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STANDARDIZED CATCH RATES IN BIOMASS FOR THE STOCK OF THE NORTH ATLANTIC BLUE SHARK (*PRIONACE GLAUCA*) CAUGHT BY THE SPANISH SURFACE LONGLINE FLEET IN THE PERIOD 1997-2013

B. García-Cortés[1], A. Ramos-Cartelle, J. Fernández-Costa and J. Mejuto

SUMMARY

*Standardized catch rates per unit of effort (CPUE) were obtained for the stock of the North Atlantic blue shark (*Prionace glauca*) using General Lineal Models (GLM) for a total of 5,639 trips of the Spanish surface longline fleet targeting swordfish, during the 1997-2013 period. The main factors considered were year, area, quarter, gear and ratio between swordfish and blue shark catches. The significant model explained the 84% of CPUE variability in blue shark. A major part of this variability was explained by the proxy of the targeting criteria, shown as the ratio between the two most prevalent species caught during the trip; swordfish and blue shark. Gear was identified as the second most important factor. Other factors were also significant, but less important. The standardized CPUE trend obtained suggests a stable trend of the North Atlantic blue shark stock and differs substantially from the nominal CPUE trends observed during the period considered.*

RÉSUMÉ

*Des taux de capture standardisés par unité d'effort (CPUE) ont été obtenus pour le stock de requin peau bleue (*Prionace glauca*) de l'Atlantique Nord au moyen de modèles linéaires généralisés (GLM) pour 5.639 sorties réalisées par la flottille palangrière de surface espagnole ciblant l'espadon entre 1997 et 2013. Les principaux facteurs pris en compte étaient l'année, la zone, le trimestre, l'engin et le ratio entre les prises d'espadon et de requin peau bleue. Le modèle significatif expliquait 84% de la variabilité de la CPUE du requin peau bleue. Une grande partie de cette variabilité s'expliquait par l'indice approchant du critère de ciblage, présenté en tant que ratio entre les deux espèces majoritairement capturées pendant la sortie, à savoir l'espadon et le requin peau bleue. L'engin a été identifié comme étant le deuxième facteur le plus important. D'autres facteurs étaient également significatifs, mais étaient moins importants. La tendance de la CPUE standardisée obtenue suggère une tendance stable du stock de requin peau bleue de l'Atlantique Nord et diffère considérablement des tendances de la CPUE nominale observées pendant la période étudiée.*

RESUMEN

Se obtuvieron tasas estandarizadas de captura por unidad de esfuerzo (CPUE) para la tintorera (Prionace glauca) del Atlántico norte usando Modelos Lineales Generalizados (GLM) a partir de 5.639 mareas realizadas durante el periodo 1997-2013 por la flota española de palangre de superficie que captura pez espada en el stock Atlántico norte. Los principales factores considerados en el modelo fueron año, área, trimestre, arte y ratio entre la captura del pez espada y la tintorera. El modelo significativo obtenido explicó el 84% de la variabilidad de la CPUE de esta especie. La mayor parte de la variabilidad de la CPUE fue explicada por el direccionamiento de los patrones de pesca el cual está representado por la ratio de los niveles de captura entre las dos especies más prevalentes en los desembarques, pez espada y tintorera. El factor arte fue identificado como el segundo más importante. Otros factores fueron también identificados como significativos pero menos importantes. La CPUE estandarizada obtenida sugiere una tendencia estable para este stock de tintorera del Atlántico norte, y difiere sustancialmente de la CPUE nominal observada durante el periodo considerado.

KEYWORDS

Blue shark, Sharks, CPUE, GLM, Longline, Spanish fleet

[1] Instituto Español de Oceanografía. P.O. Box 130, 15080 A Coruña. Spain. E-Mails: tunidos.corunha@co.ieo.es; http://www.co.ieo.es/tunidos

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. The odd presence of recruits was even described very near coastal areas, ports and marinas (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 around 37 pups per litter (Castro *et al.* 2000, Mejuto and García-Cortés 2005). The biomass of blue shark in the oceanic-epipelagic layers is regularly higher than that of many other 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 is a very prevalent species caught by the surface and deep longline fisheries targeting tunas and/or swordfish around the world.

The Spanish surface longline fishery targeting swordfish began operating in the Mediterranean Sea and the Atlantic Ocean centuries ago. The most important bycatch of shark species in North Atlantic areas was blue shark (Mejuto 1985). Blue shark accounted for an average of 87% of the pelagic shark landings of the Spanish surface longline fleet from combined Atlantic areas during the overall 1997-2006 period (Mejuto *et al.* 2009a). However, this proportion could be slightly higher in recent years after the implementation of several regulations on shark species. A detailed description of the activity of this fleet, changes in the targeting criteria over time, increases of the catches vs. landing and other relevant information about this fishery can be found in several papers (i.e. Mejuto 1985, Mejuto and De la Serna 2000, Mejuto *et al.* 2000, 2001 2002).

The Generalized Linear Modeling technique (GLM) (Robson 1966, Gavaris 1980, Kimura 1981) has been regularly used to estimate standardized catch rates based on data from commercial fleets with unbalanced spatial and temporal activity. This has become a basic routine task in stock assessments, in accordance with the scientific dynamics of RFMOs. The standardized catch per unit of effort data from commercial fleets is frequently considered as an abundance indicator in a great number of large pelagic fisheries. The standardized CPUE provides useful information *per se* on stock trends –or stock fractions- over time. Additionally, this index is regularly required as key input data for tuning stock assessment models. However, the CPUE indicators as abundance indices must be evaluated case by case, 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 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 to update the previous biomass index obtained from the Spanish longline fleet (Mejuto *et al.* 2009b).

2. Material and methods

The records used for this analysis were voluntary reports from the Spanish surface longline fleet targeting swordfish in the North Atlantic stock during the period 1997-2013. Data are mostly records per trip obtained when fish were landed at the different base-ports used by the North Atlantic fleet. Other sources of information such as interviews, some scientific observers or aggregated logbook data were also used in some cases. Nominal effort was defined by thousands of hooks per trip. The nominal catch per unit of effort was calculated as total kilograms of gutted weight (GW) caught per thousand hooks. Catch per unit of effort (CPUE) per trip -the response variable considered for this study- was measured as biomass (total gutted weight in kg) per thousands hooks set. 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, 2009b; Ortiz 2007, Ortiz *et al.* 2007, 2014, García-Cortés *et al.* 2014). The standardized log (CPUE) analysis was done using the GLM procedure (SAS 9.2).

Two main types-styles of longline were clearly identified: the Spanish traditional multifilament gear and the monofilament gear introduced around the end of the 20th century. However, other gear characteristics or fishing practices have also been taken into consideration and compiled by means of skipper surveys (light sticks, clips, species declared as preference, etc.) in order to categorize gear-levels into GLM runs.

The model defined includes '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 hypothetical boundary line between both Atlantic stocks was kept at 5ºN latitude, as assumed by the ICCAT. The 'year' factor consisted of trip records over the period 1997-2013. The 'quarter' definition used for GLM runs was the same as that previously used in the Atlantic for swordfish, blue shark and shortfin mako (Mejuto *et al.* 1999, 2009b, 2013; Mejuto and De la Serna 2000, Ortiz *et al.* 2007). A total of seven 'gear' levels were finally categorized. The 'area' factor used for final runs included 5 areas (**Figure 1**).

Blue shark had been historically caught by this fishery as bycatch species. However, a change in the targeting criteria was progressively observed during the period analyzed. As in the case of several fleets operating in the Atlantic, Indian and Pacific oceans, the 'ratio' between the swordfish and blue shark catches could be considered to be a good proxy indicator of the fishing criteria of these skippers during the period considered. After analyzing the behavior of the Spanish fleet in the Atlantic for decades, it was concluded that this ratio was a good proxy of the targeting criteria of the skippers to classify trips, mainly and clearly aiming at swordfish at the beginning of the time series *vs*. a more diffused fishing strategy aimed at the two main species combined or in favor of blue shark in a more recent period (Mejuto and De la Serna 2000). The Working Group on stock assessment methods of ICCAT reviewed this type of matters. The use of these ratios was found to perform best among the different proxy methods simulated and it was considered the preferred proxy, although this method may not necessarily provide the best performance in all cases or fleets (Anon. 2001). In this case, the 'ratio' variable was defined for each trip as the percentage of swordfish related to both the swordfish and blue shark caught. The ratio values were categorized into ten levels of 10% intervals in order to classify the levels-types of trip for modeling. A similar approach -or via a prior clustering approach- 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 target species are diffused or have changed over time. 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.* 2014, 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; Fernández-Costa *et al.* 2014).

3. Results and discussion

A total number of 5639 trip records were available during the period 1997-2013. Spatial-temporal coverage was appropriate for blue shark catches and fishing activity over time (**Figure 1**). The average coverage of the level of catches was 18.8%.

Table 1 shows the nominal CPUE in weight (GW) and **Table 2** provides the ANOVA summary obtained from the GLM 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 significant model tested for the blue shark for the period 1997-2013 explained 84% of the CPUE variability in biomass for the North Atlantic stock. All the explanatory factors tested contributed significantly to explain part of the deviance. As in the case of the previous blue shark CPUE analyses, the CPUE variability (Type III SS) may be primarily attributed to the targeting criteria shown as levels of the 'ratio' factor and, secondly, to the 'gear' factor. The 'quarter' and 'area' factors were also significant, although less important.

Table 3 provides information on estimated parameters, 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 seems to have a relatively stable trend over time (**Figure 4).** The scaled standard CPUE showed a stable trend with a small variability between some years (i.e. years 2000-2003). The scaled nominal CPUE showed a moderate upward trend until year 2006, and a higher increase afterwards. The trend obtained for the standardized CPUE is in line with the results of the last ICCAT assessment, which suggests that biomass levels of the stock were above (and fishing mortality rates well below) the level at which MSY is reached. The stability obtained in the standardized CPUE of this fleet supports those conclusions.

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Table 1. Nominal CPUE (kg gutted weight -GW-) for blue shark in the North Atlantic during the 1997-2013 period.

Year	*Nominal CPUE*
1997	220.72
1998	235.92
1999	316.35
2000	477.55
2001	606.60
2002	512.85
2003	571.76
2004	658.81
2005	647.13
2006	810.39
2007	881.07
2008	923.39
2009	976.15
2010	1021.82
2011	1220.28
2012	1142.26
2013	987.05

Table 2. Summary of ANOVA for CPUE analysis in biomass. GLM run: R square, mean square error (root) and F statistics. North Atl. Spain. LL. BSH, CPUE in biomass. Dependent variable: log (CPUE) (gutted weight -GW-)

Source	DF	Sum of Squares	Mean Square	F Value	Pr > F
Model	50	10263.6985	205.27397	606.66	<.0001
Error	5588	1890.78414	0.33837		
Corrected Total	5638	12154.48264			

R-Square	Coeff Var	Root MSE	cpue1 Mean
0.844437	10.69908	0.581692	5.436838

Source	DF	Type III SS	Mean Square	F Value	Pr > F
yr	16	65.308446	4.081778	12.06	<.0001
qtr	3	36.317454	12.105818	35.78	<.0001
area	4	26.938423	6.734606	19.9	<.0001
gear	6	344.435548	54.405925	169.66	<.0001
ratio	9	4968.25397	552.02822	1631.46	<.0001
qtr*area	12	35.366793	2.947233	8.71	<.0001

Table 3. Estimated parameters (lsmean), standard error (stderr), CV%, relative mean CPUE in biomass of blue shark (CPUE) (gutted weight -GW-) and upper and lower 95% confidence limits for the Spanish longline fleet in the North Atlantic during the period 1997-2013 analyzed.

Year	*Lsmean*	*Stderr.*	*CV%*	*UCPUE*	*Mean CPUE*	*LCPUE*
1997	5.05441	0.038301	0.758	169.054	156.828	145.486
1998	5.03910	0.039731	0.788	166.961	154.453	142.882
1999	5.19157	0.042723	0.823	195.628	179.914	165.462
2000	5.36057	0.043266	0.807	231.901	213.046	195.725
2001	5.37270	0.041736	0.777	234.011	215.631	198.694
2002	5.21373	0.042486	0.815	199.917	183.944	169.247
2003	5.40555	0.046297	0.856	244.047	222.877	203.543
2004	5.17653	0.047817	0.924	194.687	177.270	161.411
2005	5.11571	0.049525	0.968	183.829	166.824	151.391
2006	5.17531	0.053654	1.037	196.746	177.107	159.428
2007	5.22987	0.055549	1.062	208.572	187.056	167.760
2008	5.37248	0.060859	1.133	243.135	215.796	191.531
2009	5.27650	0.063806	1.209	222.204	196.083	173.032
2010	5.34093	0.055411	1.037	233.007	209.027	187.514
2011	5.39723	0.055303	1.025	246.448	221.132	198.416
2012	5.47071	0.056140	1.026	265.687	238.003	213.204
2013	5.31375	0.060696	1.142	229.191	203.485	180.662

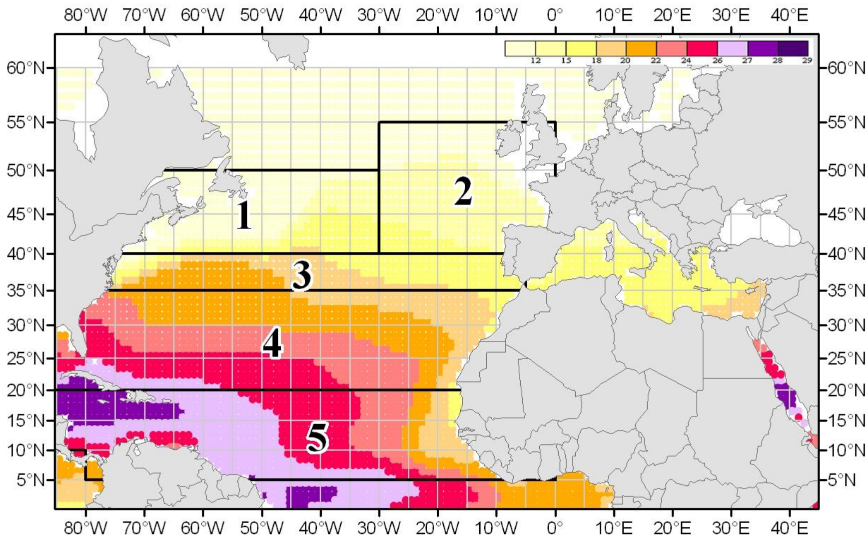

Figure 1. Geographical area stratification used for the GLM run of blue shark. The areas were kept as in previous GLM analyses. Areas are superimposed on average sea temperature (ºC) at 50m depth.

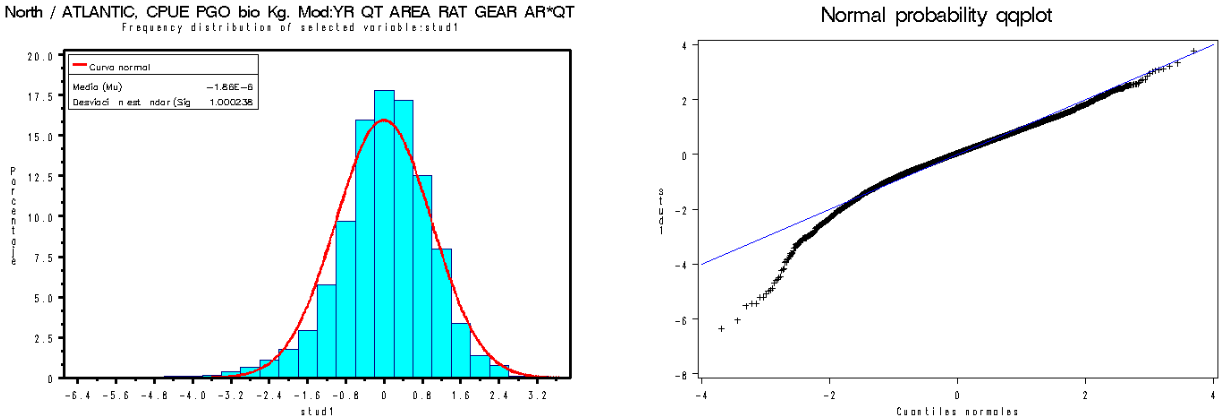

Figure 2. Distribution of the standardized residual of blue shark CPUE in gutted weight (left) and normal probability *qq*-plots (right), in the North Atlantic for years 1997-2013 combined.

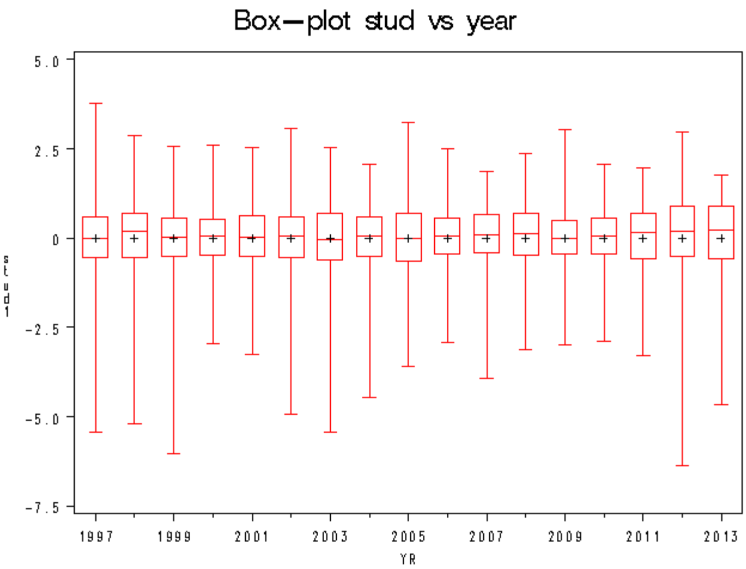

Figure 3. Box-plots of the standardized residuals *vs*. year for the North Atlantic stock of the blue shark during the 1997-2013 period.

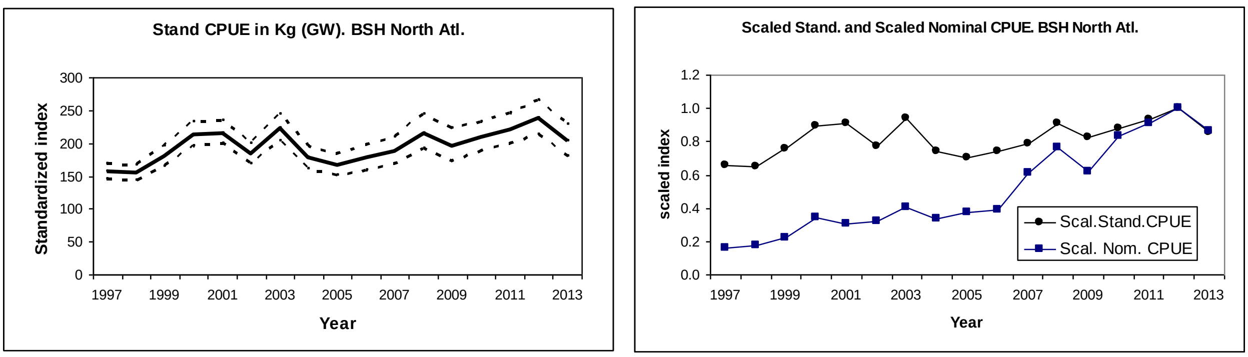

Figure 4. Standardized CPUE for the blue shark and 95% confidence intervals (left) and scaled nominal and standardized CPUEs (rigth) for the North Atlantic areas during the 1997-2013 period.