SCRS/2023/040 Collect. Vol. Sci. Pap. ICCAT, 80(4): 111-124 (2023)

UPDATED STANDARDIZED CATCH RATES IN BIOMASS FOR THE NORTH ATLANTIC STOCK OF BLUE SHARK (*PRIONACE GLAUCA*) FROM THE SPANISH SURFACE LONGLINE FLEET FOR THE PERIOD 1997-2021

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SUMMARY

*Standardized catch rates per unit of effort (CPUE) were updated for the North Atlantic stock of blue shark (*Prionace glauca*) using Generalized Linear Models (GLM). A total of 15,795 trips (94.6% of coverage) of the Spanish surface longline fleet catching swordfish between 1997-2021 period were analyzed. The main factors considered were year, quarter, area, gear and the targeting strategy. The base case model explained the 83% CPUE variability in weight. Most of the variability was explained by the proxy of the targeting criteria of skippers followed by gear factor. Other factors were also significant, but less important. The standardized CPUE show an increasing trend until 2008 and remains stable since then to 2021.*

RÉSUMÉ

*Les taux de capture standardisés par unité d'effort (CPUE) ont été mis à jour pour le stock de requin peau bleue (*Prionace glauca*) de l'Atlantique Nord au moyen de modèles linéaires généralisés (GLM). Un total de 15.795 sorties (94,6% de la couverture) de la flottille espagnole de palangriers de surface capturant l'espadon entre 1997 et 2021 ont été analysées. Les principaux facteurs pris en compte étaient l'année, le trimestre, la zone, l'engin et la stratégie de ciblage. Le cas de base du modèle expliquait 83% de la variabilité de la CPUE en poids. La plus grande partie de la variabilité a été expliquée par l'approximation des critères de ciblage des capitaines, suivie par le facteur de l'engin. D'autres facteurs étaient également significatifs, mais moins importants. La CPUE standardisée montre une tendance à la hausse jusqu'en 2008 et reste stable depuis lors jusqu'en 2021.*

RESUMEN

*Se actualizaron las tasas estandarizadas de captura por unidad de esfuerzo (CPUE) para el stock norte de la tintorera (*Prionace glauca*) del Atlántico usando Modelos Lineales Generalizados (MLG). Fueron analizadas un total de 15.795 mareas (94,6% de cobertura) realizadas durante los años 1997-2021 por la flota española de palangre de superficie que captura pez espada en el stock del Atlántico Norte. Los principales factores considerados en el modelo fueron año, trimestre, área, arte y el direccionamiento de los patrones. El modelo base explicó el 83% de la variabilidad de la CPUE en peso. La mayor parte de la variabilidad de la CPUE fue explicada por el direccionamiento de los patrones de pesca seguido por el factor arte. El resto de factores aunque significativos fueron menos importantes. La CPUE estandarizada obtenida sugiere una tendencia creciente hasta 2008, manteniéndose estable hasta 2021.*

KEYWORDS:

Blue shark, CPUE, GLM, abundance, longline

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1. Introduction

Blue shark (*Prionace glauca*) is a highly migratory species of wide ranging in the oceanic-epipelagic ecosystem with very high abundance and a broad and circumglobal distribution in tropical, subtropical and temperate areas. Although they are present in high latitude waters, they are not common at latitudes above 50º (Compagno 1984).

The Spanish surface longline fishery was developed since late 1970's in the North Atlantic areas targeting mainly swordfish (*Xiphias gladius*). The blue shark has been the most important bycatch of shark species in the Spanish surface longline fleet (García-Cortés *et al.* 2023 *in press*, Mejuto 1985, 2007; Mejuto *et al.* 2009[a]). However, since mid of 1980´s with the gradually introduction of on-board freezing systems together with other factors such as the quota allocation for swordfish and the increased economic importance in the market of blue shark allowed and encouraged skippers to retain on board and landing the swordfish and all blue shark caught and derivatives. This change in the fishing strategy for the targeting happened in several longline fleets in recent periods of their fishing activities. The impact of these changes on the fishing strategy has already been described in abundant ICCAT literature and also considered in the recent standardized CPUE analysis of Spanish fleet (e.g. Fernández-Costa *et al.* 2017, Mejuto and De la Serna 2000, Mejuto *et al.* 2001[a], 2001[b], 2009[b], 2017, 2021; García-Cortés *et al.* 2016, Ramos-Cartelle *et al* 2016, 2021[a], 2021[b]) as well as in many other fleets and it has been assessed by the SCRS Methods Working Group considering different scenarios (Anon. 2001).

An important change in the gear configuration took place in the early 2000's in the Spanish fleet when the multifilament style traditionally used was replaced by the American-style monofilament, broadly introduced in the Spanish Atlantic fleet and most vessels have been fishing with this new monofilament gear since then (García-Cortés *et al.* 2016, Mejuto and De la Serna 2000, Mejuto *et al.* 2001[a], 2001[b], 2009[b]). Catch-per-unit-effort (CPUE) data from fishery-dependent data have traditionally been used as the main source of information in order to obtain the relative index of abundance used in the ICCAT fish stock assessment. These indices may be considered in some cases to be an indicator of changes in abundance over time (Maunder and Punt 2004, Maunder *et al.* 2006, Ortiz and Arocha 2004). 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 bias the index and those standardized CPUE can be used as annual indices of abundance when data are robust and representative of the stock.

The main objective of this paper is to update the standardized CPUE series of the North Atlantic stocks of blue shark previously provided (e.g. García-Cortés *et al.* 2016, Mejuto *et al.* 2009[b]) for the forthcoming stock assessment. Detailed information about this fishery and methods can be found in document previously cited.

2. Material and methods

The data used in this analysis were voluntarily reported and taken for scientific purposes from the Spanish surface longline fleet targeting swordfish and from the scientific observers onboard in the North Atlantic stock, during the period 1997-2021. The catch per unit of effort (CPUE) was calculated as kilograms of gutted weight caught per thousand hooks and it was standardized using Generalized Linear Models (GLM). The methodology used in this paper is based on previous research carried out on the Spanish longline fleet in the Atlantic (Fernández-Costa *et al.* 2017, Mejuto and De la Serna 2000, Mejuto *et al.* 2009[b], 2017; García-Cortés *et al.* 2016, Ramos-Cartelle *et al*. 2016, 2021[a], 2021[b]). The analysis was done using GLM procedures (SAS 9.4). A sensitive analysis was also carried out using Generalized Linear Mixed Models (GLMM).

The areas definition used on the models were the same as those used in previous analyses for the North Atlantic stock of blue shark (García-Cortés *et al.* 2016). The hypothetical boundary line between North and South Atlantic stocks was located at 5ºN latitude as assumed by ICCAT. Two main gear types were considered in the analysis: the Spanish traditional multifilament style and the American monofilament style.

The fishing strategy for the targeting has changed since final 1990's and early 2000´s as well as during posterior periods. After analyzing the behavior of the Spanish fleet over time and considered a large amount of many contacts and interviews with skippers, it was concluded that the percentage in weight of swordfish landed by trip in relation to the amount of combined swordfish and blue shark landed is the best *proxy* indicator in this fleet for the skipper's targeting criteria to classify trips clearly targeted to swordfish of those trips more diffuse targeted to blue shark or toward both species (swordfish and/or blue shark) during the trip (Anon. 2001, Mejuto 2007, Mejuto and De la Serna 2000, Ortiz *et al.* 2010). In this case, the targeting criteria labeled as '*ratio*' variable was defined for each trip as the percentage of swordfish related to both the swordfish and blue shark caught. The targeting was categorized for each record and later considered in the base case model in ten levels (0.1 quantiles) in order to classify the level of type of trip (Mejuto 2007, Mejuto and De la Serna 2000). A similar approach to classify the type of trip or sets in multi-specific fisheries is frequently used in the case of other longline fleets where changes for targeting are known, it is diffused or they have changed over time (e.g. Carvalho *et al.* 2010, , Coelho *et al.* 2023, García-Cortés *et al.* 2016, Ortiz *et al.* 2010).

The response variable was the lnCPUE measured in kg gutted weight per 1000 hooks. The following explanatory variables were considered in the base case analysis: year, quarter (January-March, April-June, July-September, and October-December), area, ratio and gear and the quarter*area interaction.

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

Where, u= overall mean, Y= year effect, Q= quarter effect, A= area effect, R= ratio effect, G= gear effect, e= normally distributed error term. A sensitivity analysis was done using Generalized Linear Mixed Models (GLMM) procedure in which the year interactions were included in the model as random effect.

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

Following suggestion of a previous Working Group about to explore reducing the number of ratio categories, a sensitivity analysis were also performed for testing this categorical classification of the targeting. In this sensitivity analysis the targeting levels were broken down in 5 categories (0.2 quantiles) instead of 10 categories (0.1 quantiles) as in the base case.

3. Results and discussion

A total of 15,795 trip records were available for the analysis between 1997 and 2021. The spatial and temporal coverage of the observations were highly representative of the whole activity of this Spanish feet during the period analyzed. The percentage of catch covered in the analysis was the 94.59% of blue shark catch-task I data during this period. This coverage and representativeness is probably much higher than in many other CPUE analyses presented so far on this stock. **Figure 1** shows the geographical areas stratification used in the GLM models. They were the same areas used in previous analyses for the North Atlantic stock of blue shark (García-Cortés *et al.* 2016).

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 considered. The base case model explained the 83% of the CPUE variability in biomass. This value indicates a good model fit taking into consideration the factors selected and it probably is higher than most fit values in the CPUE modeling approaches of blue shark achieved in other fleets, although this value is some times omitted in results presented on other fleets. All the explanatory variables tested contributed significantly to explaining part of the deviance. The CPUE variability (Type III SS) may be mainly attributed to the targeting criteria (*ratio*) followed by the *gear* effect. The *year*, *quarter* and the interaction *quarter*area* were also significant, although less important.

Table 2 provides information on estimated base case parameters *(*lsmeans), their standard error, coefficient of variation, standard CPUE in biomass and upper and lower 95% confidence intervals obtained for the base case model. The mean CPUE in biomass (CPUEw) and their 95% confidence intervals are plotted in **Figure 4**. The results show an upward trend at the beginning with a peak in the year 2000, followed by a slightly decrease in the trend until 2006 and then a change on the trend increasing until 2008. From 2008 to recent years the trend remains stable.

Figure 2 provides a satisfactory distribution of standardized residuals and the normal probability *qq*-plot over the 1997-2021 period. The box-plot of the standardized residuals obtained by year is shown in **Figure 3**. The fit of the model seems not to be biased and residuals are normally distributed.

The sensitivity analysis carried out with GLMM procedure also showed that all the explanatory variables tested contributed significantly to explaining part of the deviance. The results were similar to the base case GLM model. Another sensitivity model run to view the effect of reducing the number of levels in the targeting criteria, reducing the levels to five categories (0.2 quantiles) explained the 80% of the CPUE variability in biomass. All the explanatory variables tested also contributed significantly to explaining part of the deviance. The CPUE variability (Type III SS) may also be mainly attributed in this case to the targeting criteria of skippers followed by *gear*. The *year*, *quarter* and the interaction *quarter*area* were also significant, although less important. So, the results obtained are consistent to those obtained using the base case GLM model but with a lower fit achieved. **Figure 5** shows a comparative between standardized CPUE performed in the base case and sensitivity analyzes. The CPUE were scaled to their maximum values to be compared. The trend were similar in all analyzes.

Historically, many ICCAT fisheries have been originated or reported as “single species” or had been considered “clear target species type”. As the fisheries, regulations and markets evolved –and/or the scientific knowledge improved– targeting practices often changed and may even change by trip, skipper, seasonally, year, etc. The SCRS and species working groups have requested to a previous ICCAT Working Group on Methods to evaluate and make specific recommendations on methods of CPUE standardization that take the issues of targeting and the spatial heterogeneity into account. The issue of *targeting* has been assessed by the ICCAT Methods Working Group in year 2000 using simulations for five different fishery-scenarios and several alternatives (Anon. 2001). The different cases identified for those simulations were based on some ICCAT fisheries in which systematic changes in targeting has been suspected in some fleets, or well described in the scientific literature in other fleets. One of the scenarios considered was: Swordfish (original target species) and blue shark (secondary target species). This concern is raised and revisited in some fleets in particular, although similar approaches based on different *proxies of the targeting* are regularly implemented in the analyses of many fleets. Some scientists have also expressed concern about how different sources of information used and model changes in targeting in fleets that may have different fishing practices and target species over area-times or years may affect the representativeness of the standardized catch rate series of blue shark CPUE –and probably in other species too– as indicators of the relative abundance of the stock (e.g., Walter *et al.* 2014).

Of course, a desired and direct way to estimate targeting is to use very detailed information on fishing practices that can define whether a given species is targeted or not. It is therefore recommended that when possible such detailed information be collected and used. Often, however, this information at such a *fine* level of details is not available neither provided with the catch and effort data and the targeting is in many cases unknown by scientists or very diffuse in available datasets. In such cases, it could be attempt to use other information, for instance the catches or information of a secondary target or by-catch species to develop indices with which fishing effort can be assigned to a particular target species. The results of the assessment performed using simulations (Anon. 2001) have suggested that there is no clearly *best method* that could be generally applied to all fleets-cases and that any one *proxy* -even if it performs best relative to the others- could still produce some biased results. Therefore, whenever it is of interest to try to correct for targeting when only total catch of each species and total effort is available, the results and conclusions of that study should be at least consulted and taken into consideration. In that sense, main conclusions of the ICCAT Methods Working Group (Anon. 2001) are: *Of the proxy methods evaluated, the use of the ratio of catch of the target species to total catch, performed best on average and remains the preferred proxy, although this method may not provide the best performance in all cases. These evaluations have not tested the bias in using CPUE as relative abundance indices when the effect of targeting is neglected. This source of bias could be substantial and should be evaluated within the simulations outlined above to provide a basis for comparing the costs and benefits of applying proxies for targeting relative to ignoring targeting effects*. So, it would be advisable to know and well identify the various particular conditions in each fishery of interest based on the empirical knowledge of each fishery and previous works before suggesting relative merits of a method versus other.

As previously indicated, the *type of trip* (targeting) was categorized in the present case as the percentage in weight of swordfish landed per trip in relation to the amount of the two species swordfish and blue shark landed per trip. Taking into consideration the information obtained from skippers, shipowners, observers and other sources, this information summarize the intention or species prioritization followed by the skippers of this fleet during each trip. After analyzing the behaviour of this fleet over time, testing several methodological approaches of categorization of the targeting and assessing the impact of this variable within the CPUE and standardized models, it was concluded that the ratio between these species is the best available *proxy* indicator for the skipper’s targeting criteria belonging to this fleet over time to categorize the type of trips (Mejuto and De la Serna 2000, Ortiz *et al.* 2010). This approach performed *best* among the different proxies simulated by the ICCAT Methods Working Group (Anon. 2001). Taking into consideration previous analyses, the best fit was achieved broken down the targeting into ten categories at 10% intervals for modelling the level of type of trip, but other type of categorizations were also tested. Consistent conclusion was recently achieved in another similar fleet testing different methods of categorization, including clusters (Coelho *et al.* 2023), but the cluster methods -also tested with similar results- are described by some authors as been more useful in analyses of multi-species fisheries because data often do not provide enough information on the intention of skippers, fishing behavior and operations (Carvalho *et al.* 2010). The “targeting strategy” was indentified in several studies as the main descriptive factor for standardized blue shark catch rates and, along with other factors that are known to influence catchability, it may be included in the standardization of the CPUE series using Generalized Linear Models (GLM) (Gulland 1983). The possible presence of collinearity among some factors it was considered as a less of a problem if the goal of the analysis to generate an index of relative abundance for use in a stock assessment because additional variables that are correlated tend not to add much explanatory power beyond the first variables selected (Maunder and Punt 2004).

It is recognized by many scientists as almost impossible to avoid some degree of model misspecification due to complexity and heterogeneity in the fishery operations among very different ICCAT fleets, several species likely targeted in some cases and their respective fishing patterns. A first step is to determine in each fleet which explanatory variables should be a priori considered that they may influence catchability of the species. The empirical information obtained from the fishing actors is one of the main keys. In each fleet, methodology to standardize catch rates is often developed and adapted to their respective casuistry in terms of the history of the fishery (the greater or lesser knowledge of the fishery and information recorded from fishermen), the deficiencies or lacks of the historical data available (e.g. Kai 2023, Walter *et al.* 2014), the empirical knowledge on the target and by-catch species, the fishing practices and changes over time (e.g. Cardoso *et al.* 2023); among other factors considering their respective particularities. So, it is important to create a hypothesis and configure models based on a strong empirical basis to identify those real changes in targeting for suggesting a realistic model and taking into consideration those fishing facts empirically observed.

A study proposes the implementation of *Finite Mixture Modeling* (FMM) in the CPUE standardization in those *multispecies-fisheries* in which the target species is *completely unknown* and some of the variables considered in the model do not adequately capture the type of "target" (Shibano *et al.* 2021). In those cases, the authors propose that the implementation of FMM models would allow simultaneously estimate the *various target species* and the *annual trends in abundance*, compared to methodological alternatives such as suggested on blue shark and other species by main authors that incorporate the so-called *target strategy* in the model as an explanatory variable, for instance using six different fishing levels according to the percentage of target species (Carvalho *et al.* 2010). The *target strategy* was in the last case the most important factor explaining the catch rate variance of the blue shark in all GLM models tested**.** In the present case, based on the empirical knowledge of this fishery and studies done since the eighties, the authors also propose to categorize the stratification of the targeting (the *type of trip*) as an explanatory variable because it was empirically identified, identifiable in scientific data available and well recorded over time; so considered the best available approximation in this case to explain the fishing strategy of the skippers over time. The transitions or changes over time in this case from a more strict targeting from SWO to a diffuse SWO and/or BSH fishing strategy was scientifically tracked and manifested itself over the series in the prioritization of the catches looking for and retaining the skippers both species within each trip. Likewise, the use of the different methods and levels of targeting has been previously studied and it was considered an appropriate approach based on this and other similar fleets where blue shark is very important or a dominant component of the catches (e.g., Carvalho *et al.* 2010, Coelho *et al*. 2023). Moreover, this approach is supported in the present case on the fact that there have been no substantial changes in the fishing areas of this fleet throughout the years analyzed, the transition of the longline style occurred was scientifically tracked during the period and also modelled. Nor in this case was there identified significant changes in terms of the depth of the fishing gear, the day-night fishing pattern, type of vessel size, changes in hooks "per basket", branchline types, tunas vs. swordfish targeting, deep and/or shallow sets targeting tunas and/or swordfish, etc.; as it has been described in other fleets whose effects could be taken into consideration in those cases for the significant effects on the catchability of the different species and in the blue shark in particular; but whose complete details are rarely provided in logbooks dataset (e.g. Cortés 2017), in dealer landing systems, or even in scientific observers at sea datasets (e.g. Zhang and Cortés 2023) and *proxies* have to be also used in such cases. In summary, main changes that have occurred in the fishery analyzed in the present paper have been empirically studied and documented. This approach makes it possible to compare the standardized series during the different periods of activity of this fleet within which these processes have been evaluated and incorporated in the standardization. Without ruling out other possible methodological approaches that could be applied to particular casuistic the suitability of the methods could be compared adapted to each case. That was in fact the exercise already performed by Anon. (2001) simulating this particular case among other scenarios tested, although this methodological approach does not necessarily performs *best* for the fishing histories of other fleets throughout the years considering their respective data availability and their different and probably diffuse -or unknown- targeting strategies over time on several or combined species modelled.

Another alternative also suggested for standardizing the CPUE of a by-catch species like blue shark could be to consider as a factor in GLM the different levels of nominal catch rates observed in several potentially target species (assuming equal effort). This last approach could be started from the hypothesis that there was an *on-off* opportunistic activity of the fleet according to "local" abundance or availability among the various species in the area-time of the fishery and/or a relationship between the nominal catch rates of the blue shark (by-catch) and those of the targeted species (e.g., yellowfin tuna, bigeye tuna, swordfish, etc.). Taking into consideration some changes regularly required in the gear configuration for targeting those different species, the *on-off* fishing strategy at sea should be *a priori* assumed with some caution. In other hand, if catch rates of other species are closely related to the catch rates of the species of interest (the blue shark) and are being fished down at the same time, the inclusion of catch rates of those other species as explanatory variables may confuse the time trends and attributed to the year effect (e.g., Maunder and Punt 2004). Regardless of the plausibility of that hypothesis, these last scenarios described are not the one that has happened in the fleet analyzed in the present paper. But perhaps it is the one empirically observed and considered as *best proxy* in such cases based on the deviance explained by the *catch per unit of effort* of the target species considered (or group of "target" species combined) related to the *catch per unit of effort* of a by-catch specie such as the blue shark (e.g., Zhang and Cortés 2023).

It has also been in some cases hypothesized that the introduction of the *targeting* as an explanatory variable within the GLM models could cause a false vision of *hyper-stability* in the standardized CPUE trends. The truth is that in the case of this fleet and its history compile over time, it has been seen and previously described that the non-inclusion of the change in targeting over time could produces a fake and systematic inter-annual *hyper-instability* predicting false changes in the relative abundance throughout the years. The omission of the targeting factor in the present case would falsely adjudicate a large part of the variability in CPUE observed to the year effect, but it was really due to changes in targeting among both species that occurred over time with subsequent effects on the respective CPUE of swordfish and blue shark (Mejuto 2007). In this sense, conclusion of Anon. (2001) seems to be very relevant: *the benefits of applying proxies for targeting relative to ignoring targeting effects*.

The coefficients of variation (CV) provided in the present study were suggested as been relatively shorter than those obtained -when described- in studies of other fleets. The CV is a statistical measure that tells us about the relative dispersion around the mean of a dataset analyzed. Dispersion of the data could be affected by many factors. It is convenient to put in context the meaning of the CVs obtained in the different studies considering the respective fleets, gear-styles modeled, targeting criteria, model approach, volume of data used and the representativeness of each dataset, area-time definitions, quality of the observations and filtering implemented before modeling; and of course, the aggregation degree of the respective records modeled. For instance, the standardization of catch rates carried out on shortfin mako based on data from observers at sea using a relative low data coverage it regularly have produced broader confidence intervals and higher CVs (range 19-47%) than those obtained using mandatory logbooks data (range 7-13%) with a much high coverage, using in both cases set-by-set data of the same fleet, although mandatory logbook data could be affected by misreports of catches for some years (e.g. Cortés 2017). In a similar way, studies carried out in a fleet for swordfish CPUE standardization achieved lower CV (range 3-51%) when shallow sets were separately analyzed versus much higher CV values (168-269%) when deep sets considered (e.g., Sculley *et al*. 2018). Different ranges of CVs could be also obtained depending of the dataset used and the model factors considered for the same fleet (e.g. Walter *et al.* 2014). Lower CVs do not necessarily means that they better represent the abundance of the stock it doesn't mean either the opposite. For instance, a very low amount of record used from restricted areas-times and with low variability in the fishing practices observed could achieve relatively lower CVs (e.g., Tsai and Liu 2017) than those obtained in other fleets with highly amount of data and much greater representativeness. The assessment of each index -and weights considered in the stock assessment models- should be evaluated case by case based on *qualitative* and *quantitative* merits of the data used, the credibility of each dataset, the spatial coverage of each fleet data in relation to the stock area-distribution, as well as (inter alia) the biological plausibility of the inter-annual CPUE variability obtained in the analyses since abrupt changes in the total abundance should not be biologically plausible in this species during short time scenarios (Ramos-Cartelle *et al.* 2011).

Acknowledgments

The authors would like to give their sincere thanks to all the members of the team who were involved in the scientific recording and processing of the basic data used in the analysis. We would also like to thank the scientific observers and skippers of the Spanish surface longline fleet involved in this voluntary scientific collaboration.

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Table 1. Summary of ANOVA for blue shark CPUE of the North Atlantic stock. GLM base case procedure: R square, Root MSE and F statistics. Response variable: ln (CPUEw) in gutted weight.

Source	*DF*	*Sum of Squares*	*Mean squared*	*F value*	*Pr>F*
Model	53	27049.26863	510.36356	1443.6	<.0001
Error	15741	5564.99465	0.35354		
Total	15794	32614.26328			

R-Squared	**Coeff. Var.**	**Root MSE**	**Mean CPUEw**
0.829369	9.564946	0.594588	6.216325

Source	**DF**	**Type III SS**	**Mean squared**	**F value**	**Pr>F**
yr	24	157.21366	6.55057	18.53	<.0001
qtr	3	132.55826	44.18609	124.98	<.0001
area	4	73.03098	18.25774	51.64	<.0001
ratio	9	14062.01094	1562.44566	4419.49	<.0001
gear	1	332.36887	332.36887	940.13	<.0001
qtr*area	12	131.17157	10.93096	30.92	<.0001

Table 2. Estimated parameters (lsmeans), standard error (stderr), mean CPUEw in biomass (gutted weight) of blue shark, upper and lower 95% confidence limits and coefficient of variation (CV%) for the Spanish longline fleet in the North Atlantic between 1997 and 2021.

YR	*LSMEAN*	*STDERR*	*UCPUEw*	*CPUEw*	*LCPUEw*	*CV%*
1997	5.22750	0.022600	194.815	186.374	178.298	2.26
1998	5.19467	0.022679	188.552	180.355	172.513	2.27
1999	5.35664	0.024832	222.654	212.077	202.002	2.48
2000	5.65511	0.024017	299.607	285.831	272.687	2.40
2001	5.55771	0.023598	271.577	259.302	247.582	2.36
2002	5.40647	0.023972	233.631	222.908	212.677	2.40
2003	5.55565	0.027317	273.024	258.791	245.299	2.73
2004	5.45233	0.027814	246.469	233.392	221.009	2.78
2005	5.40909	0.029293	236.733	223.524	211.052	2.93
2006	5.40160	0.032355	236.404	221.877	208.244	3.24
2007	5.52292	0.033475	267.491	250.505	234.596	3.35
2008	5.66792	0.033632	309.330	289.596	271.122	3.36
2009	5.61573	0.032028	292.663	274.856	258.132	3.20
2010	5.59506	0.031286	286.252	269.226	253.213	3.13
2011	5.63298	0.031511	297.449	279.634	262.886	3.15
2012	5.61634	0.030866	292.164	275.013	258.868	3.09
2013	5.66353	0.031931	306.931	288.311	270.820	3.19
2014	5.60659	0.029997	288.828	272.337	256.787	3.00
2015	5.64141	0.028258	298.030	281.972	266.779	2.83
2016	5.55025	0.027898	271.870	257.403	243.706	2.79
2017	5.50077	0.028867	259.244	244.983	231.507	2.89
2018	5.48602	0.031507	256.794	241.416	226.958	3.15
2019	5.47643	0.031182	254.178	239.108	224.932	3.12
2020	5.56349	0.020201	271.316	260.783	250.660	2.02
2021	5.57350	0.028150	278.403	263.459	249.316	2.82

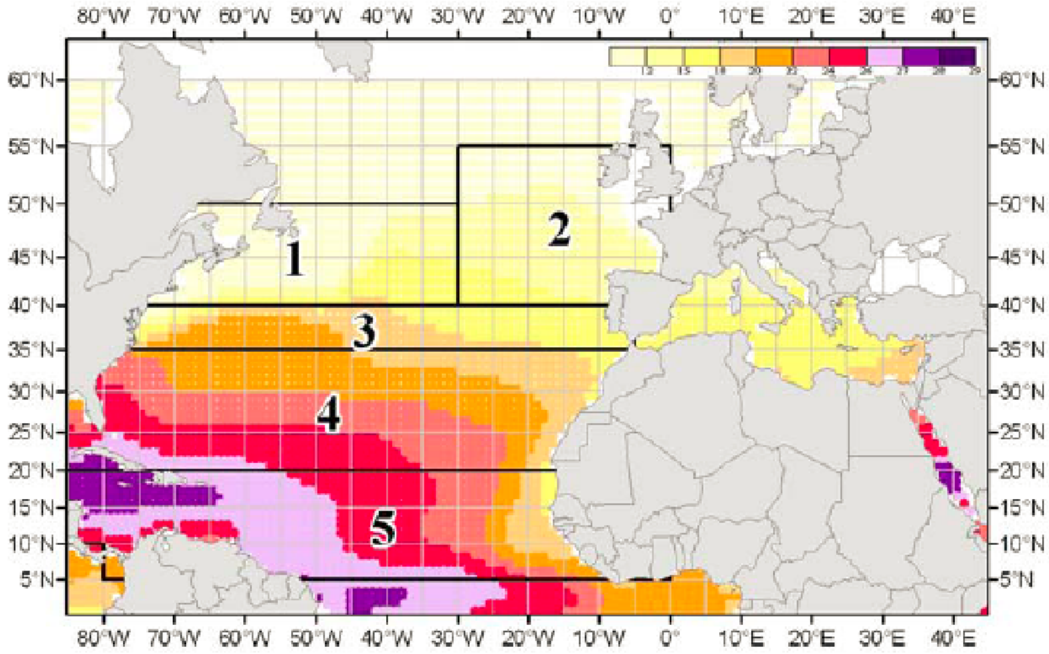

Figure 1. Geographical areas stratification used in the GLM for blue shark. The areas were kept as in previous analyses. Areas are superimposed on average sea temperature (ºC) at 50 meters depth.

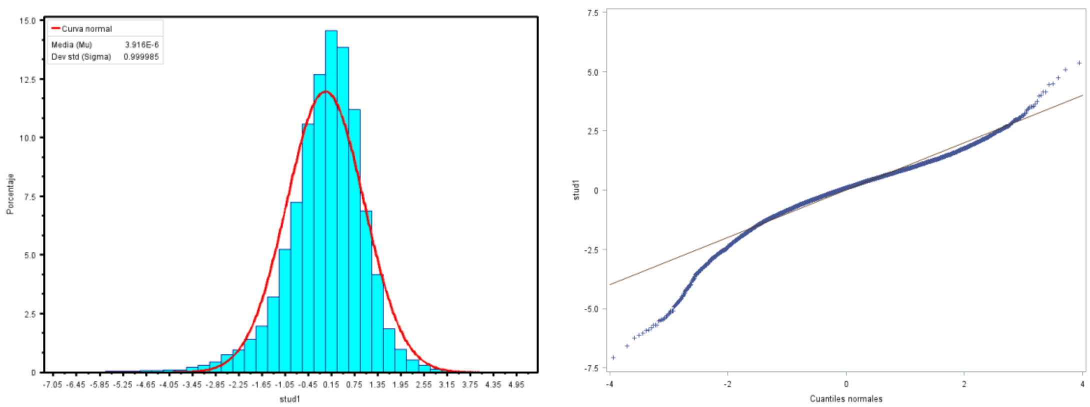

Figure 2. Distribution of the standardized residuals in gutted weight (left) and normal probability qq-plot (right) of blue shark in the North Atlantic stock for years 1997-2021 combined.

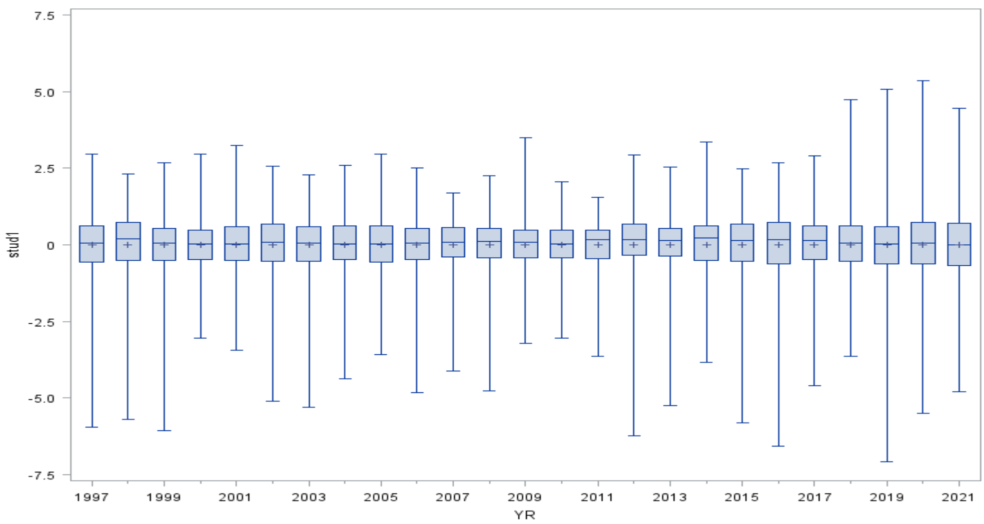

Figure 3. Box-plot of the standardized residuals *vs.* year for the North Atlantic stock of blue shark between 1997 and 2021.

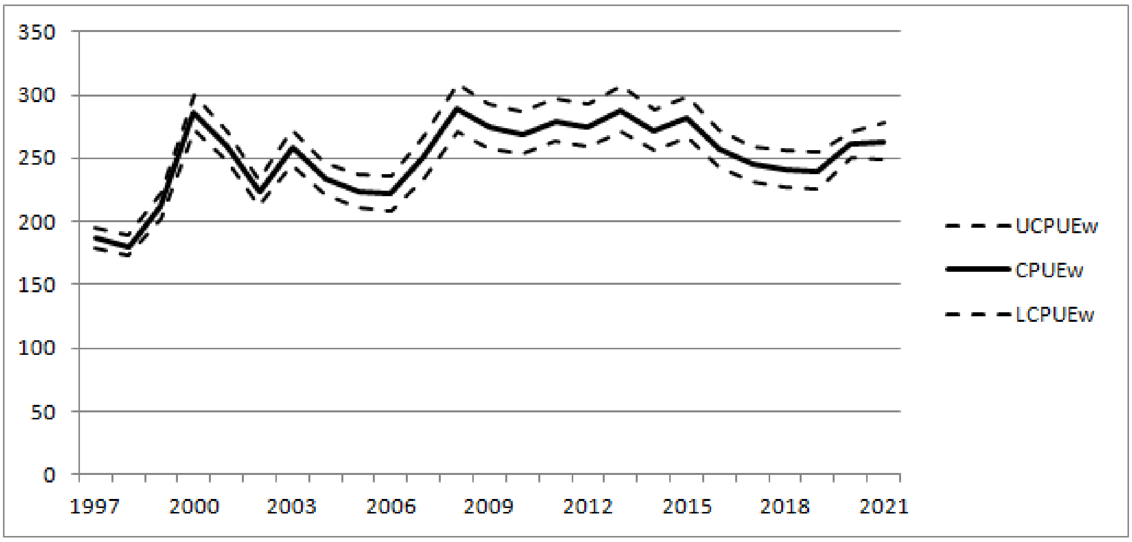

Figure 4. Standardized CPUEw for blue shark and 95% confidence intervals for North Atlantic stock between 1997 and 2021.

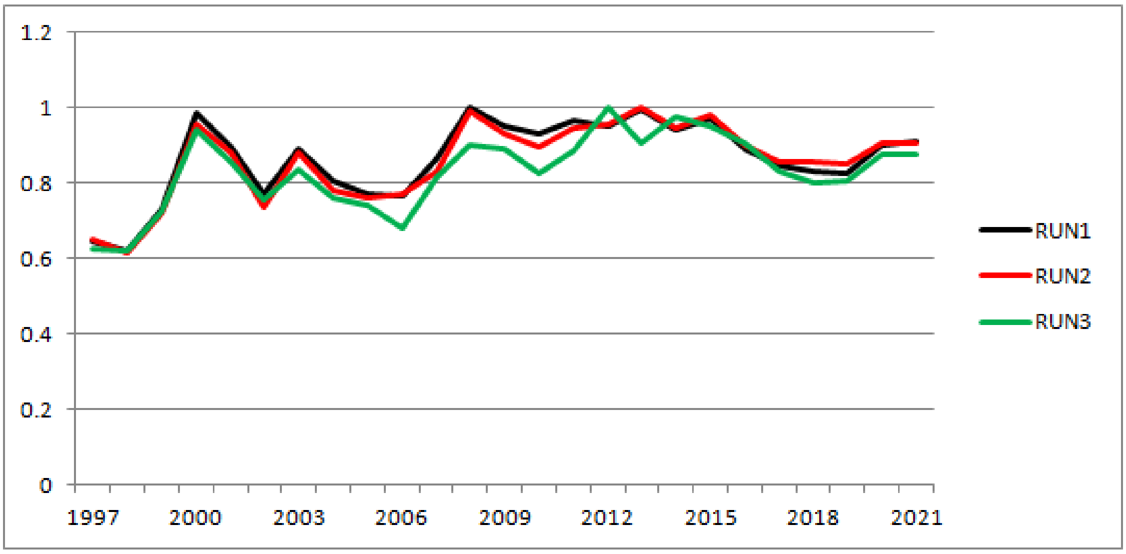

Figure 5. Comparative scaled-standardized CPUEw (in gutted weight per thousand hooks) carried out for blue shark in the North Atlantic stock between 1997 and 2021. RUN1= base case, RUN2= base case with 5 categories of ratio factor, RUN3= GLMM procedure.