SCRS/2017/108 Collect. Vol. Sci. Pap. ICCAT, 74(4): 1730-1745 (2017)

UPDATED STANDARDIZED CATCH RATES OF SHORTFIN MAKO (*ISURUS OXYRINCHUS*) CAUGHT BY THE SPANISH SURFACE LONGLINE FISHERY TARGETING SWORDFISH IN THE ATLANTIC OCEAN DURING THE PERIOD 1990-2015

[1] José Fernández-Costa, Blanca García-Cortés, Ana Ramos-Cartelle and Jaime Mejuto

SUMMARY

*Standardized catches per unit of effort (in number and weight) were obtained for the shortfin mako (*Isurus oxyrinchus*) using General Linear Modeling procedures based on trip data from the Spanish surface longline fleet targeting swordfish in the North and South Atlantic Ocean over the period 1990-2015. A base case and two GLM sensitivity analyses were carried out including a MIXED procedure. Area was identified to be the most relevant factor in explaining CPUE variability in all cases. The base case models explained between 40-46% of CPUE variability. The comparison of the standardized CPUEs obtained from the base case and the sensitivity models show a very similar and stable general trend over time regardless of the model used for the North Atlantic stock. The base case and sensitivity analysis using a mixed model also show very similar trends over time in the case of the South Atlantic stock. All scenarios tested suggest overall stable CPUE trends or a slightly increase trend, in the North and South Atlantic stocks respectively.*

RÉSUMÉ

Les prises standardisées par unité d'effort (en nombre et en poids) ont été obtenues pour le requin-taupe bleu de l'Atlantique (Isurus oxyrinchus) *au moyen du modèle linéaire généralisée reposant sur les données des sorties de la flottille palangrière de surface espagnole ciblant l'espadon dans l'Atlantique Nord et Sud au cours de la période 1990-2015. Un cas de base et deux analyses de sensibilité GLM ont été effectués, dont une procédure mixte. On a identifié que la zone était le facteur le plus pertinent pour expliquer la variabilité de la CPUE dans tous les modèles. Les modèles du cas de base ont expliqué entre 40-46% de la variabilité de la CPUE. La comparaison des CPUE standardisées obtenues à partir du cas de base et des modèles de sensibilité montre une tendance générale très similaire et stable au fil du temps quel que soit le modèle utilisé pour le stock de l'Atlantique Nord. Le cas de base et l'analyse de sensibilité utilisant un modèle mixte montrent également des tendances très similaires au fil du temps dans le cas du stock de l'Atlantique Sud. Tous les scénarios testés suggèrent des tendances globalement stables de CPUE ou une tendance légèrement à la hausse, respectivement pour les stocks de l'Atlantique Nord et Sud.*

RESUMEN

*Tasas estandarizadas de captura por unidad de esfuerzo (en número y peso) fueron obtenidas para el tiburón marrajo dientuso (*Isurus oxyrinchus*) usando modelos lineales generalizados a partir de datos por marea de la flota española de palangre de superficie que captura pez espada en el Atlántico norte y sur durante el periodo 1990-2015. Se llevaron a cabo dos análisis de sensibilidad GLM y un caso base incluyendo procedimiento «MIXED». El factor área fue identificado como el más relevante en todos los casos para explicar la variabilidad de la CPUE. Los modelos "caso base" explicaron entre 40-46% de la variabilidad de la CPUE. La comparación entre las CPUE estandarizadas obtenidas en el caso base y los análisis de sensibilidad mostraron una tendencia general estable y similar a lo largo de los años independientemente del modelo usado para el stock del Atlántico norte. El caso base y el análisis de sensibilidad usando un modelo "mixed" mostraron tendencias similares a lo largo*

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

de los años en el caso del stock del Atlántico sur. Todos los escenarios analizados sugieren una tendencia general estable de la CPUE o una tendencia a un ligero incremento, en los stocks norte y sur respectivamente.

KEYWORDS

Shortfin mako, sharks, CPUE, GLM, longline, Spanish fleet

1. Introduction

Shortfin mako (SMA) is usually the second most prevalent large pelagic shark bycatch species -after the blue shark- of many longlines fishing tuna and tuna-like species in the epipelagic layers of the Atlantic Ocean. Vertical migrations of SMA had been described at depths of up to eight hundred meters within a wide range of sea temperatures (Abascal *et al.* 2011, Vaudo *et al.* 2016). This bycatch species is fully retained and is also much prized as a regular bycatch in the Spanish surface longline fishery targeting swordfish (Buencuerpo *et al*. 1998, Fernández-Costa and Mejuto 2010, Garcés and Rey 1983, Mejuto 1985, Mejuto and González-Garcés 1984, Moreno 1995).

For decades this fleet has used the traditional multifilament surface longline style. Fishing activity targeting swordfish usually covers surface layers to a depth of around 50 m with night sets being carried out. A similar number of hooks per basket and the same longline style remained relatively constant for decades in terms of general structure and configuration (Hoey *et al*. 1988, Rey *et al*. 1988). Some technological improvements were introduced during the early periods of this fishery in order to increase the number of hooks per set. But one of the most important changes was the introduction and subsequently the broad implementation of the "American style" longline (monofilament) towards the end of the 90's (Mejuto and De la Serna 1997, 2000; Mejuto *et al*. 1997, 1998, 1999). Additionally, the more diffuse targeting criteria applied to swordfish and/or blue shark could be pointed out as another main change in the fishing patterns of this fishery at the end of the last century. Further information about the history of this fishery and its involvement in data analyses can be found in available ICCAT literature.

Full stock assessments commonly require at least catch data series and indices of abundance that should be standardized. The catches per unit of effort (CPUEs) are assumed to be reliable indicators of abundance for most large pelagic species in view of the lack of direct abundance indicators or scarce independent fishery data. CPUE indicators must be evaluated on a case by case basis taking into account -among other factors- the empirical knowledge of each fishery, the quality of the data used, the spatial coverage of each fleet in relation to the stock area-distribution, as well as the biological plausibility of the inter-annual CPUE variability obtained in the analyses for this type of long-span species, since abrupt changes in the total biomass should not be expected during short time scenarios (Ramos-Cartelle *et al.* 2011).

Generalized Linear Modeling techniques (GLM) (Gavaris 1980, Kimura 1981, Robson 1966) have been used to estimate standardized catch rates based on data from commercial fleets with unbalanced spatial-temporal activity as regularly observed, because of the complex migratory behavior of the large pelagic species linked to environment habitats and because of the adaptation of the fleets to the area-time availability of the targeted species. The standardized catch rates of the Atlantic swordfish (*Xiphias gladius*), several sharks and other species were determined in recent decades by means of GLM procedures based on data from several commercial fleets or combinations thereof (e.g. Anon. 1989, 1991; Hoey *et al*. 1989, 1993; Babcock and Skomal 2008, Brown 2008, Cortés 2008, 2009, 2010; Fowler and Campana 2009, Matsunaga 2008, Mejuto 1993, 1994; Mejuto and De la Serna 1995, Mejuto *et al*. 1999, Mourato *et al*. 2007, 2008; Nakano 1993, Ortiz *et al*. 2007, Pons and Domingo 2008, Scott *et al*. 1993). CPUE standardizations of the Spanish longline fishery were carried out covering long time periods for high prevalence large epipelagic shark species (*Prionace glauca*, *Isurus oxyrinchus)* (e.g. Mejuto *et al.* 2009, 2013) as well as for other very sporadic shark by-catch in this fishery (*Lamna nasus*) (Mejuto *et al.* 2010).

The aim of this document is to update the standardized CPUE series previously provided for the North and South Atlantic shortfin mako stocks, covering in this case a 26-year period.

2. Material and methods

The data used consisted of trip records voluntarily provided for research covering the 1990-2015 period. Nominal effort per trip was defined by thousands of hooks. The nominal catch per unit of effort was obtained as number of fish and kilograms round weight per thousand hooks. The methodology used is based on previous research carried out on the Spanish longline fleet and used in the swordfish, shortfin mako and other by-catch CPUE analysis of the Spanish and other Atlantic longline fleets or combined data (e. g. Mejuto and De la Serna 2000, Mejuto *et al.* 2009, 2013; Ortiz 2007, Ortiz *et al.* 2007).

The spatial definitions for GLM runs used five and six areas for the North and South Atlantic stocks, respectively (**Figure 1**). This area definition was kept consistent with previous analyses. The temporal definition corresponding to 'quarters' was: Q1 = January, February, March; Q2 = April, May, June; Q3 = July, August, September; Q4 = October, November and December. Two main types of longline styles were categorized: the Spanish traditional multifilament and the monofilament (or American style) introduced more recently. The type of trip was categorized taking into consideration the variable *ratio* as an indicator of the target criteria of the skipper regarding swordfish and/or blue shark during the fishing trip, defined for each trip as the percentage of swordfish related to the total of swordfish and blue shark caught (Anon. 2001, Mejuto and De la Serna 2000). These values were categorized into ten levels at 10% intervals for modeling.

The standardized Ln (CPUE) was done using GLM procedures (*SAS 9.4*). A base case GLM (in number of fish and in weight) and two sensitivity analyses (in weight) were carried out. The deviance analyses of the different factors were considered: year (Y), quarter (Q), area (A), ratio (R), gear (G) and interactions (model with all factors and possible interactions that provided a solution):

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

Where, u = overall mean, Y = *year* effect, Q = *quarter* effect, A = *area* effect, R = *ratio* effect, G = *gear* effect, e = logarithm of the normally distributed error term. The base case GLM models took into consideration the results of deviance obtained for North and South Atlantic stocks respectively, including the main factors and factor-interactions that reduce the overall deviance $\geq$ 5.0% of the full model in weight.

The first GLM sensitivity analysis considered only the main significant factors also taken into consideration in previous studies. In that case the model had been simplified: Ln (CPUE) = u + Y+ Q + A+ R+ G+ Q * A+ e. The second GLM sensitivity analysis considered a Generalized Linear Mixed Model (MIXED procedure) assuming a lognormal error distribution. The fixed factors considered in this case were the same as the base case in weight (based on the deviance analysis). Since the objective is to provide a relative annual index of abundance, interactions, particularly those involving the year factor, could not be included as a fixed interaction in this model. However, year interactions may be considered as random interactions (Maunder and Punt 2004) where the estimated variance due to interaction is incorporated into the annual trend along with its estimated standard error. The model selected in the MIXED procedures as random factors were (Y*Q + Y*R + Y*A) for both North and South Atlantic stocks. Values of least squared mean predictions, standard error, CPUE values and 95% confidence intervals and other statistical diagnoses were obtained for each run. The standardized CPUE trends in weight obtained in each run were rescaled to their mean values and compared for each stock considered.

3. Results and discussion

A total number of 15,834 and 6,826 trip records from the North and South Atlantic stocks respectively were available for the period 1990-2015. The nominal effort considered in these analyses included 515.1 and 292.4 million hooks for the North and South stocks, respectively, during the whole combined period of 26 years analyzed. The coverage of the observations used represents around 71% of the total fishing effort of this fleet (task II data) during the whole period in the North and South Atlantic stocks combined.

Some spatial-temporal limitations were applied for observations at the beginning of the time series due to the progressive geographical expansion of the fleet during the initial period, particularly in the South Atlantic. These limitations are often observed in the data sets obtained from most oceanic longline fleets when accessing new fishing areas during periods of development or geographical expansion, or owing to shifts to other fishing areas or other tuna species targeted. The data available confirm the very frequent presence and the relative medium prevalence of this species in most trips, with a very minor proportion and stable trend over time of zero catches per trip recorded (mean values of 2.8% and 4.3% for the North and South Atlantic stocks respectively, for trips longer than 9 fishing days). So, the analyses of the positive catches are recommended in this case based on trip data.

Some results and diagnoses are only presented for the analyses of CPUE in weight in order to simplify the paper and avoid redundant results because diagnoses in number are identical. The analysis of deviance (**Tables 1 and 2**) highlights the main factors and factor-interactions that reduce the overall deviance (≥ 5.0%) of the full models tested. The deviance results indicate that area and year are the two major factors for both North and South Atlantic analyses, but some other factors and their interactions may also contribute to some extent to the variability observed, especially for the North Atlantic case. As expected, the type of trip was a significant but less important factor in the case of this bycatch species. However, this factor was relatively more important in the case of the North Atlantic fleet. The significance of the type of trip (ratio) with regard to the main desirable species has been described for several important oceanic longline fleets fishing in the North and South Atlantic areas and more recently for the Pacific and Indian Ocean, as well (e.g. Chang *et al*. 2007, Hazin *et al*. 2007[a,b], Mejuto and De la Serna 2000, Mourato *et al*. 2007, Ortiz 2007, Ortiz *et al.* 2007, Paul and Neilson 2007, Yokawa 2007). The results obtained in this case suggest that this factor is significant but much less important than in the case of the swordfish and blue shark analyses, probably because the shortfin mako was and still is a regular "pure" bycatch with high occurrence but relatively medium prevalence by trip as compared to the main species. However, the fishing strategy (type of trip) suggests a moderate influence of this factor on standardized shortfin mako catch rates, particularly in the North Atlantic case where this factor is highly relevant for the standardization of swordfish and blue shark CPUE.

The base case models explained between 40% and 46% of CPUE variability, depending on the stock (North or South) and the units (number of fish or weight) considered. All base case runs indicated the area as the most important factor, but year and quarter were also relevant factors in most runs. However, area*gear was the second most relevant factor in the case of CPUE in number for the North Atlantic base case run.

Frequency distribution of the log-transformed nominal catch rates and residual histograms obtained for the base case GLM runs in weight are provided for the North and South Atlantic stocks (**Figure 2**). Box-plots of the standardized residuals obtained by the main factors considered in these base case runs and the normal probability *qq-plot* obtained for these runs are also provided (**Figures 3 and 4)**. Least squared means, standard error and CPUE values obtained and their respective confidence intervals (95%) are shown in **Tables 3 and 4.** Base case CPUE trends over time and their respective 95% confidence intervals are also plotted (**Figure 5**).

The comparison between the standardized CPUEs obtained from base case and sensitivity models shows a very similar and stable general trend over time regardless of the model used in the case of the North Atlantic stock. The base case run and the sensitivity analysis using a mixed model show very similar trends over time in the case of the South Atlantic stock **(Figure 6**). All scenarios tested suggest an overall stable CPUE trend in the North and South stocks during the 26-year period analyzed.

Acknowledgments

The authors would like to express their warmest thanks to all the members of the team who were involved in the scientific recording of the data voluntarily provided over a long period. We would also like to thank the skippers of the Spanish longline fleet involved in this voluntary scientific collaboration.

References

Abascal, F.J., Quintans, M., Ramos-Cartelle, A. and Mejuto, J. 2011. Movements and environmental preferences of the shortfin mako, *Isurus oxyrinchus*, in the southern Pacific ocean. Mar. Biol. Vol. 158(5): 1175-1184.

Anonymous. 1989. Second ICCAT Swordfish Workshop. Collect. Vol. Sci. Pap. ICCAT, 29: 71- 162.

Anonymous. 1991. Informe del período bienal 1990-1991. I part. ICCAT.

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.

Babcock, E.A. and Skomal, G. 2008. Indices of blue, mako and thresher shark abundance derived from U.S. Atlantic recreational fishery data. Collect. Vol. Sci. Pap. ICCAT, 62(5): 1405-1416.

Brown, G.A. 2008. Updated standardized catch rates for mako (unclassified *Isurus spp.*) and blue (*Prionace glauca*) sharks in the Virginia-Massachusetts (U.S.) rod and reel fishery, 1986-2006. Collect. Vol. Sci. Pap. ICCAT, 62(5): 1417-1433.

Buencuerpo, V., Ríos, S. and Morón, J. 1998. Pelagic sharks associated with the swordfish, *Xiphias gladius*, fishery in the Eastern North Atlantic Ocean and Strait of Gibraltar. Fish. Bull. 96:667-685.

Chang, S. K., Lee, H.H. and Liu, H.I. 2007. Standardization of South Atlantic swordfish by-catch rate for Taiwanese longline fleet. Col. Vol. Sci. Pap. ICCAT, 60(6): 1974-1985.

Cortés, E. 2008. Standardized catch rates for blue and mako sharks from the U.S. pelagic longline logbook and observer programs. Collect. Vol. Sci. Pap. ICCAT, 62(5): 1447-1466.

Cortés, E. 2009. Standardized catch rates for blue and mako sharks from the U.S. pelagic longline logbook and observer programs. Collect. Vol. Sci. Pap. ICCAT, 64(5): 1595-1613.

Cortés, E. 2010. Standardized catch rates for porbeagle sharks from the U.S. pelagic longline logbook program. Collect. Vol. Sci. Pap. ICCAT, 65(6): 2058-2068.

Fernández-Costa, J. and Mejuto, J. 2010. A short note on the FAO statistics for porbeagle shark (*Lamna nasus*) in the Atlantic and its relation to other Lamnid. Collect. Vol. Sci. Pap. ICCAT, 65(6): 2031-2050.

Fowler, G.M. and Campana, S.E. 2009. Commercial by-catch rates of shortfin mako (*Isurus oxyrinchus*) from longline fisheries in the Canadian Atlantic. Collect. Vol. Sci. Pap. ICCAT, 64(5): 1668-1676.

Garcés, A.G. and Rey J.C. 1983. Análisis de la pesquería española de pez espada, *Xiphias gladius*, entre los años 1978 y 1981. Collect. Vol. Sci. Pap. ICCAT, 18(3): 622-628.

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.

Hazin, H.G., Hazin, F., Travassos, P., Carvalho, F.C. and Erzini, K. 2007a. Fishing strategy and target species of the Brazilian tuna longline fishery, from 1978 to 2005, inferred from cluster analysis. Collect. Vol. Sci. Pap. ICCAT, 60(6): 2029-2038.

Hazin, H.G., Hazin, F., Travassos, P., Carvalho, F.C. and Erzini, K. 2007b. Standardization of swordfish CPUE series caught by Brazilian longliners in the Atlantic Ocean, by GLM, using the targeting strategy inferred by cluster analysis. Collect. Vol. Sci. Pap. ICCAT, 60(6): 2039-2047.

Hoey, J., Mejuto, J., Iglesias, S. and Conser, R.J. 1988. A comparative study of the United States and Spanish longline fleet targeting swordfish in the Atlantic Ocean, north of 40º latitude. Collect. Vol. Sci. Pap. ICCAT, 27: 230-239.

Hoey, J., Mejuto, J. and Conser R. J. 1989. CPUE indices derived from combined Spanish and U.S. catch and effort data. Collect. Vol. Sci. Pap. ICCAT, 29: 228-249.

Hoey, J., Mejuto, J., Porter, J. and Uozumi, Y. 1993. A standardized biomass index of abundance for North Atlantic swordfish Collect. Vol. Sci. Pap. ICCAT, 40(1): 344-352.

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.

Matsunaga, H. 2008. Standardized CPUE for shortfin mako caught by the Japanese tuna longline fishery in the Atlantic Ocean, 1994-2005. Collect. Vol. Sci. Pap. ICCAT, 62(5): 1581-1586.

Maunder, M. and Punt, A.E. 2004. Standardizing catch and effort data: A review of recent approaches. Fisheries Research 70(2-3): 141-159.

Mejuto, J. 1985. Associated catches of sharks, Prionace glauca, Isurus oxyrinchus, and *Lamna nasus*, with NW and N Spanish swordfish fishery, in 1984. I.C.E.S., CM 1985/H:42.

Mejuto, J. 1993. Age specific standardized indices of abundance for Swordfish (*Xiphias gladius*) from the Spanish longline fleet in the Atlantic, 1983-1991. Collect. Vol. Sci. Pap. ICCAT, 40(1): 371-392.

Mejuto, J. 1994. Standardized indices of abundance at age for swordfish (*Xiphias gladius*) from the Spanish longline fleet in the Atlantic, 1983-1992. Collect. Vol. Sci. Pap. ICCAT, 42(1): 328-334.

Mejuto, J., García, B. and De la Serna, J.M. 1997. Activity of the Spanish surface longline fleet catching swordfish (*Xiphias gladius*) in the Atlantic, years 1994 and 1995. Collect. Vol. Sci. Pap. ICCAT, 46(3): 308-310.

Mejuto, J. and González-Garcés, A. 1984. Shortfin mako, Isurus oxyrinchus, and porbeagle, *Lamna nasus*, associated with longline swordfish fishery in the NW and N Spain. ICES C.M. 1984/G:72.

Mejuto, J. and De la Serna, J.M. 1995. Standardized catch rates by age and length groups for swordfish (*Xiphias gladius*) from the Spanish longline fleet in the Atlantic, 1983-93. Collect. Vol. Sci. Pap. ICCAT, 19(3): 114-125.

Mejuto, J. and De la Serna, J.M. 1997. Updated standardized catch rates by age for swordfish (*Xiphias gladius*) from the Spanish longline fleet in the Atlantic, using commercial trips from the period 1983-1995 Collect. Vol. Sci. Pap. ICCAT, 46(3): 323-335.

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., De la Serna, J.M. and García, B. 1998. Updated standardized catch rates by age, sexes combined, for the swordfish (*Xiphias gladius*) from the Spanish longline fleet in the Atlantic, for the period 1983-1996 Collect. Vol. Sci. Pap. ICCAT, 48(1): 216-222.

Mejuto, J., De la Serna, J.M. and García, B. 1999. Updated standardized catch rates by age, combined sexes, for the swordfish (*Xiphias gladius*) from the Spanish longline fleet in the Atlantic, for the period 1983-1997. Collect. Vol. Sci. Pap. ICCAT, 49(1): 439-448.

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.

Mejuto, J., Ortiz, M., García-Cortés, B., Ortiz de Urbina, J. and Ramos-Cartelle, A. 2010. Historical data and standardized catch rates of porbeagle (*Lamna nasus*) caught as by-catch of the Spanish surface longline fishery targeting swordfish (*Xiphias gladius*) in the Atlantic Ocean. Collect. Vol. Sci. Pap. ICCAT, 65(6): 2006-2030.

Mejuto, J., Garcia-Cortés, B., Ramos-Cartelle, A., De La Serna, J.M., González-González, I, Fernández Costa, J. 2013. Standardized catch rates of shorfin mako (*Isurus oxyrinchus*) caught by the Spanish surface longline fishery targeting swordfish in the Atlantic Ocean during the periodod 1990-2010. Collect. Vol. Sci. Pap. ICCAT, 69(4): 1657-1669.

Moreno. J.A. 1995. Guía de los tiburones de aguas ibéricas, Atlántico Nororiental y Mediterráneo. Ediciones Pirámide, S.A.:310pp.

Mourato B.L., Andrade, H.A., Amorim, A.F. and Arfelli, C.A. 2007. Standardized catch rate of swordfish (*Xiphias gladius*) caught by Santos longliners off southern Brazil (1971-2005). Collect. Vol. Sci. Pap. ICCAT, 60(6): 1943-1952.

Mourato, B.L., Amorim, A.F. and Arfelli, C.A. 2008. Standardized catch rate of shortfin mako (*Isurus oxyrinchus*) and bigeye thresher (*Alopias superciliosus*) caught by São Paulo longliners off southern Brazil. Collect. Vol. Sci. Pap. ICCAT, 62(5): 1542-1552.

Nakano, H. 1993. Estimation of standardized CPUE for the Atlantic swordfish using the data from the Japanese longline fishery. Collect. Vol. Sci. Pap. ICCAT, 40(1): 357-370.

Ortiz, M. 2007. Update of standardized catch rates by sex and age for swordfish (*Xiphias gladius*) from the U.S. longline fleet 1981-2005 Collect. Vol. Sci. Pap. ICCAT, 60(6): 1994-2017.

Ortiz, M., Mejuto, J., Paul, S., Yokawa, K., Neves, M. and Hoey, J. 2007. An updated biomass index of abundance for North Atlantic swordfish 1963-2005. Collect. Vol. Sci. Pap. ICCAT, 60(6): 2048-2058.

Paul, S. D. and Neilson, J. D. 2007. Updated sex- and age-specific CPUE from the Canadian swordfish longline fishery, 1988-2005. Collect. Vol. Sci. Pap. ICCAT, 60(6): 1914-1942.

Pons, M. and Domingo, A. 2008. Estandarización de la CPUE del tiburón moro (*Isurus oxyrinchus*) capturado por la flota de palangre pelágico de Uruguay (1981-2006). Collect. Vol. Sci. Pap. ICCAT, 62(5): 1526-1536.

Ramos-Cartelle, A., García-Cortés, B., Fernández-Costa, 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.

Rey, J.C., Mejuto, J. and Iglesias, S. 1988. Evolución histórica y situación actual de la pesquería de pez espada (*Xiphias gladius*). Collect. Vol. Sci. Pap. ICCAT, 27: 202-213.

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

Scott, G.P., Restrepo, V.R. and Bertolino, A. 1993. Standardized catch rates for swordfish (*Xiphias gladius*) from the U.S. longline fleet though 1991 Collect. Vol. Sci. Pap. ICCAT, 40(1):458-468.

Vaudo, J.J., Wetherbee, B.M., Wood, A.D., Weng, K., Howey-Jordan, L.A., Harvey, G.M. and Shivji, M.S. 2016. Vertical movements of shortfin mako sharks Isurus oxyrinchus in the western North Atlantic Ocean are strongly influenced by temperature. Marine Ecology Progress Series, 547: 163-175.

Yokawa, K. 2007. Update of standardized CPUE of swordfish caught by Japanese longliners. Collect. Vol. Sci. Pap. ICCAT, 60(6): 1986-1993.

Table 1. Deviance table of the factors tested for log CPUE (in weight) for the shortfin mako of the North Atlantic stock. Highlighted are the factors with ≥ 5.0% of deviance explained.

Model factors catch rates values	d.f.	Res. deviance	Change in deviance	% of total deviance	p	chi-sq
		25913.2664				
Year	25	23844.2171	2069.0493	23.0%	< 0.001	0
Year Quarter	3	23138.6824	705.5347	7.8%	< 0.001	1.324E-152
Year Quarter Area	4	19395.8926	3742.7898	41.5%	< 0.001	0
Year Quarter Area Ratio	9	18159.5519	1236.3407	13.7%	< 0.001	1.7287E-260
Year Quarter Area Ratio Gear	1	18091.5644	67.9875	0.7%	< 0.001	1.64535E-16
Year Quarter Area Ratio Gear Year*Gear	15	18036.3686	55.1958	0.6%	< 0.001	1.65551E-06
Year Quarter Area Ratio Gear Quarter*Gear	3	17827.7307	263.8337	2.9%	< 0.001	6.66012E-57
Year Quarter Area Ratio Gear Ratio*Gear	9	17791.8063	299.7581	3.3%	< 0.001	2.93763E-59
Year Quarter Area Ratio Gear Area*Gear	4	17606.5183	485.0461	5.4%	< 0.001	1.1485E-103
Year Quarter Area Ratio Gear Year*Quarter	75	17290.7012	800.8632	8.9%	< 0.001	5.9603E-122
Year Quarter Area Ratio Gear Year*Ratio	225	17167.3014	924.2630	10.3%	< 0.001	1.85934E-85
Year Quarter Area Ratio Gear Year*Area	100	16985.9703	1105.5941	12.3%	< 0.001	3.674E-169
Year Quarter Area Ratio Gear Area*Ratio	36	16949.6708	1141.8936	12.7%	< 0.001	2.318E-216
Year Quarter Area Ratio Gear Quarter*Area	12	16922.2017	1169.3627	13.0%	< 0.001	6.8431E-243
Year Quarter Area Ratio Gear Quarter*Ratio	27	16899.4132	1192.1512	13.2%	< 0.001	3.9353E-234

Table 2. Deviance table of the factors tested for log CPUE (in weight) for the shortfin mako of the South Atlantic stock. Highlighted are the factors with ≥ 5.0% of deviance explained.

Model factors catch rates values	d.f.	Res. deviance	Change in deviance	% of total deviance	p	chi-sq
		7991.2508				
Year	25	6902.6971	1088.5537	29.4%	< 0.001	9.0893E-214
Year Quarter	3	6079.2564	823.4407	22.2%	< 0.001	3.5679E-178
Year Quarter Area	5	4821.2449	1258.0115	33.9%	< 0.001	7.9736E-270
Year Quarter Area Ratio	9	4662.9871	158.2578	4.3%	< 0.001	1.70873E-29
Year Quarter Area Ratio Gear	1	4607.978	55.0091	1.5%	< 0.001	1.19973E-13
Year Quarter Area Ratio Gear Year*Gear	10	4570.2042	37.7738	1.0%	< 0.001	4.15508E-05
Year Quarter Area Ratio Gear Area*Gear	5	4563.1389	44.8391	1.2%	< 0.001	1.56436E-08
Year Quarter Area Ratio Gear Quarter*Gear	3	4562.1819	45.7961	1.2%	< 0.001	6.26683E-10
Year Quarter Area Ratio Gear Ratio*Gear	9	4545.1825	62.7955	1.7%	< 0.001	3.86502E-10
Year Quarter Area Ratio Gear Quarter*Ratio	27	4524.6600	83.3180	2.2%	< 0.001	1.17511E-07
Year Quarter Area Ratio Gear Area*Ratio	45	4494.0054	113.9726	3.1%	< 0.001	6.63847E-08
Year Quarter Area Ratio Gear Quarter*Area	15	4465.9404	142.0376	3.8%	< 0.001	9.11491E-23
Year Quarter Area Ratio Gear Year*Quarter	75	4404.4285	203.5495	5.5%	< 0.001	8.21927E-14
Year Quarter Area Ratio Gear Year*Area	109	4369.7471	238.2309	6.4%	< 0.001	1.23271E-11
Year Quarter Area Ratio Gear Year*Ratio	216	4285.2867	322.6913	8.7%	< 0.001	3.37543E-06

Table 3. Least squared mean, standard error, predicted CPUE in number of fish and in weight, and 95% confidence intervals, by year, for the North Atlantic stock of the shortfin mako during the 1990-2015 period.

	NUMBER					WEIGHT				
Yr	**Lsmean**	**Stderr**	**Ucpue**	**Cpue**	**Lcpue**	**Lsmean**	**Stderr**	**Ucpue**	**Cpue**	**Lcpue**
1990	0.0746	0.0477	1.1844	1.0787	0.9824	3.7610	0.0457	47.0712	43.0357	39.3462
1991	-0.0090	0.0475	1.0891	0.9922	0.9039	3.7504	0.0456	46.5619	42.5833	38.9446
1992	0.1340	0.0491	1.2602	1.1447	1.0398	3.9388	0.0470	56.3773	51.4141	46.8879
1993	0.0836	0.0467	1.1927	1.0884	0.9932	3.8785	0.0447	52.8353	48.3997	44.3365
1994	-0.0037	0.0459	1.0913	0.9974	0.9115	3.7173	0.0440	44.9052	41.1931	37.7878
1995	-0.1439	0.0427	0.9425	0.8668	0.7972	3.5974	0.0409	39.5868	36.5342	33.7169
1996	0.0857	0.0406	1.1806	1.0904	1.0070	3.7727	0.0389	46.9754	43.5293	40.3361
1997	-0.4202	0.0406	0.7119	0.6575	0.6072	3.2756	0.0389	28.5774	26.4790	24.5347
1998	-0.2832	0.0411	0.8172	0.7540	0.6957	3.3653	0.0394	31.2877	28.9646	26.8141
1999	-0.3911	0.0452	0.7397	0.6770	0.6197	3.3333	0.0433	30.5393	28.0554	25.7736
2000	-0.2741	0.0452	0.8315	0.7610	0.6966	3.3377	0.0433	30.6756	28.1807	25.8887
2001	-0.1287	0.0449	0.9611	0.8801	0.8060	3.3853	0.0431	32.1559	29.5539	27.1623
2002	0.1918	0.0441	1.3220	1.2126	1.1123	3.7344	0.0422	45.5131	41.8980	38.5700
2003	0.3576	0.0480	1.5730	1.4316	1.3030	3.9345	0.0460	56.0252	51.1904	46.7729
2004	0.3877	0.0496	1.6261	1.4754	1.3387	3.9323	0.0476	56.0753	51.0841	46.5371
2005	0.3234	0.0523	1.5331	1.3837	1.2488	3.8433	0.0501	51.5659	46.7387	42.3633
2006	0.2487	0.0572	1.4369	1.2845	1.1483	3.7269	0.0548	46.3315	41.6116	37.3726
2007	0.4958	0.0599	1.8497	1.6448	1.4627	3.9862	0.0574	60.3633	53.9407	48.2015
2008	0.5549	0.0590	1.9587	1.7448	1.5543	4.0633	0.0565	65.0853	58.2581	52.1470
2009	0.5191	0.0575	1.8839	1.6832	1.5039	4.0584	0.0551	64.5756	57.9668	52.0343
2010	0.4436	0.0561	1.7420	1.5607	1.3983	3.9596	0.0537	58.3447	52.5122	47.2627
2011	0.2432	0.0563	1.4263	1.2773	1.1438	3.7512	0.0540	47.3924	42.6354	38.3558
2012	0.4250	0.0565	1.7116	1.5321	1.3714	3.9406	0.0542	57.2971	51.5249	46.3342
2013	0.1441	0.0598	1.3008	1.1571	1.0292	3.6574	0.0573	43.4360	38.8243	34.7021
2014	0.0900	0.0560	1.2229	1.0958	0.9819	3.6198	0.0537	41.5287	37.3826	33.6505
2015	0.2221	0.0565	1.3971	1.2507	1.1196	3.7546	0.0542	47.5704	42.7800	38.4720

Table 4. Least squared mean, standard error, predicted CPUE in number of fish and weight and 95% confidence intervals, by year, for the South Atlantic stock of the shortfin mako during the 1990-2015 period.

	NUMBER					WEIGHT				
Yr	**Lsmean**	**Stderr**	**Ucpue**	**Cpue**	**Lcpue**	**Lsmean**	**Stderr**	**Ucpue**	**Cpue**	**Lcpue**
1990	-0.1500	0.0754	1.0006	0.8632	0.7446	4.0436	0.0744	66.1690	57.1898	49.4292
1991	-0.3821	0.0695	0.7840	0.6841	0.5969	3.7078	0.0686	46.7438	40.8596	35.7161
1992	-0.1016	0.0599	1.0178	0.9051	0.8048	3.9899	0.0591	60.7963	54.1463	48.2237
1993	-0.0552	0.0496	1.0442	0.9474	0.8597	3.9826	0.0490	59.1307	53.7208	48.8058
1994	-0.0617	0.0524	1.0432	0.9415	0.8496	3.9249	0.0517	56.1232	50.7168	45.8312
1995	0.0858	0.0492	1.2015	1.0910	0.9906	4.0587	0.0486	63.7613	57.9675	52.7002
1996	0.2582	0.0472	1.4215	1.2960	1.1816	4.2429	0.0466	76.3393	69.6821	63.6054
1997	-0.0454	0.0395	1.0333	0.9564	0.8852	4.0260	0.0390	60.5254	56.0758	51.9533
1998	-0.2732	0.0450	0.8320	0.7617	0.6974	3.8360	0.0444	50.6053	46.3853	42.5172
1999	-0.4924	0.0519	0.6775	0.6120	0.5528	3.6147	0.0512	41.1186	37.1903	33.6372
2000	-0.0817	0.0601	1.0386	0.9232	0.8206	3.9468	0.0593	58.2536	51.8591	46.1665
2001	0.1312	0.0484	1.2550	1.1415	1.0383	4.1234	0.0477	67.9038	61.8385	56.3150
2002	0.0599	0.0502	1.1731	1.0631	0.9634	4.0491	0.0496	63.2722	57.4133	52.0970
2003	0.0420	0.0547	1.1627	1.0445	0.9383	4.0391	0.0540	63.2079	56.8603	51.1501
2004	-0.0109	0.0586	1.1114	0.9908	0.8833	3.9905	0.0578	60.6748	54.1737	48.3693
2005	0.0810	0.0675	1.2406	1.0868	0.9521	4.1322	0.0666	71.1669	62.4537	54.8074
2006	-0.0990	0.0610	1.0226	0.9074	0.8052	3.9595	0.0602	59.1050	52.5280	46.6829
2007	-0.1685	0.0665	0.9647	0.8468	0.7433	3.8454	0.0656	53.3128	46.8765	41.2173
2008	-0.2921	0.0558	0.8343	0.7478	0.6703	3.7063	0.0551	45.4132	40.7634	36.5897
2009	-0.1045	0.0529	1.0007	0.9021	0.8132	3.9175	0.0522	55.7704	50.3439	45.4454
2010	0.0060	0.0568	1.1262	1.0076	0.9015	4.0057	0.0560	61.3823	54.9970	49.2760
2011	0.2914	0.0542	1.4905	1.3403	1.2052	4.3012	0.0535	82.0655	73.8968	66.5413
2012	0.2215	0.0612	1.4096	1.2503	1.1090	4.2264	0.0604	77.2181	68.5980	60.9401
2013	0.2880	0.0647	1.5171	1.3365	1.1774	4.3604	0.0638	88.9039	78.4499	69.2253
2014	0.2738	0.0673	1.5036	1.3179	1.1551	4.3154	0.0664	85.4350	75.0082	65.8539
2015	0.1699	0.0679	1.3570	1.1879	1.0399	4.1796	0.0670	74.6787	65.4860	57.4248

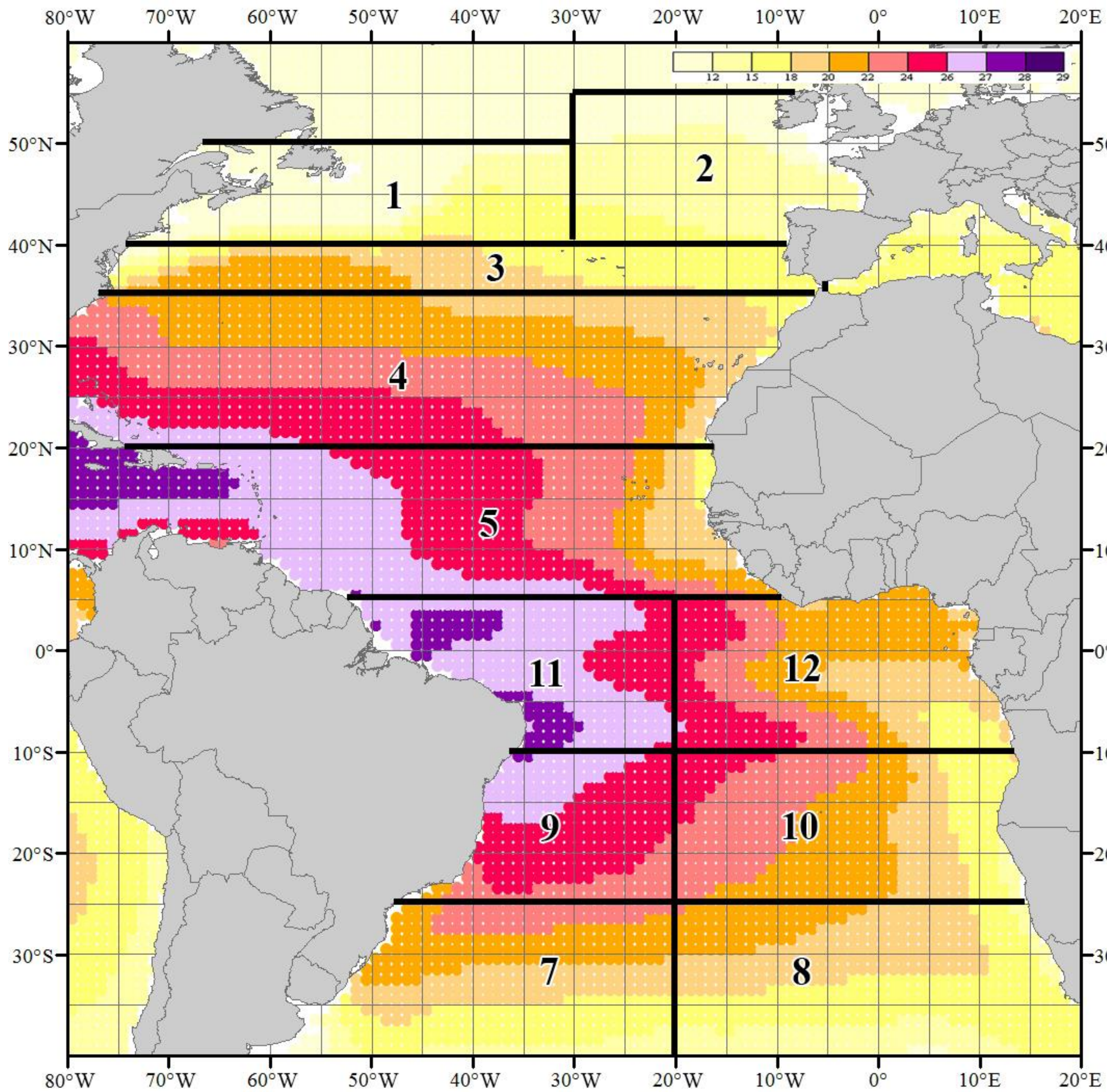


Figure 1. Geographical area stratification used for the GLM runs of the shortfin mako, for the North Atlantic stock (areas 1-5) and South Atlantic stock (areas 7-12). The area stratification was kept as in previous analyses. Areas are superimposed on average sea temperature ºC at 50m depth.

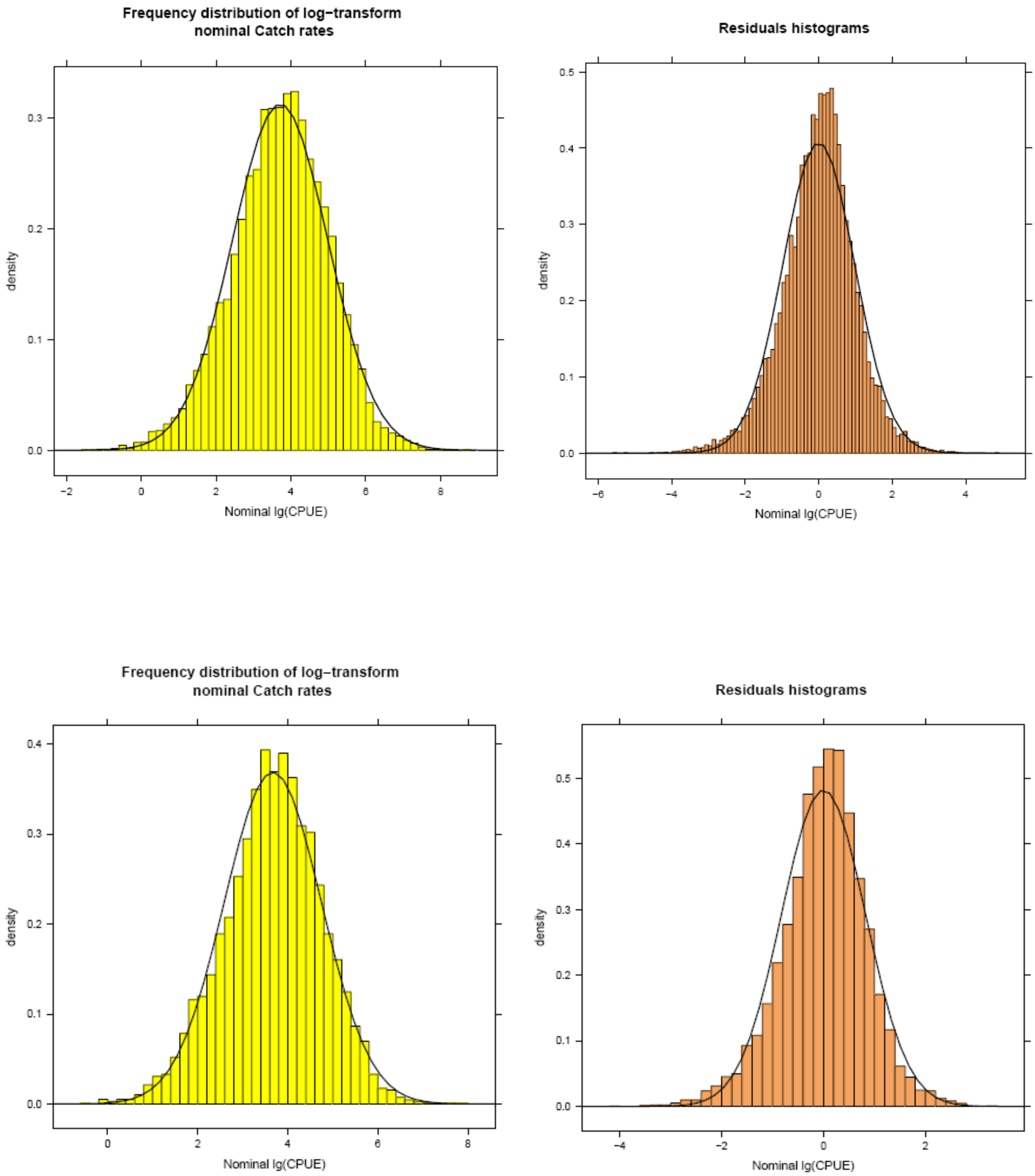


Figure 2. Frequency distribution of the log-transformed nominal catch rates (left panels) and residual histograms (right panels) obtained for the base case GLM runs (in weight) of the shortfin mako. North Atlantic stock (upper panels). South Atlantic stock (lower panels).

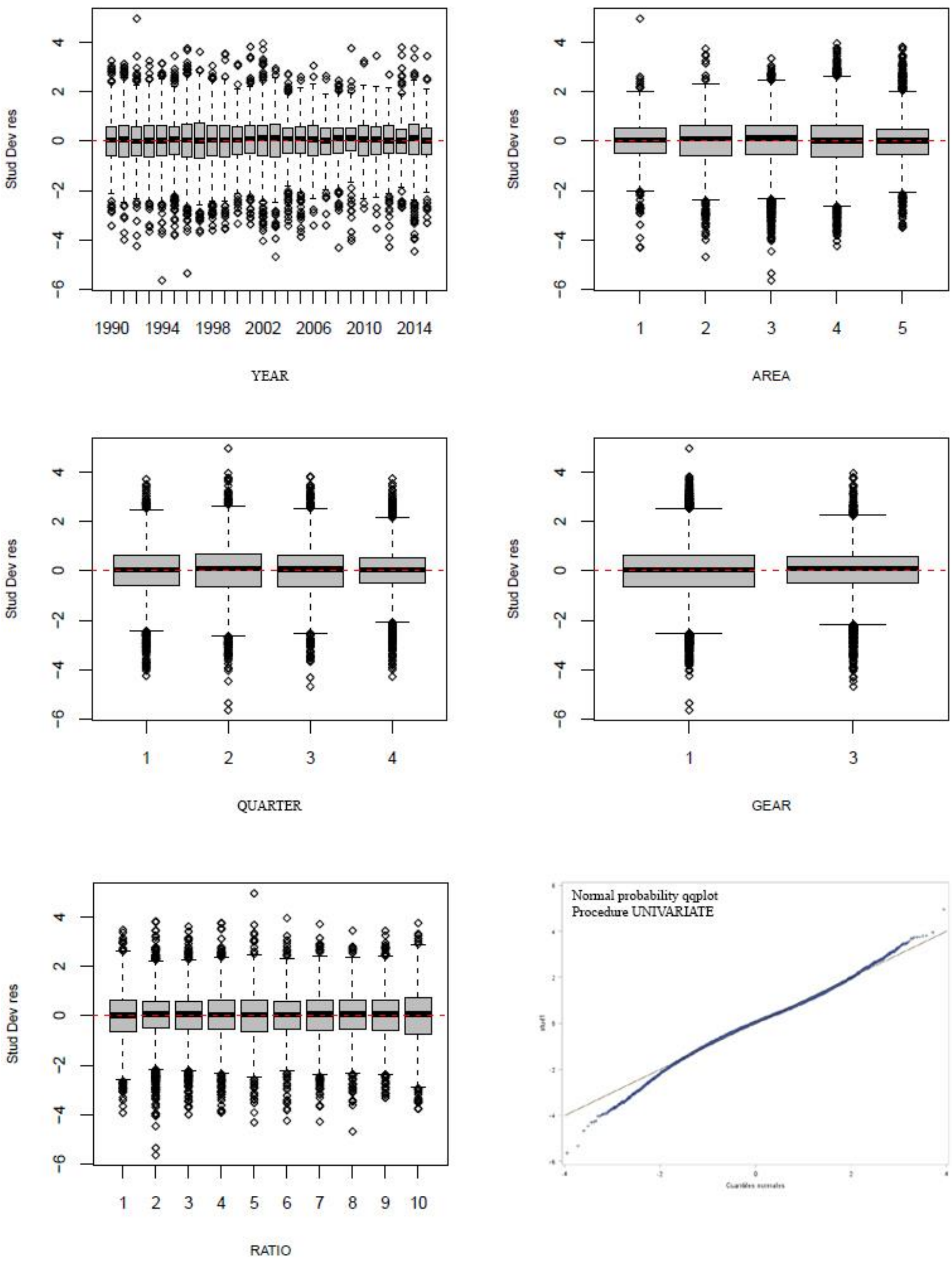


Figure 3. Standardized deviance residuals *versus* explanatory variables and qq-plot obtained from the GLM base case analyses in weight of the North Atlantic stock.

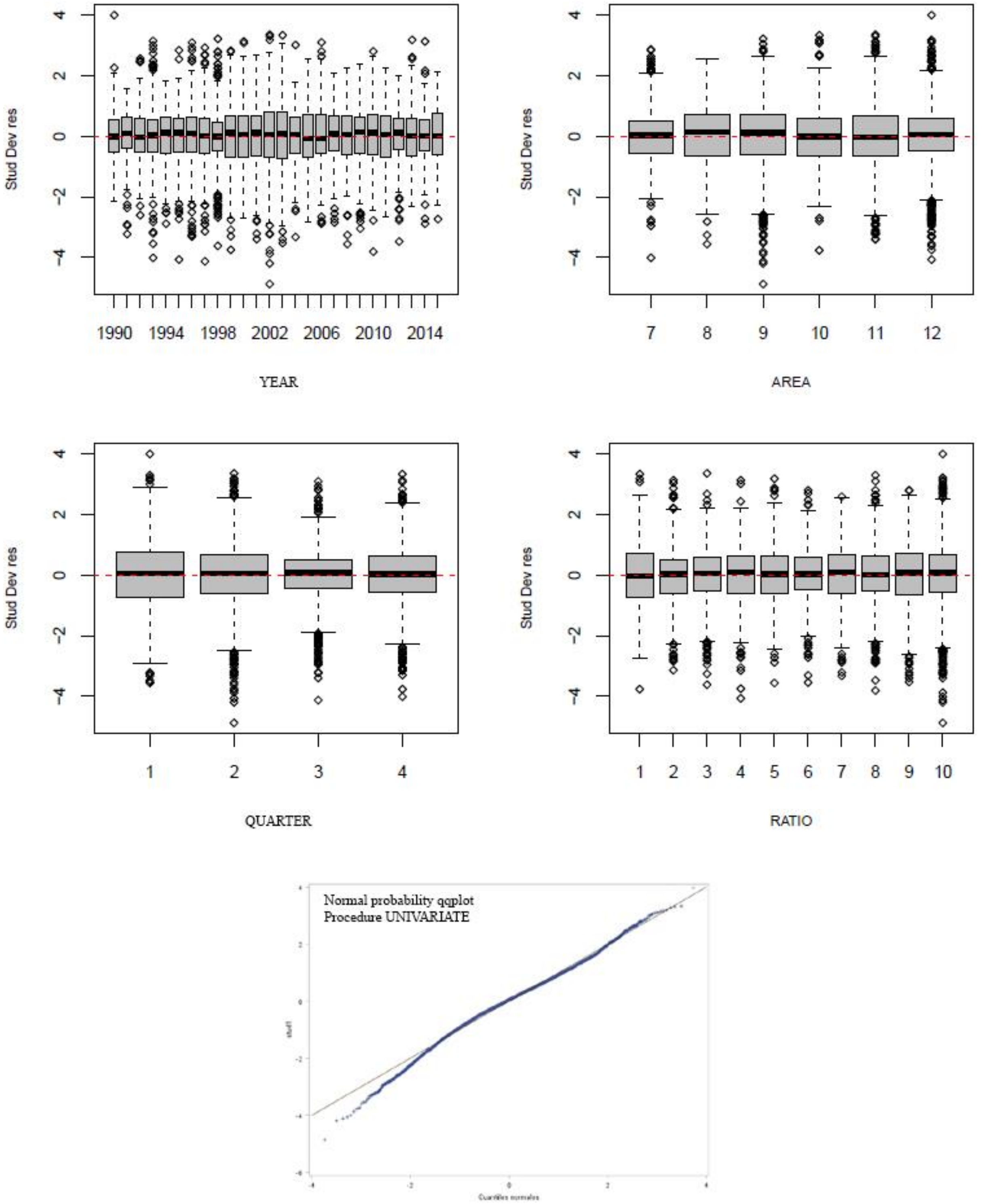


Figure 4. Standardized deviance residuals *versus* explanatory variables and qq-plot obtained from the GLM base case analyses in weight of the South Atlantic stock.

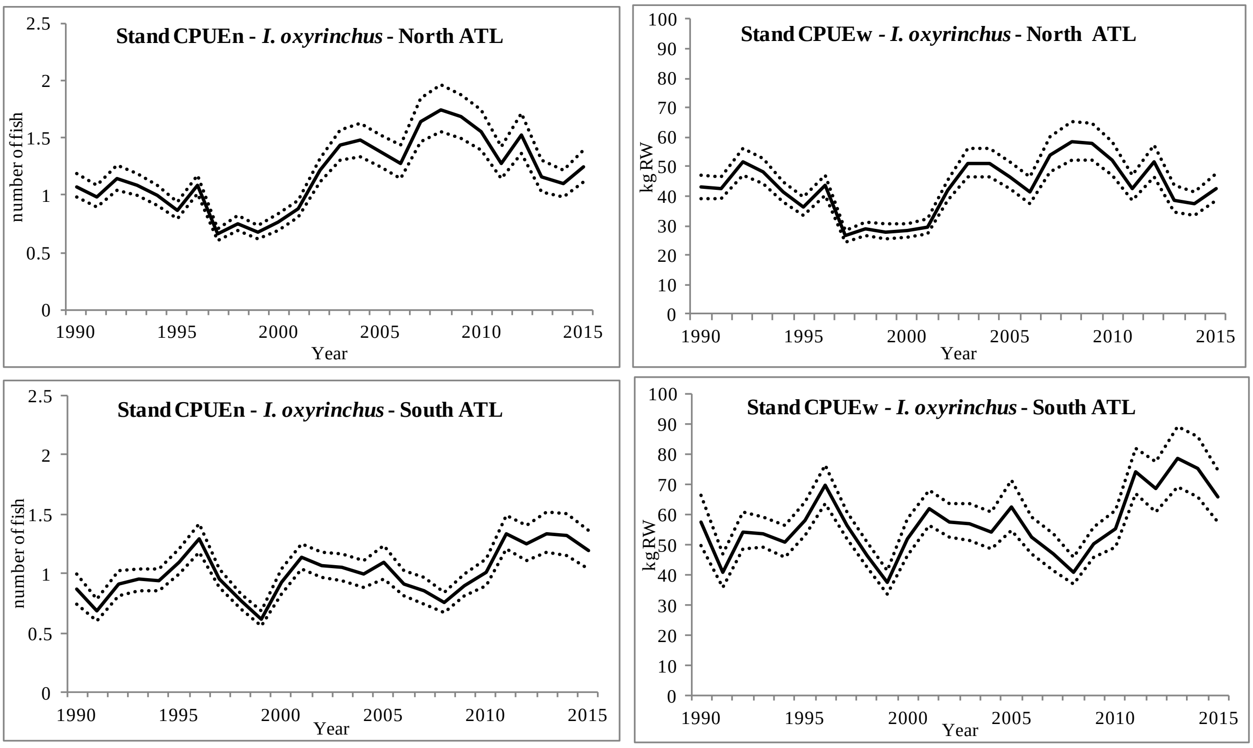
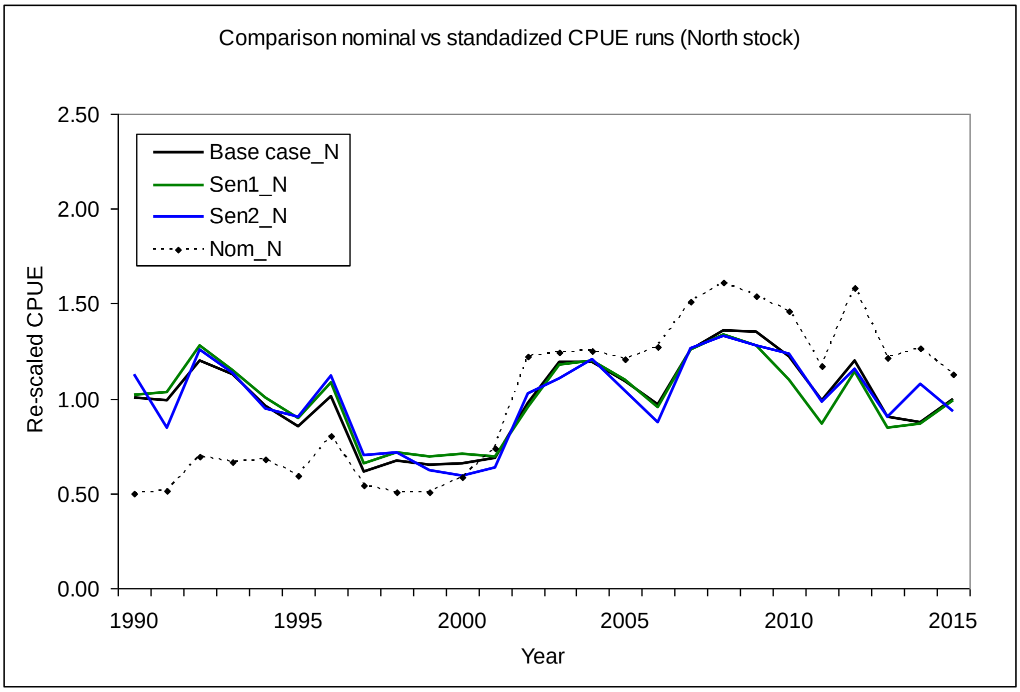


Figure 5. Base case standardized CPUE by year, in number of fish (CPUEn), in weight (CPUEw), and confidence intervals (95%) of the North and South Atlantic stocks of the shortfin mako, during the 1990-2015 period.



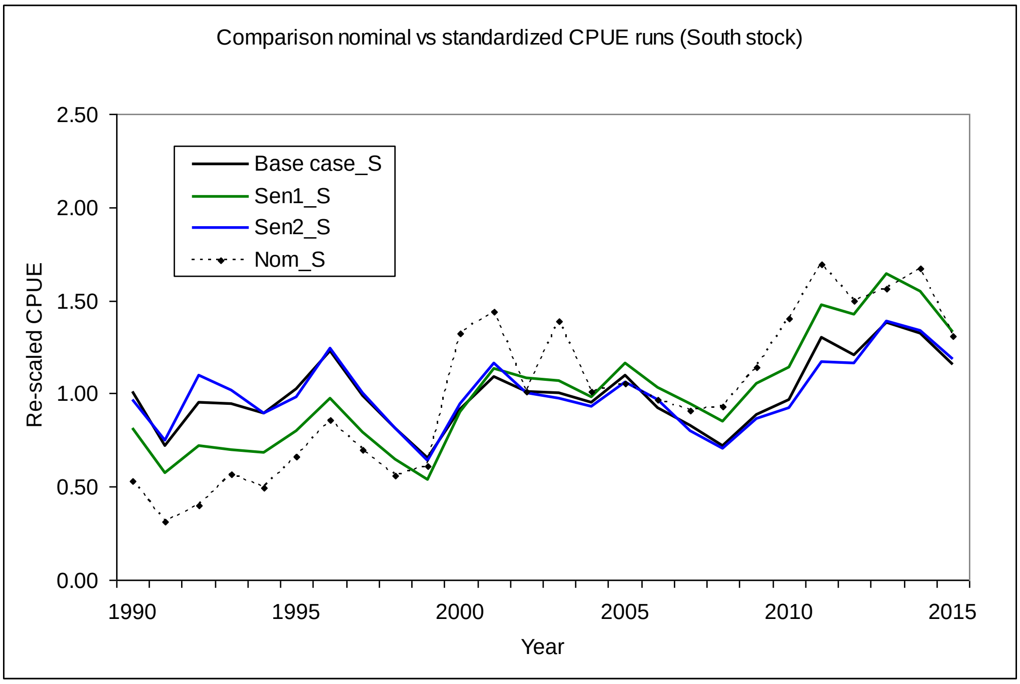


Figure 6. Re-scaled values of the nominal CPUE (in weight) and the standardized CPUEs (in weight) obtained in the base case and sensitivity runs, for the North Atlantic (upper panel) and South Atlantic (lower panel) stocks of shortfin mako.