, 2013; Mejuto and De la Serna 2000, Ortiz *et al.* 2007, Fernández-Costa *et al.* 2014). The '*ratio*' values were categorized into ten levels of 10% intervals in order to classify the types of trips. Two main types-styles of longline were clearly identified: the Spanish traditional multifilament gear and the monofilament gear broadly introduced around the end of the 20^{th} century (Mejuto *et al.* 2006 a,b). However, other gear characteristics or fishing practices have been also taken into consideration and compiled by means of skipper surveys (light sticks, clips, species declared as preference, etc.) in order to categorize several gear-levels into GLM runs. A total of four '*gear*' levels were finally categorized.

Trends over time of the standardized CPUE were plotted using rescaled values to the highest value obtained in each run.

3. Results and discussion

A total number of 1838 trip records were available during the period 2001-2013. Spatial-temporal coverage was appropriate for blue shark catches and fishing activity of this fleet over time (figure **1**). The average coverage of these observations represents 86.7% of the reported catches.

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

The significant *base case* model tested for the blue shark for the period 2001-2013 explained 82% of the CPUE variability in biomass of the Indian stock. All the explanatory factors tested contributed significantly to explain part of the deviance. As it was the case of the previous blue shark CPUE analyses (Mejuto *et al.* 2009), the CPUE variability (Type III SS) may be primarily attributed to the targeting criteria. The '*year*', '*area*' and '*gear*' factors were also significant, although less important. Only 6 trips were done with traditional gear and the rest of trips were done with monofilament style gear with different variations.

Table **2** provides information on estimated *base case* parameters per year, their standard error, CV%, relative CPUE in biomass and upper and lower 95% confidence limits. Figure **2** provides the aggregate standardized residual distribution by years and the normal probability *qq*-plot for the run. The box-plot of the standardized residuals obtained by year is shown in figure **3**. The fitting of the model seems not to be biased and residuals are distributed normally.

The standardized CPUE in biomass (*base case*) show a general stability of the relative abundance with the highest values obtained in years 2003, 2010 and 2012 followed by a moderate decrease in the last year. The *base case* general diagnosis suggests a relatively stable trend over time with a negligible negative-slope over time**.** The comparison between rescaled standardized and nominal CPUEs is also provided (figure **4).** Mimetic results were almost obtained in the *sensitivity 1* run using the areas defined by Semba and Nishida (2008) (figure **5**).

The *sensitivity 2* run (without the ratio effect) produced a similar general trend over time than the *base case*. However, the general trend showed a slightly positive slope (a more optimistic view) probably because an increase of the skipper's preference which was not buffered by the model defined. The result achieved a worse fit, explaining only 36% of the CPUE variability which was mainly attributed (Type III SS) to the '*area*' and '*area*quarter*' factors. The '*year*' and '*quarter*' main factors were also identified as significant although less important, whereas the '*gear*' was not considered significant in this run.

Blue shark was historically captured in the longline fisheries as bycatch species. However, a change in the targeting criteria was progressively observed during recent periods. As in the case of several fleets operating in the Atlantic, Indian and Pacific oceans, the ratio between the swordfish and blue shark catches is considered to be a good proxy indicator of the targeting priority of these skippers during the trips. After analyzing the behavior of the Spanish fleet in the Atlantic, Pacific and Indian oceans during decades, it was concluded that this ratio is a good proxy of the targeting criteria of the skippers, mainly and clearly aiming at swordfish at the beginning of the time series vs. a more diffuse fishing strategy aimed at the two main species combined or in favor of the blue shark in more recent period (Mejuto and De la Serna 2000). 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) although this method may not necessarily provide the best performance in all cases-fleets and particular proxies should be developed in each case. In this case, the '*ratio*' variable was defined for each trip as the relative importance of swordfish related to both the swordfish and blue shark combined. This ratio provides a good approximation of the skipper priority by trip and the targeting criteria. A similar approach -or via a prior clustering- to classify the type of trips or sets in bi/pluri-specific fisheries, is frequently used in the case of other longline fleets where the criteria for targeting are diffused -or have changed over time- and differences in gear characteristics or distinct working practices can not be identified. Similar findings were described in the case of other fleets catching swordfish and other species in the North and South Atlantic (i.e. Anon. 2001, Chang *et al.* 2007, García-Cortés *et al.* 2003, 2004, 2008; Hazin *et al.* 2007a,b; Mejuto and De la Serna 2000, Mourato *et al.* 2007, Ortiz 2007, 2010; Ortiz *et al.* 2007, 2010, 2014; Paul and Neilson 2007, Santos *et al.* 2014, Yokawa 2007) or in the Indian Ocean (i.e. Santos *et al.* 2012, 2013; Mejuto *et al*. 2008, Fernández-Costa *et al.* 2014).

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

Source	**DF**	**Sum of Squares**	**Mean Square**	**F Value**	**Pr > F**
Model	51	1017.161018	19.944334	157.29	<.0001
Error	1786	226.464508	0,1268		
Corrected Total	1837	1243.625526			

R-Square	Coeff Var	Root MSE	cpuew Mean
0.8179	5.691867	0.35609	6.256113

Source	**DF**	**Type III SS**	**Mean Square**	**F Value**	**Pr > F**
yr	12	21.1384466	1.7615372	13.89	<.0001
qtr	3	1.913363	0.6377877	5.03	0.0018
area	6	19.0616981	3.1769497	25.05	<.0001
gear	3	11.1999218	3.7333073	29.44	<.0001
ratio	9	570.9082416	63.4342491	500.27	<.0001
qtr*area	18	12.0378875	0.6687715	5.27	<.0001

Table 2. Base case estimated parameters (lsmean), standard error (stderr), CV%, mean CPUE in biomass of blue shark (CPUEw) (gutted weight -GW-) and upper and lower 95% confidence limits for the Spanish longline fleet in the Indian Ocean during the period 2001-2013 analyzed.

Year	**Lsmean**	**Stderr.**	**CV%**	**UCPUEw**	**Mean CPUEw**	**LCPUEw**
2001	5.86044	0.14113	2.408	467.321	354.390	268.750
2002	5.77017	0.13726	2.379	423.525	323.627	247.292
2003	5.84166	0.13525	2.315	453.006	347.515	266.590
2004	5.71666	0.13615	2.382	400.524	306.718	234.882
2005	5.59897	0.13693	2.446	356.642	272.692	208.503
2006	5.51848	0.13463	2.440	327.477	251.526	193.190
2007	5.56629	0.13806	2.480	345.991	263.965	201.385
2008	5.65468	0.13837	2.447	378.216	288.372	219.870
2009	5.74890	0.13851	2.409	415.700	316.869	241.535
2010	5.86361	0.14196	2.421	469.623	355.556	269.194
2011	5.79442	0.14078	2.430	437.137	331.732	251.742
2012	5.82787	0.13907	2.386	450.393	342.936	261.117
2013	5.62539	0.13809	2.455	367.082	280.037	213.633

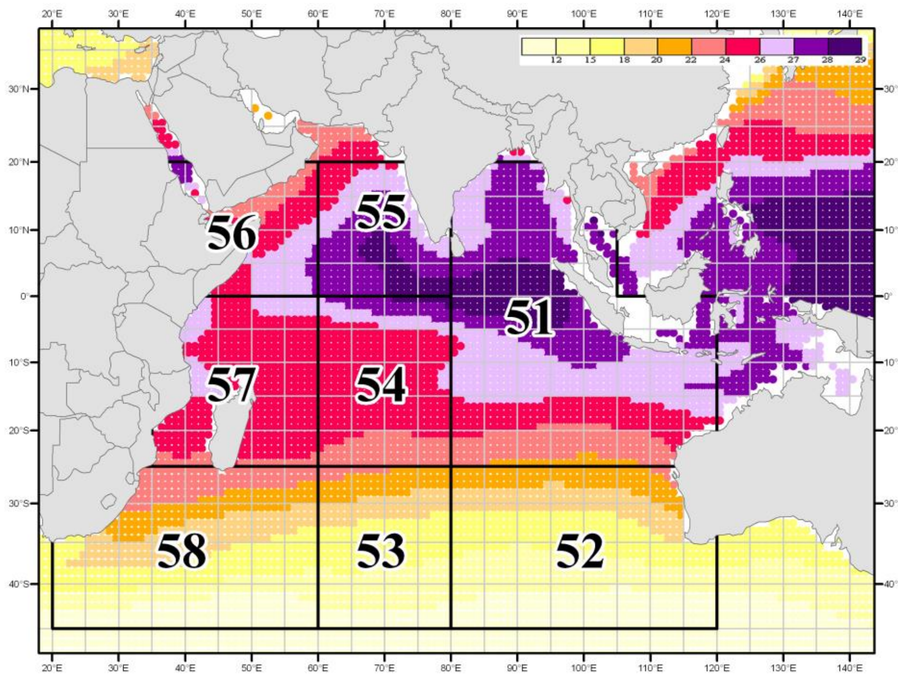

Figure 1. Geographical area stratification used for the GLM *base case* run of blue shark. Areas are superimposed on average sea temperature (ºC) at 50m depth.

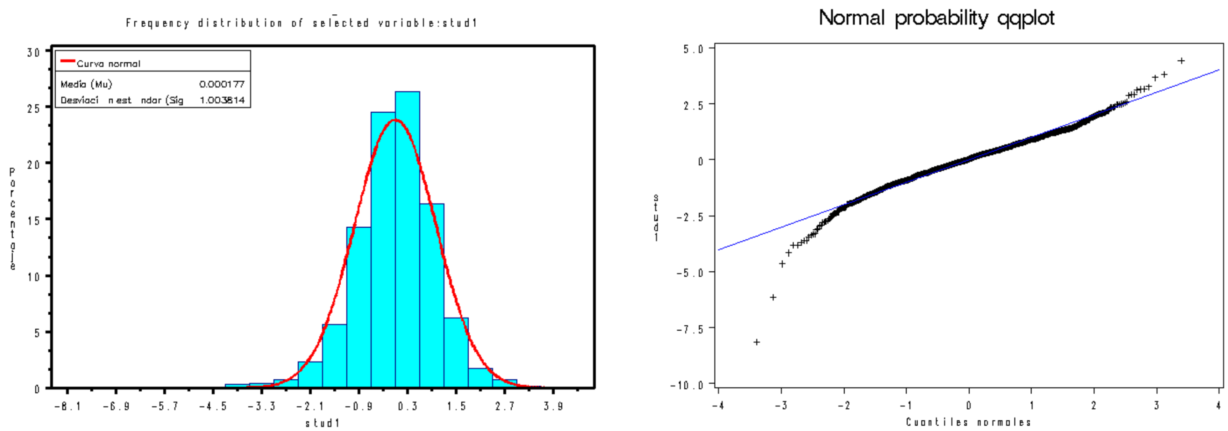

Figure 2. Distribution of the standardized residuals (base case) of blue shark in weight (left) and normal probability *qq*-plots (right), in the Indian Ocean for years 2001-2013 combined.

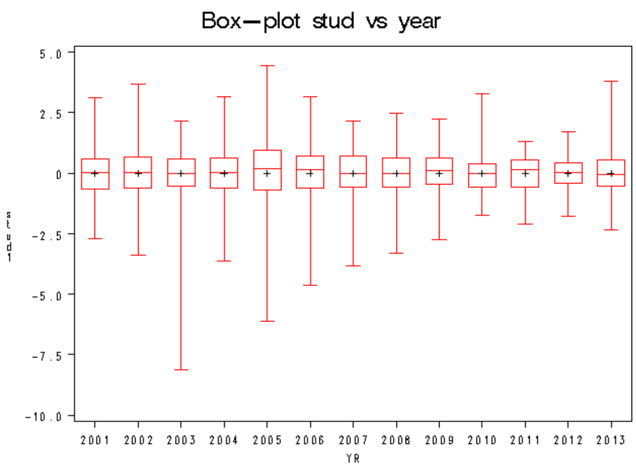

Figure 3. Box-plots (base case) of the standardized residuals *vs.* year for the Indian Ocean stock of the blue shark during the 2001-2013 period.

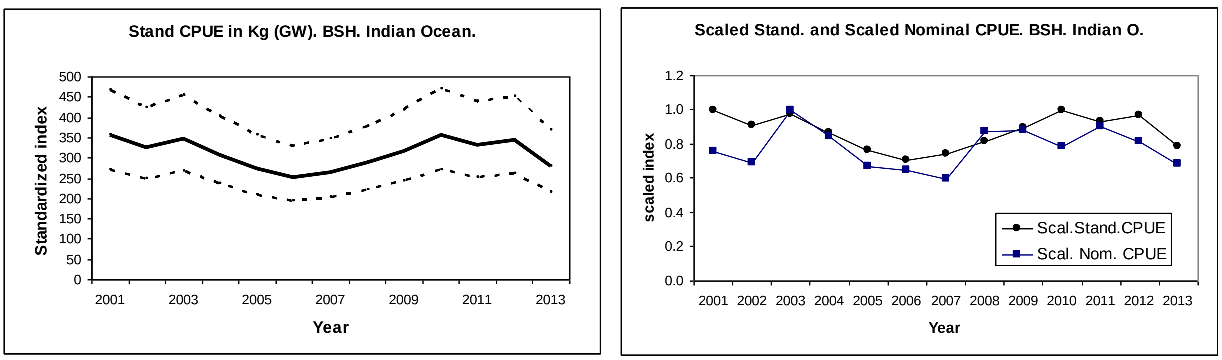

Figure 4. Standardized CPUE (base case) for the blue shark and 95% confidence intervals (left panel) and scaled nominal versus standardized CPUE (right panel), for the Indian Ocean during the 2001-2013 period.

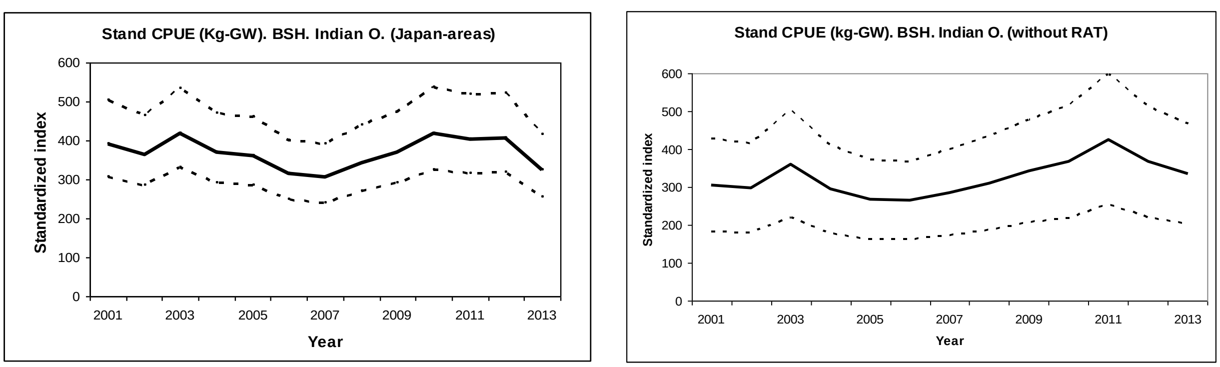

Figure 5. Standardized CPUEs obtained for sensitivity 1 (areas defined by Semba and Nishida 2008) and sensitivity 2 (without ratio) analyses for the blue shark during the 2001-2013 period, in the Indian Ocean.