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STANDARDIZED CATCH PER UNIT EFFORT (CPUE) OF SHORTFIN MAKO (*ISURUS OXYRINCHUS*) FOR THE MOROCCAN LONGLINE FISHERY

M. Serghini[1], H. Moustahfid[2], H. Habiba[1], L. Aziza[1], N. Abid[1], S. Baibbat[1]

SUMMARY

Shortfin mako shark Isurus oxyrinchus *is harvested as bycatch by the Moroccan longliners targeting swordfish Xiphias gladius in the south of Moroccan waters. The average catch of shortfin mako reached 680 tons during the period 2012-2016. A time series of standardized catch per unit effort (CPUE) for shortfin mako was estimated by first analyzing the fleet dynamic and identification of fishing tactics using multi-table method, and then using two statistical models, including Generalized Linear Models (GLM) and Boosted Regression Trees model (BRT) with main effects and two-way interactions. BRT with two-way interactions was selected as the best model to estimate CPUE with less RMSE and high PDE. The standardized CPUE analysis indicates a declining trend since the early years and slight increase and stability in the last three years of the time series.*

RÉSUMÉ

*Le requin-taupe bleu (*Isurus oxyrinchus*) est capturé comme prise accessoire par les palangriers marocains ciblant l'espadon (*Xiphias gladius*) au sud des eaux marocaines. La capture moyenne de requin-taupe bleu a atteint 680 tonnes sur la période 2012-2016. Une série temporelle de capture par unité d'effort standardisée (CPUE) pour le requin-taupe bleu a été estimée en analysant d'abord la dynamique de la flottille et l'identification des tactiques de pêche en utilisant une méthode à tableaux multiples, puis en utilisant deux modèles statistiques, y compris des modèles linéaires généralisés (GLM) et un modèle à arbre de régression augmentée (BRT) avec des effets principaux et des interactions à double sens. Le BRT avec des interactions à double sens a été sélectionné comme le meilleur modèle pour estimer la CPUE avec moins de RMSE et une PDE élevée. L'analyse de la CPUE standardisée indique une tendance à la baisse depuis les premières années et une légère augmentation et stabilité au cours des trois dernières années de la série temporelle.*

RESUMEN

*El marrajo dientuso (*Isurus oxyrinchus*) es capturado de forma fortuita por los palangreros marroquíes que dirigen su actividad al pez espada (*Xiphias gladius*) en la parte meridional de las aguas marroquíes. La captura media de marrajo dientuso alcanzó las 680 t durante el periodo 2012-2016. Se estimó una serie de captura por unidad de esfuerzo (CPUE) estandarizada para el marrajo dientuso, analizando en primer lugar la dinámica de la flota e identificando las tácticas de pesca utilizando un método de tablas múltiples y usando después dos modelos estadísticos, modelos lineales generalizados (GLM) y el modelo de árbol de regresión potenciado (BRT) con efectos principales e interacciones en dos sentidos. Se eligió BRT con interacciones en dos sentidos como el mejor modelo para estimar la CPUE con menos RMSE y PDE elevada. El análisis de la CPUE estandarizada indica una tendencia descendente desde los primeros años y un ligero incremento y estabilidad en los tres últimos años de la serie temporal.*

KEYWORDS

Shortfin mako, Isurus oxyrinchus, *catch per unit effort,*
CPUE, fleet dynamic, fishing tactics, multi-table analysis, boosted regression trees,
generalized linear model, longline fisheries, Morocco

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1. Introduction

Shortfin mako *Isurus oxyrinchus*, is distributed worldwide in temperate and tropical waters. It has an important role in the equilibrium of the marine ecosystem (Bonhommeau *et al.*, 2009). This species is harvested as bycatch by the Moroccan longliners targeting swordfish *Xiphias gladius* between the latitudes 20 and 26 N° (**Figure 1**). The average catch of shortfin mako reached 680 tons during the period 2012-2016. During the same period, this species represented 22% of the total catch of the longliners operating in the North Atlantic.

Because of the growing demand for shortfin mako, the catch of this species have increased during the last two decades as estimated by the SCRS. In 2017, the North Atlantic shortfin mako was assessed by the SCRS as being overexploited, however this assessment has not used the data from the Moroccan longline fishery that harvest a significant amount of this species. In this paper, we provide for the first time a standardized CPUE of shortfin mako using the most recent catch and effort data available from the Moroccan longline fishery.

2. Material and methods

2.1 Description of data source

Three types of data were used : i) data for the period 2010-2017 from the Office National des Pêches (ONP) to identify different trips, ii) data from the Moroccan Fishery Department to get technical characteristics of each longliner, and iii) data from port survey conducted by the Institute National de Recherche Halieutique (INRH) at the different ports. These survey data served to identify the types of gears, fishing areas, target and bycatch species and fishing season by gear.

The first type of data was aggregated to get the total catch by vessel, species and trip at the national level. From this database, a new dataset was constructed by aggregating for each vessel the number of trips by year and by port. Then this matrix was analyzed to cluster the vessels by landing port. Given that the VMS data series do not cover the whole study period (DPM), we assumed that each landing port represents one particular fishing area. This hypothesis was confirmed by interviewing the fishermen. Each cluster of vessels was identified as having the maximum of catch landed in a group of ports. As a result, six groups of ports were determined (**Table 9**).

With the purpose of standardizing the CPUE for the shortfin mako, we focused our analysis on the group of ports that accounted for more 50% of the total catches of this species (the group Dakhla-Tantan). Then, to identify the different tactics of this fishery that changes inter-annually, we used the tactics analysis following the approach described in Serghini *et al.,* In preparation. The results of this analysis showed that the group of vessels within the selected group of ports (mainly Dakhla) practice several tactics of which fishing for swordfish is the main tactic in association with the large pelagic sharks including shortfin mako. This tactic contains 979 trips that were used for standardizing CPUE for this species.

2.2 Estimation of the fishing effort

The catch data by fishing vessel and by daily sales of each species landed were used to estimate the fishing effort (number of days at sea). First, the commercial data (ONP) of longliners by their corresponding port were compiled with catches by species (in kg), registration numbers, and date of landing for the period 2010 to 2017. The daily sales of each species for one trip were added together by vessel and by port. Then, we built a data matrix with daily sales, registration number, port, date and catch per species as variables. According to the survey conducted in each port, generally a sale of the catch landed by one vessel corresponds to one trip (in general sales are one to two days). Then, to estimate the successive daily sales that correspond to one trip we aggregated by registration number, port and species. Finally, a new matrix was created with rows correspondent to the different trips.

To estimate the number of fishing days elapsed between two successive trips we subtracted the number of days that the vessel spent to navigate to fishing grounds and returning back to the port (2 days on average) and the days staying at the port (2 days). To calculate the effort we multiplied the number of hooks deployed during one fishing day (estimated to 1200 hooks) by the number of fishing days.

2.3 Size structure of catches

Juvenile's size 110-240 cm dominated the size structure of the catches (**Figure 2**). This is similar to the size structure of the fish targeted by longliners in North Atlantic (Natanson *et al.*, 2006).

Those sizes correspond to fish aged 2-20 years depending on the sex of fish, as the first age at maturity vary largely between males (185 cm) and females (275 cm) (Natanson *et al.*, 2006).

2.4 Impact of the management regulation

Since its development in 2003, the Moroccan longline fishery targeting swordfish and catching the shortfin mako as bycatch remained stable in terms of both target species and the geographic extent of the fishing area. The fishing activity takes place almost the whole year except for the month of May to repair the vessels and the gears. In addition, there was no big changes in the ICCAT management regulation for the target species; the TAC for swordfish has remained the same over the period considered for the analysis (2010-2017) (e.g. 13700 tonnes). Therefore, there is no impact on our CPUE standardization.

2.5 Standardization of the CPUE

2.5.1 Selecting of explanatory variables and trips for the standardization of CPUEs

Analysis of fleet dynamic and identification of fishing tactics is particularly important for standardizing CPUE (Serghini *et al.*, In preparation). This approach helps to select a sample of the fleet to be used for CPUE standardization and to remove all fishing trips that are directed to other species. Given that fishing tactics can be described by a combination of many characteristics variables, the approach is to extract all fishing trips that contributed to the constitution of each fishing tactics and use its significant characteristics variables as explanatory variables in the model to standardized CPUE. This approach allowed us to select the following explanatory variables to construct a full model: species, year, Gross registered tonnage (GRT), month and quarter. Species and GRT were log(x+1) transformed for use in the final statistical model using Boosted Regression Trees (BRT) and Generalized Linear Models (GLM):

LOG(Shortfin.mako+1)
~YEAR+QUARTER+MONTH+LOG(GRT+1)+LOG(Swordfish+1)+LOG(Blue.shark+1)+LOG(Yellowfin.tuna+1)+LOG(Bigeye.tuna+1)

2.5.2 Boosted Regression Trees (BRT) and Generalized Linear Models (GLM)

The BRT is an ensemble of method that combine statistical models and machine learning through two algorithms : regression trees are from the classification and regression tree (decision tree) group of models, and boosting build (Machine Learning) (Elith *et al.*, 2008). Handling exploratory variables of different types, treatment of missing data, handling outliers and insensitive to data distribution, dealing with complex nonlinear relations. Moreover, interactions are easily implemented, without concern for potentially complicated calculations of the standardized year effect (De'ath, 2007; Elith *et al.*, 2008; Hastie *et al.*, 2009).

In the current study, shortfin mako CPUE was standardized using BRT main effect (tree complexity tc=1) and two way interactions (tc=2). The Catch and effort data (979 longline sets) were subdivided on the training and test data sets (70%,30%) for residual analyses and test prediction model with test data. After the validation of the model, the global data (train data + test data) were used to estimate final standardized CPUE. We could justify this choice by the number of rows of data (979), lower than the requested rows number (1000). The small size of the training and test data sets degrades prediction error model (PE; accuracy) (De'ath, 2007). The reader is referred to (Albeare, 2009; Mateo and Hanselman, 2014) for more descriptions of R script to performed BRT.

A Generalized Linear Models (GLM) approach (Mccullagh and Nelder, 1989) was applied with the same data used for BRT models, under a log normal error distribution assumption. The step AIC analysis was performed to select the statistically significant factors in the final model.

3. Results and discussions

The number of observations (trips) analyzed by variables combination is summarized in **Tables 1 and 2**. A total of 979 trips, which represent an average of 122 observations per year, were used to compute the standardized CPUE of shortfin mako for the period 2010-2017.

The GLM ANOVA results showed that the variables Quarter, Year, Month, GRT and swordfish are significant at 1% level and contribute with 51%, 16.4%, 14.2%, 9.6% and 6.9%, respectively (**Table 5**). However, in BRT models, the relative influence of explanatory variables are ordered according to importance as follows: month (39,8%), Swordfish (19,0%), Year (17,4%), Blue shark (12,6%), GRT (5,3%) and quarter (3,6%) (**Table 3).**

The diagnostic plots showed that both BRT and GLM models fit well the data given the normal pattern of the residuals.The fitted values vs the residuals did not show any particular trend (**Figure 3, 4, 5 and 7**). The computed annual standardized CPUE using the BRT and GLM models are summarized in **Tables 7 and 8**. The yearly trend of the CPUE is illustrated by the **Figures 8 and 9**. The comparison between the different models shows that the BRT two-way interactions (RMSE= 0.778 and PED = 68%) fit better the data than BRT main effect model (RMSE= 0.801 and PED = 50%) and GLM (RMSE= 0.82 and PED = 38%) (**Tables 4 and 5**).

The standardized CPUE obtained from the best fit model (BRT two-way interactions) indicates a declining trend since the early years and slight increase and stability in the last three years of the time series (**Figure 8)**.

Finally, to evaluate the changes in patterns of yearly-standardized CPUE we used step plots technique (Bentley *et al.,* 2012). The results are shown is **Table 6.**

These results shows that when we added the variable "Months" in the model, the effect appears positive (green color) in 2010 and negative (pink color) in 2012 and 2016. The variable GRT has a positive effect in 2010. The swordfish had a negative effect on standardized CPUE in 2010 and 2017 and a positive effect in 2011 and 2014. The Blue shark had a positive effect during the period 2011 and 2013, and a negative effect in 2016. The interaction analysis (**Figure 6**) of the explanatory variables shows that there is interaction between pairs of factors in model fitting: (Swordfish, Year), (Blue shark, Swordfish) and (Blue shark, Month).

These changes in patterns and interaction analysis indicates that further research and analysis are necessarily to understand the contribution of each explanatory variables.

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Table 1. Number of observations by year and month.

Year/Month	***1***	***2***	***3***	***4***	***5***	***6***	***7***	***8***	***9***	***10***	***11***	***12***	***Total***
2010	0	0	14	0	0	0	0	0	0	0	13	6	33
2011	10	16	15	1	0	12	15	14	9	16	17	7	132
2012	11	12	5	10	7	13	6	18	15	17	13	6	133
2013	12	15	19	16	6	2	17	17	11	15	14	8	152
2014	10	13	16	19	3	9	13	12	15	19	16	10	155
2015	18	18	16	17	3	2	13	13	8	16	17	10	151
2016	16	7	17	7	0	10	8	8	12	11	2	1	99
2017	18	16	13	8	0	1	12	7	10	14	18	7	124
Total	95	97	115	78	19	49	84	89	80	108	110	55	979

Table 2. Number of observations by year and quarter.

Year/Quarter	***1***	***2***	***3***	***4***	***Total***
2010	14	0	0	19	33
2011	41	13	38	40	132
2012	28	30	39	36	133
2013	46	24	45	37	152
2014	39	31	40	45	155
2015	52	22	34	43	151
2016	40	17	28	14	99
2017	47	9	29	39	124
Total	307	146	253	273	979

Table 3. Model 1-Shortfin mako-tc2-BRT-Two-way Interaction: Relative influence of model terms calculated by the contribution of each term in reducing overall model deviance.

Variable	***Relative influence***
MONTH	39,773
Swordfish	19,044
YEAR	17,362
Blue.shark	12,575
GRT	5,329
QUARTER	3,573
Yellowfin.tuna	2,067
Bigeye.tuna	0,150
Bullet.tuna	0,127

Table 4. Brief model summary statistics: Model 1-Shortfin mako-tc2-BRT-Two-way Interaction and Model 1-Shortfin mako-tc1-BRT- main effects model.

Model 1-Shortfin mako-tc2-BRT-Two-way Interaction	fitting final gbm model with a fixed number of 2900 trees for Shortfin.mako
	mean total deviance = 0.901
	mean residual deviance = 0.29
	estimated cv deviance = 0.474 ; se = 0.03
	training data correlation = 0.829
	cv correlation = 0.69 ; se = 0.025
Percentage of explained deviance	**68%**
RMSE	**0.7784669**
Model 1-Shortfin mako-tc1-BRT-main effects model	fitting final gbm model with a fixed number of 1350 trees for Shortfin.mako
	mean total deviance = 0.901
	mean residual deviance = 0.452
	estimated cv deviance = 0.517 ; se = 0.032
	training data correlation = 0.707
	cv correlation = 0.657 ; se = 0.023
Percentage of explained deviance	**50%**
RMSE	**0.8015348**

Table 5. GLM: Summary of the results of the ANOVA.

	Df	***Deviance***	***% deviance***	***Resid.Dev***	***F***	***Pr(>F)***
NULL	978	848,190				
YEAR	7	52,616	16.4	795,580	13,608	<2,2e-16***
QUARTER	3	163,705	51.0	631,870	98,791	<2,2e-16***
MONTH	8	45,711	14.2	586,160	10,344	5,862e-14***
GRT	1	30,828	9.60	555,330	55,812	1,800e-13***
Swordfish	1	22,289	6.90	533,050	40,352	3,278e-10***
Blue_shark	1	0,836	0,30	532,210	1,513	0,21895
Yellowfin_tuna	1	2,893	0,90	529,320	5,238	0,02232*
Bigeye_tuna	1	1,693	0,50	527,620	3,065	0,08034.
Bullet_tuna	1	0,671	0,20	526,950	1,214	0,27078

Signif. codes: 0 ‘***’ 0.001 ‘**’ 0.01 ‘*’ 0.05 ‘.’ 0.1 ‘ ’ 1

R^2 = 0.38 (Adjusted-R^2 = 0.36) and RMSE= 0.82

Table 6. Changes in patterns of yearly-standardized CPUE of Shortfin mako removing each explanatory variables one at a time. Cell with the pink color: negative influence, Cell with the green color: positive influence. Unit is kg/1200 hook*day.

Year	*Month*	*GRT*	*Swordfish*	*Blue.shark*	*Quarter*	*Yellowfin.tuna*	*Bigeye.tuna*	*Bullet.tuna*
2010	28,1	10,0	-14,7	-0,4	1,6	-0,6	4,7	2,0
2011	-1,1	-1,4	10,1	4,2	0,9	-1,4	0,4	0,8
2012	-8,4	-2,6	-1,5	4,2	0,5	-0,2	-0,5	-0,1
2013	2,3	-0,7	0,7	4,4	0,8	0,2	1,2	0,8
2014	-1,1	0,5	6,6	-1,3	-0,8	-0,7	0,1	0,9
2015	0,7	3,4	2,1	-3,9	0,3	0,9	1,3	0,9
2016	-6,5	3,3	-1,8	-6,9	-0,6	0,9	1,0	0,2
2017	1,8	2,3	-10,2	-0,7	-0,3	-1,0	-2,6	2,6

Table 7. Nominal and standardized CPUE using the BRT Two-way interactions.

YEAR	*Nom.CPUE*	*Stand.CPUE*
2010	112,075	130,433
2011	113,303	112,664
2012	85,598	83,968
2013	108,812	113,917
2014	56,010	63,306
2015	85,074	93,118
2016	90,339	85,611
2017	108,336	90,913

Table 8. Nominal and standardized CPUE using the GLM approach.

YEAR	*Nom.CPUE*	*Stand.CPUE*	*UpperLim*	*LowerLim*	*CV(%)*
2010	112,158	121,802	160,342	92,468	2,895
2011	113,287	96,868	110,740	84,718	1,476
2012	85,566	78,744	89,911	68,948	1,527
2013	108,752	102,815	116,217	90,945	1,334
2014	56,014	53,705	60,876	47,365	1,570
2015	85,059	88,288	100,063	77,884	1,407
2016	90,318	84,835	98,951	72,712	1,745
2017	108,319	87,726	103,643	74,230	1,877

Table 9. Fleet dynamic; percentage of trips of vessel in and out of cluster.

Cluster name	*Ports*	*% trips in cluster*	*% trips out cluster*	*number of vessel*	*number of trips in cluster*	*number of trips out cluster*
Cluster 1	DAKHLA	92,000	8,000	270	20384	1800
	TANTAN					
Cluster 2	AGADIR	97,000	3,000	290	19777	703
	SAFI					
	LAAYOUNE					
	TANTAN					
	BOUJDOUR					
	JORF AL ASFAR					
	ESSAOUIRA					
	TARFAYA					
	JADIDA					
	SIDI IFNI					
Cluster 3	LARACHE	70,000	30,000	77	1264	529
	CASABLANCA					
	JADIDA					
	MEHDIA					
Cluster 4	TANGER	99,000	1,000	67	58851	544
	AL HOCEIMA					
	NADOR					
	MDIQ					
	RAS KABDANA					
Cluster 5	MOHAMEDIA	97	3,000	59	4936	132
	MEHDIA					
Cluster 6	ASILAH	96	4	17	1727	38

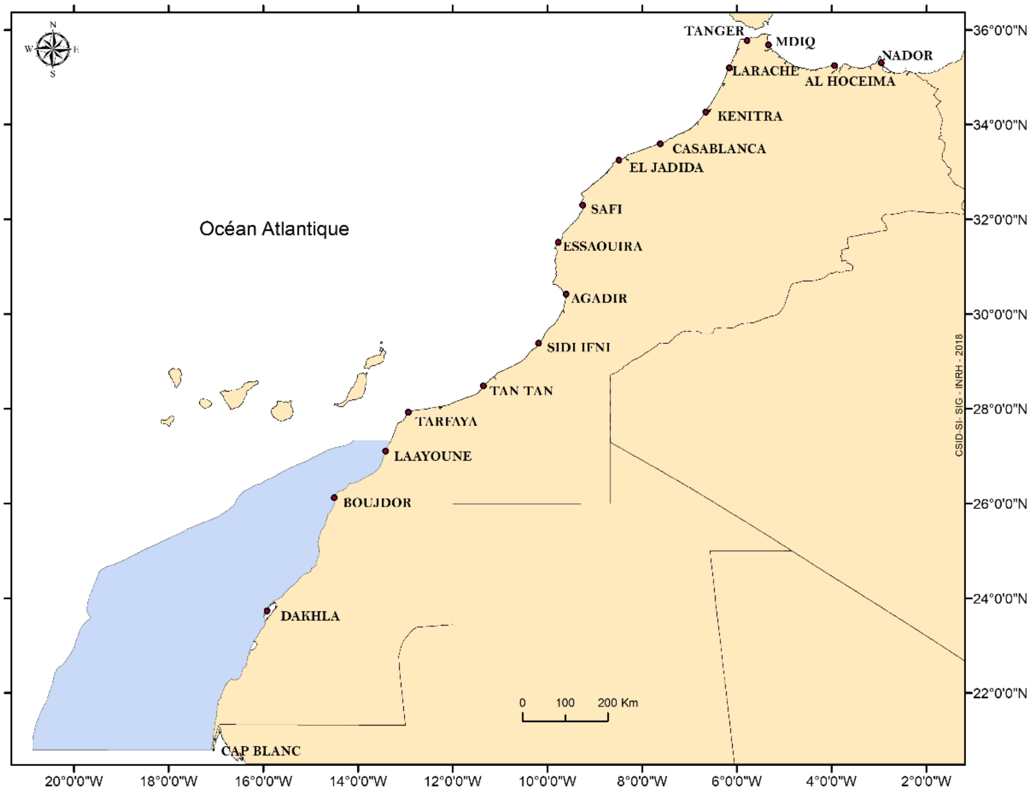


Figure 1. Geographical delimitation of the fishing area of the swordfish longline fishery operating south of the Moroccan Atlantic waters.

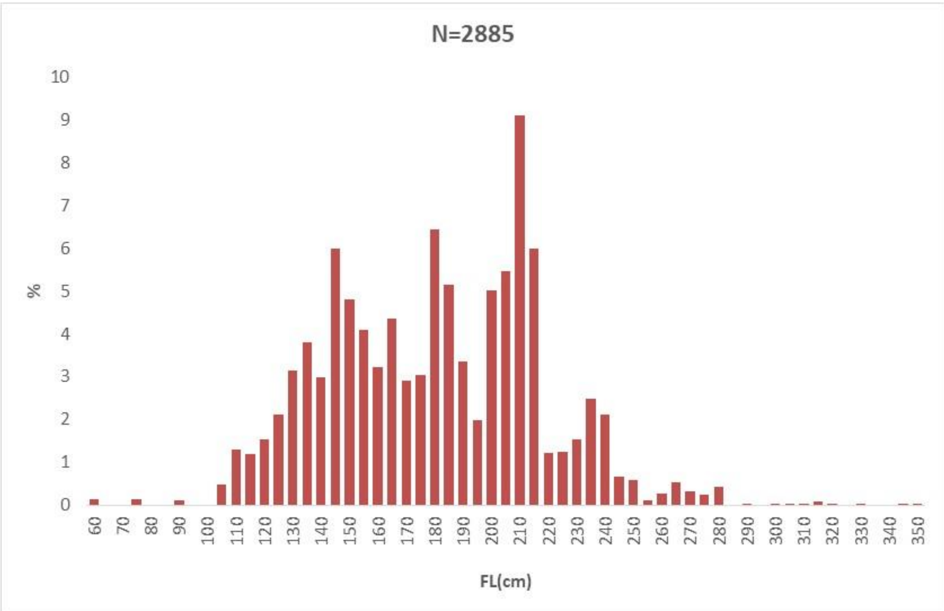


Figure 2. Size frequency of shortfin mako catches by the Moroccan longline fishery in the Atlantic for the period 2014-2017.

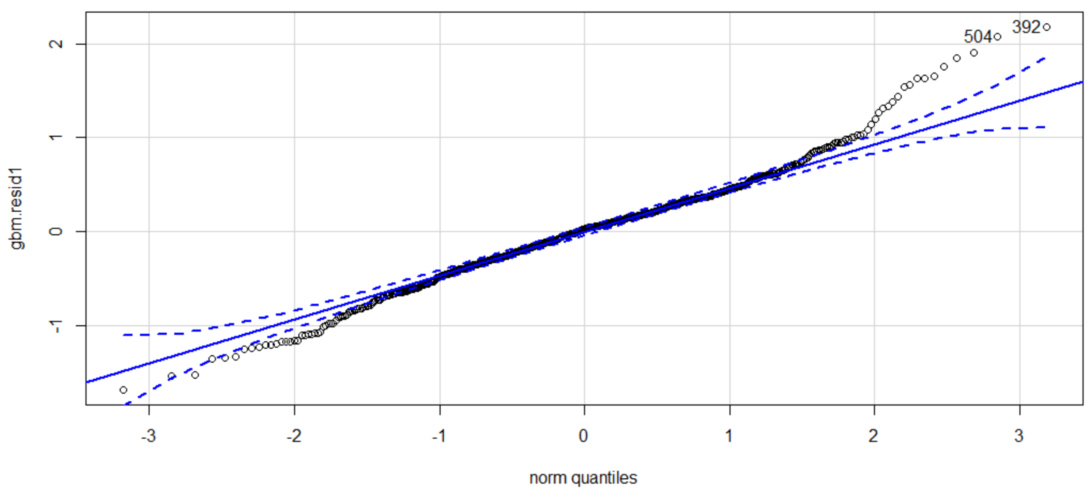


Figure 3. Shortfin mako-tc2-BRT-Two-way Interaction. QQ plots.

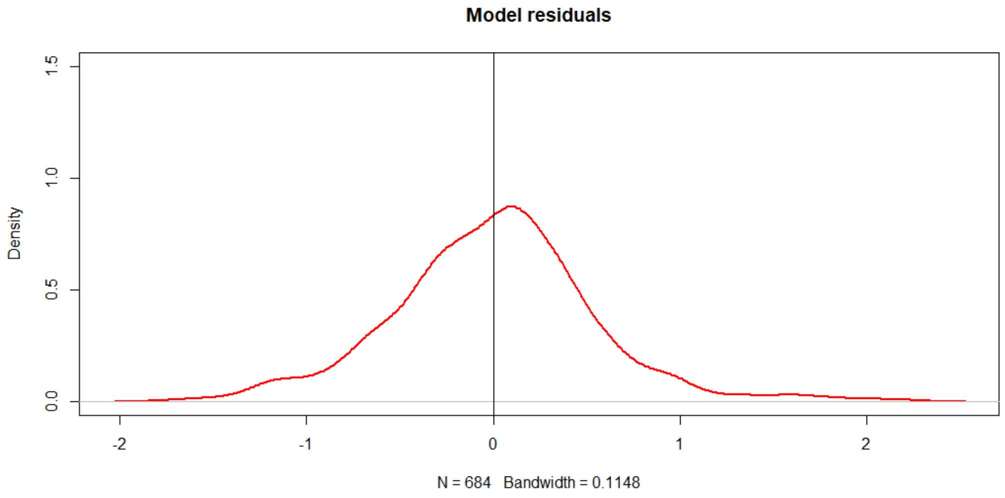


Figure 4. Shortfin mako-tc2-BRT-Two-way Interaction. Density functions for the BRT model residuals; values calculated using the default Gaussian kernel.

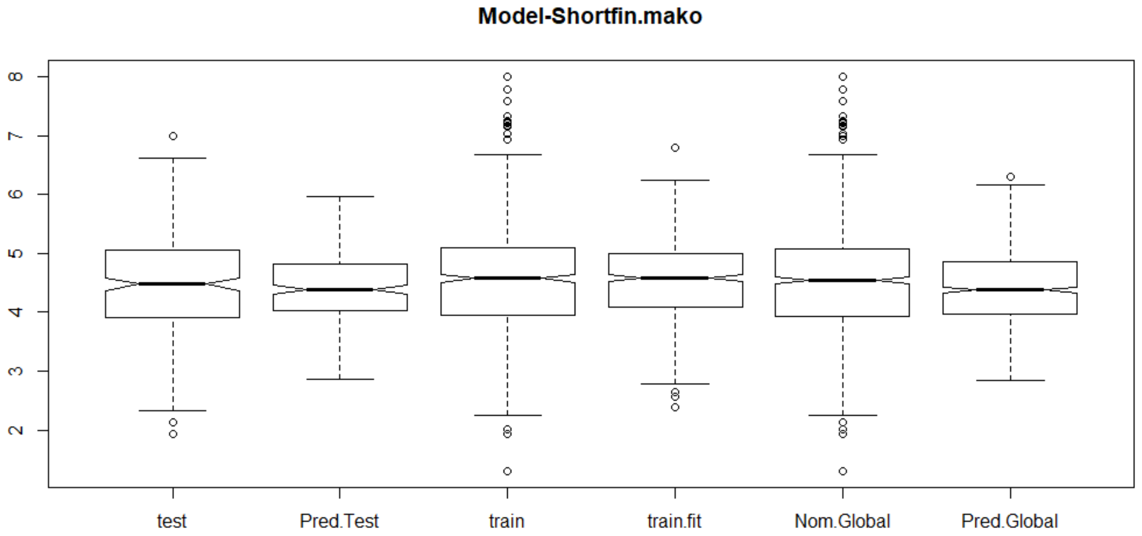


Figure 5. Boxplots of actual log(CPUE+1) data versus model predictions, using the test dataset, train dataset and global data; notches indicate robust estimates of the medians.

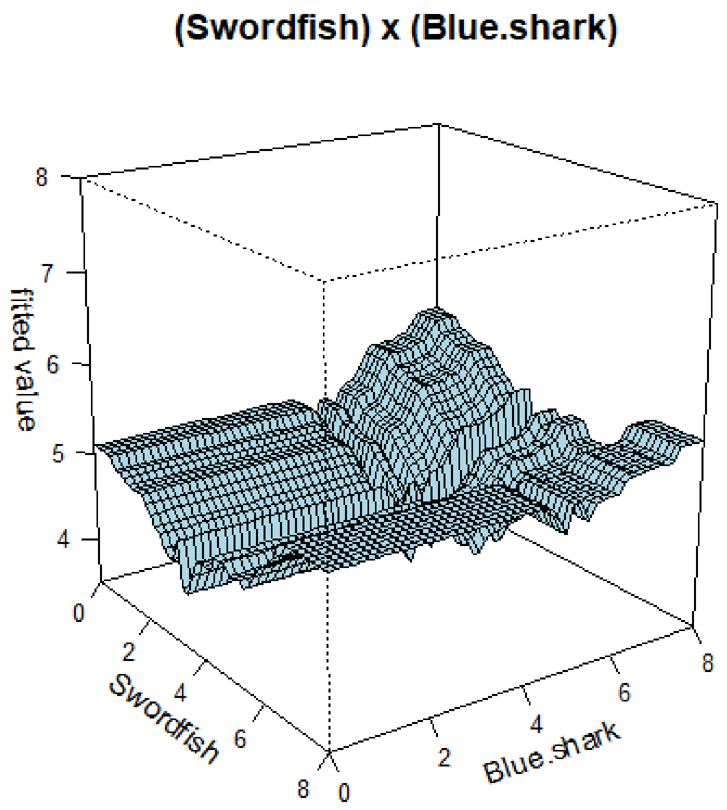


Figure 6. Shortfin mako-tc2-BRT-Two-way Interaction: Interaction plot for the Swordfish x Blue.shark cross-term using global data; interaction size= 5.79.

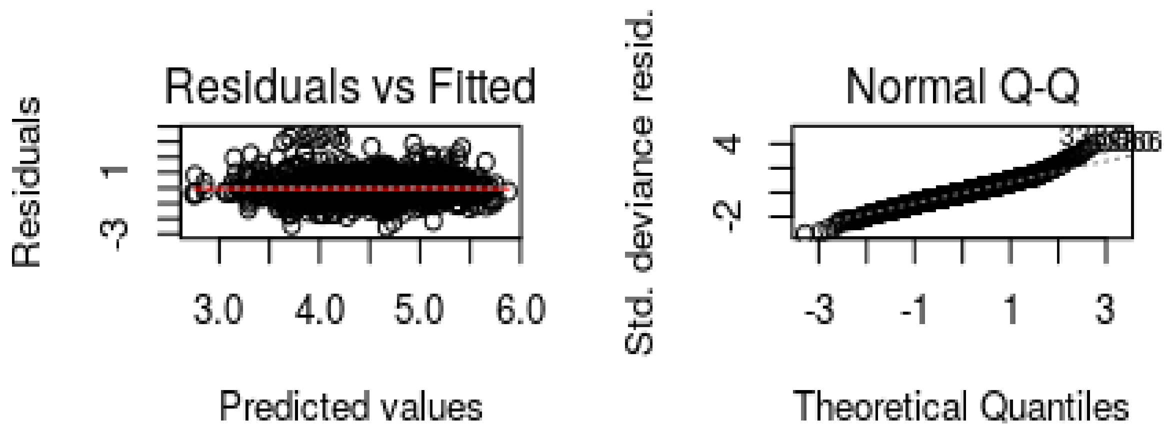
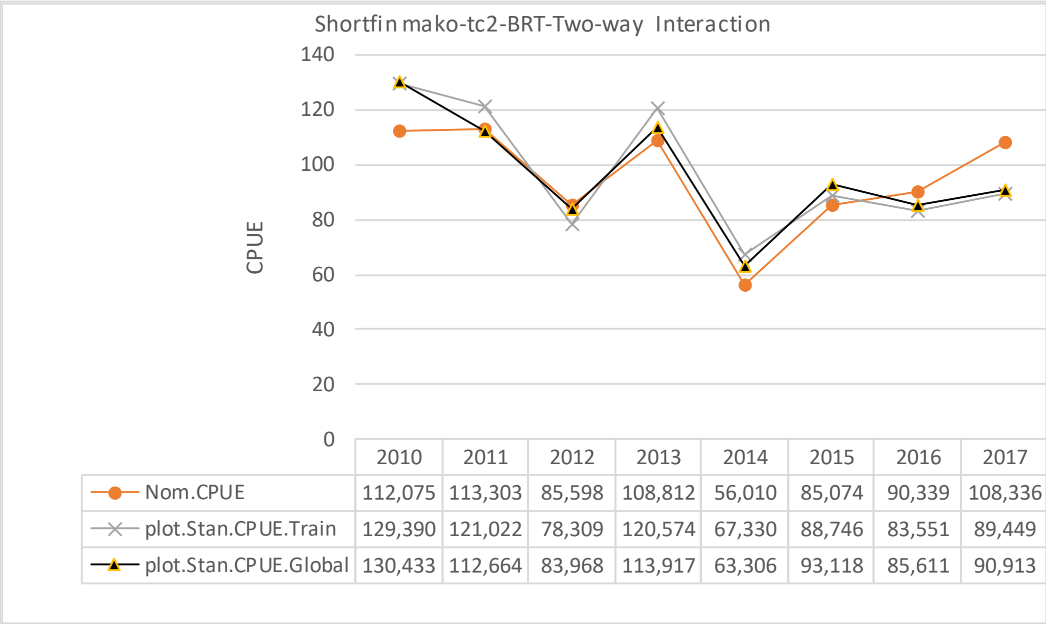
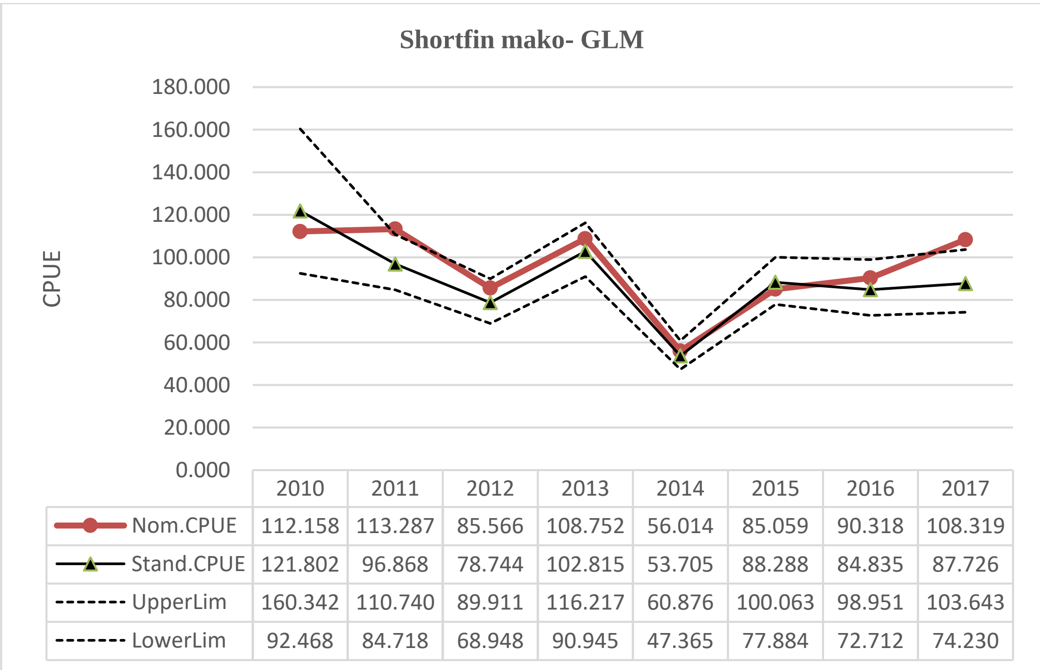


Figure 7. Shortfin mako-GLM, Residuals *vs* predicted and QQ plots.



	2010	2011	2012	2013	2014	2015	2016	2017
Nom.CPUE	112,075	113,303	85,598	108,812	56,010	85,074	90,339	108,336
plot.Stan.CPUE.Train	129,390	121,022	78,309	120,574	67,330	88,746	83,551	89,449
plot.Stan.CPUE.Global	130,433	112,664	83,968	113,917	63,306	93,118	85,611	90,913

Figure 8. Comparisons of the standardized CPUE indices and nominal indices of Shortfin mako from the trained and global models.



	2010	2011	2012	2013	2014	2015	2016	2017
Nom.CPUE	112.158	113.287	85.566	108.752	56.014	85.059	90.318	108.319
Stand.CPUE	121.802	96.868	78.744	102.815	53.705	88.288	84.835	87.726
UpperLim	160.342	110.740	89.911	116.217	60.876	100.063	98.951	103.643
LowerLim	92.468	84.718	68.948	90.945	47.365	77.884	72.712	74.230

Figure 9. Comparisons of the standardized and nominal index of Shortfin mako from the Moroccan longline fishery, 2010-2017.