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STANDARDIZED CATCH RATES OF THE OCEANIC WHITETIP SHARK (*Carcharhinus longimanus*) FROM OBSERVATIONS OF THE SPANISH LONGLINE FISHERY TARGETING SWORDFISH IN THE INDIAN OCEAN DURING THE 1998-2011 PERIOD

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Abstract

The standardized catch per unit of effort for the oceanic whitetip shark (*Carcharhinus longimanus*) was obtained by means of a General Linear Mixed Model (GLMM) based on 2806 set records for the 1998-2011 period. Since the number of zero catch observations was considerably high, catch rates were modeled with a delta-lognormal approach using year, quarter, zone and gear as the main explanatory variables. The best models were chosen based on the Akaike information (AIC) and the Bayesian information criteria (BIC). Diagnostics for both models indicated relatively good model fits. The obtained results, together with the full analysis of the managed data, suggest that the standardized index shows a statistically satisfactory fitting level, allowing to identify some significant values which could partially explain the variability of the observed CPUE. However, the high variability of the standardized catch rates between consecutive years and the limited availability of specimens in some years-areas suggest that this index could show the availability rates of this low-prevalence species during a particular period instead of being a representative and plausible indicator of the stock abundance at large. This paper discusses the difficulty to obtain biologically plausible abundance indexes for this kind of species with a low occurrence-prevalence in these fisheries.

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1. Introduction

The oceanic whitetip shark (*Carcharhinus longimanus*) is considered to be one of the most widespread oceanic-epipelagic sharks in tropical and subtropical areas across oceans, being more frequent in warmer waters (Compagno 1984). This species is usually found far offshore in the open sea but some reports also suggest sporadic inshore presence or around the oceanic islands with narrow continental shelves. Although this species can be found in oceanic waters warmer than 18ºC, it generally prefers and chooses waters between 20-28ºC and tends to be less present or absent in waters with lower temperatures. Its occurrence in the Indian Ocean is widely described in García-Cortés *et al.* (2012). Therefore, its presence and potential vulnerability to fleets-gears is dependent on the temperature chosen by the fleets when they catch their target species.

This species is reported in the Indian Ocean and also in the Red Sea, usually as a low-prevalent bycatch of the drift nets, purse seines and different longline fisheries (Delgado de Molina *et al.* 2005, 2007, García-Cortés *et al.* 2012, Poisson and Taquet 2001), being more abundant in the Northern hemisphere of the Indian Ocean (Semba and Yokawa 2011). Even though this species has generally been reported as a low-prevalence bycatch of the abovementioned fleets, it cannot be ruled out that it can be a target catch species for some artisanal fisheries from coastal communities washed by warm waters and for recreational or charter fisheries in some touristic areas. Some reports suggest that this species could represent an important proportion of the total shark bycatch in some areas-fisheries out of the Indian Ocean, such as the Gulf of Mexico and some tropical waters of the Atlantic and the Pacific (Bonfil 1994, Bonfil *et al* 2008). The available information from Indian areas-fleets reports a relatively low prevalence of this species among target and/or other bycatch species caught by longliners targeting swordfish or tunas (García-Cortés and Mejuto 2001, 2005; Ramos-Cartelle *et al.* 2008, 2009; Semba and Yokawa 2011). However, the oceanic whitetip shark can sometimes be the second most prevalent bycatch species of shark after the blue shark in some surface longline fleets fishing in areas with warmer waters and mean catch rates around 0.11 fish per thousand hooks (Poisson and Taquet 2001).

The catch and landing records for the oceanic whitetip shark have generally been poor in most oceanic fleets. There is little or no information available from the artisanal or recreational fisheries. The relatively low commercial value of this species in the international markets intended for human consumption, together with a generally low prevalence in the catch of oceanic commercial fleets, may be the most likely causes for the scant attention that the oceanic whitetip shark has received for statistical purposes. Its recording as a species in log-books has generally been inappropriate and, at best, it is recorded as unclassified shark, *Carcharhinus* genus or *Carcharhinidae* family. Nevertheless, few actions have been initiated in recent years in order to train fleets on how to improve the taxonomic identification and the catch records of these and other low-prevalence species. In spite of the above limitations, there are many descriptions on catch rates for the oceanic whitetip shark (e.g. Bonfil 1994, Bonfil *et al.* 2008, Cortés 2001, Gilman *et al.* 2012, Guitart-Manday 1975, Walsh and Clarke 2011, Poison 2007, Poisson and Taquet 2001, Semba and Yokawa 2011). However, many of them only provide point data on catch rates and/or describe areas which are relatively limited regarding the known distribution of the species-stock. Only a few reports provide catch rates over time in the oceanic regions where this species is preferably located.

Domestic regulatory measures, modifications in fishing gears, changes in the fishing areas-seasons and/or in the target species are some of the factors which, amongst others, may contribute to the reduced catch and catch rates reports for this bycatch species in some fleets. Therefore, the data on catch-effort and catch rates should be interpreted cautiously, since the presence and local abundance of this species is very sensitive to space-time variations, to the different fishing patterns executed in each season and, in some cases, to domestic regulations, the established systems for data collection or the type of analysis applied in each case and period.

The poor availability of historic records regarding the catch of this and other low-prevalence bycatch species is not a problem that is specific to the Indian Ocean, but it is generalized in all oceans. In this sense and in order to address these gaps in the short term, some scientific groups have developed methods, within the RFO framework, for the indirect estimation of historic catches by fleet or by combined fleets based on data considered plausible, or have applied quantitative assessment methods which are less dependent on the reported catch levels. Recommendations should not be the only way to promote the enhancement of the statistic methods used to record these low-prevalence species. It is necessary to design consistent training programs in order to implement statistic systems which are truly operational, reliable and efficient for this type of species.

Scientific estimations on the annual landings of *C. longimanus* in the EU-Spain longline fishery in the Indian Ocean have been reported for the period 1993- 2008 (García-Cortés and Mejuto 2001, 2005; Ramos-Cartelle *et al.* 2008, 2009), as well as for the most recent period, 2009-2010, reported as 'task I' data. The mean annual landing of this species by this fishery during the 1998-2010 period was 24.5 t/year (CI95%: 42.7 t - 9.4 t) and its mean prevalence for the whole period was 0.31% (CI95%: 0.52%-0.13%) or 0.55% (CI95%: 0.92%- 0.23%), depending on whether all landed species were taken into consideration or if swordfish was excluded, respectively. A recent scientific study on this species (García-Cortés *et al.* 2012) has been considered as the basis for approaching this paper.

The catch per unit of effort (CPUE) is regularly assumed as a possible indicator of abundance for many large pelagic fish due to the lack of direct abundance indicators, especially when the available data cover large oceanic areas where these species-stocks are broadly distributed. However, CPUE indicators must be evaluated taking into account, among other limitations, the knowledge of the fishery, the amount and quality of the data used, the spatial-temporal coverage in relation to stock distribution and the biological plausibility of the interannual CPUE variability in this type of long-span and widespread species (Ramos-Cartelle *et al.* 2011). In some cases, the consistency in the fishing patterns of the fleets over time can facilitate the interpretation of these indices as 'abundance indicators'. The Generalized Linear Modeling technique (GLM) (Robson 1966, Gavaris 1980, Kimura 1981) has been used together with similar approaches (Lo *et al.* 1992) 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 and the environmental and physiological requirements of their respective biological processes. The standardized catch rates of the swordfish (*Xiphias gladius*) and several large shark species have been obtained in recent decades by means of GLM based on data from several commercial fleets or combinations thereof (e.g. Babcock and Skomal 2008, Brown 2008, Cortés 2008, 2009, 2010; Fowler and Campana 2009, Hoey *et al.* 1989, 1993; Matsunaga 2008, Mejuto *et al.* 1999, Mourato *et al.* 2007, 2008; Nakano 1993, Nishida and Wang 2006, Ortiz *et al.* 2007, Okamoto *et al.* 2001, Pons and Domingo 2008, Saito and Yokawa 2003, Scott *et al.* 1993, Wang *et al.* 2006, Yokawa 2007). CPUE standardizations of the Spanish longline fishery in the Atlantic were carried out recently for the most prevalent large epipelagic shark species such as *Prionace glauca* and *Isurus oxyrinchus* (Mejuto *et al.* 2009, in press), as well as for the sporadic occurrence of the porbeagle in this fishery (Mejuto *et al.* 2010).

The objective of this document is to provide a preliminary standardized CPUE analysis for this species, which is relatively scarce in the catch of commercial Spanish surface longline fisheries targeting swordfish in the Indian Ocean.

2. Material and methods

The data used in this case consisted of set records obtained at sea and voluntarily provided for research purposes (García-Cortés *et al.* 2012). The catch-per-unit-of-effort data (kg of dressed weight per thousand hooks) were standardized by using a General Linear Mixed Model (GLMM) with year (1998-2011), quarter (four natural quarters), zone (four zones as defined in García-Cortés *et al.* 2012) (**Figure 1**), and gear (traditional longline vs. monofilament longline), as main explanatory variables. Since the number of zero catch observations for the oceanic whitetip was considerably high in this fishery, catch rates were standardized with a delta-lognormal approach (Lo *et al.* 1992). The number of positive sets (sets with at least one individual caught) was assumed to follow a binomial distribution and the catch rates for trips with a positive catch was assumed to be log-normally distributed. The resulting standardized delta-lognormal abundance index is the product of the year effects of both models (binomial and log-normal), with the corresponding standard errors estimated according to the method of Lo *et al.* (1992). The best models were chosen based on the Akaike information (AIC) and the Bayesian information criteria (BIC). All main effects used were treated as fixed and interactions between factors as random effects. All analyses were conducted in R (R-Development Core Team 2012, Bates *et al.* 2012, Mazerolle 2012)

3. Results and discussion

A total of 2806 set records were available for the 1998-2011 period. Some of the observations stem from areas which have been sporadically observed during surveys, whereas some others were obtained from regular commercial activities. That is why some of the observations are limited or available only for a few years in some areas (**Table 1**). Some of the years only include a scarce number of sampled fish (see table 3 of García-Cortés *et al.* 2012 for details). The reduced number of available observations, the small amount of fish caught in some of the years and the space distribution of the available observations represent a limitation when carrying out a representative analysis of the abundance trends of this species-stock over the years. The coverage of the fishing effort sampled represents, in average, 5.78% (CI95%= ± 2.64%) of the total fishing effort of this fishery during the overall analyzed period. Zero catch observations were predominant (62%) and the catch per set was lower than 3 fishes in 80% of the available observations (**Figure 2**).

As regards sets with positive catch records, the best model (based on AIC and BIC, **Table 2**) included year, quarter, zone, gear and the interaction between quarter and gear. Logged positive catch rates were approximately normally distributed (**Figure 2**), hence justifying the appropriateness of the log-normal error assumption. As for the number of sets with presence or absence of positive observations, the best model (based on AIC and BIC, **Table 2**) included year, quarter, zone, gear and the interactions between quarter and zone. Box-plots of the observed CPUE per set (kg dressed weight per thousand hooks) for each main factor initially considered for the GLMM analysis are shown in **figure 3**. Regarding model goodness of fit, diagnostics for both models were not far from expected under the assumed error distributions, indicating a relatively good model fit. Residuals and qq-plots are shown in **figure 4**. Standardized delta-lognormal CPUE values, standard errors, coefficients of variation and corresponding 95% confidence limits based on a normal approximation are reported in **table 3**. The delta-lognormal index predicted a general declining trend from 1999 to 2007, followed by an ascending trend for the most recent period (**Figure 5**).

The standardized CPUE predictions for the 1998-2011 period suggest that the increments of the CPUE in biomass between pairs of consecutive years ($CPUE_{yr+1}$ vs. $CPUE_{yr}$) were relatively high, especially after 2006, with average year-to-year variations of around 70% if the absolute increments were considered for the whole period. This high variability is frequently observed in analyses of species in which the number of observations is small and/or there is a predominance of zero catch or sporadic observations.

Additionally, a sensitivity analysis was conducted excluding Zone 4, where there were just a few positive observations available for the 2003-2006 period. The occurrence-prevalence of this species is lower in this zone because waters are generally less warm than the ones that the oceanic whitetip sharks usually choose as their habitat. The results obtained from this analysis suggest a more moderate downward trend for the 2003-2006 period than the one predicted by the base case model run and a significant increase in the confidence intervals of some of the years. However, they do not substantially modify the general average trend of the base case for the analyzed period. The data used for this analysis (García-Cortés *et al.* 2012) point out that between 2002 and 2004 there were only 6, 35 and 66 fish available in the observed catch data, respectively. In 2005 and 2006 the number of fish included in the observations was the highest for the analyzed series. However, it was mostly made up of juvenile fish with a low body biomass which were only present in restricted areas, according to the studies of those authors.

The results of the analyses, the global statistic diagnoses and the study of all the managed data suggest that the CPUE standardized index shows a statistically satisfactory fitting level. Several statistically significant factors which could contribute to explain some of the CPUE variability observed in this fleet were identified. However, this standardized index could be showing the availability rates of this low-prevalence species in this fleet for a particular period, instead of being a representative indicator of the overall stock abundance. Zones 1 and 2, where this species is considered to be potentially more abundant (Semba and Yokawa 2011), have been subject to very few observations over the analyzed period. On the other hand, the geographical stratification of the different population fractions could have an impact on the biomass levels predicted by the model, since the structure by size-age/year could not be included in the analyses, as there were not enough data to conduct annual studies. It was not feasible to carry out further analyses including other factors such as the kind of bait.

The obtained results advise of the difficulty to obtain abundance indexes from the records of the fleets in which these and other species are usually present with a very low occurrence-prevalence and/or the risk of not having a correct taxonomic identification in the commercial records. In order to have a data set to conduct a robust and representative analyses on these low-occurrence-prevalence species it is necessary that fleets are properly trained for these tasks. Usually, the way to attain this involves the organization of training programs which are consistent over time and a closer cooperation between scientists and fleets.

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Table 1. Number of observations (fishing sets) by year and zone used for the GLMM models.

Year/ Zone	OCS1	OCS2	OCS3	OCS4	Total
1998	0	0	76	0	76
1999	12	57	79	0	148
2000	0	0	19	0	19
2001	0	22	84	0	106
2002	0	0	79	20	99
2003	4	0	0	517	521
2004	34	0	27	58	119
2005	118	40	15	65	238
2006	316	247	143	243	949
2007	0	0	178	0	178
2008	0	0	147	0	147
2009	0	0	60	0	60
2010	0	0	90	0	90
2011	0	0	56	0	56
Total	484	366	1053	903	2806

Table 2. Analysis of deviance of the modelled log of CPUE values and the presence/absence of the oceanic whitetip shark.

Analysis of deviance table. Fixed effects model for log of CPUE (kg * 1E-03 hooks). AIC best model.							
	Df	*Deviance*	*Resid. Df*	*Resid Dev.*	*F*	*Pr(>F)*	*% deviance*
NULL			1071	858.31			
year	13	44.86	1058	813.46	4.90	2.1080E-08	5.23
quarter	3	5.08	1055	808.38	2.41	6.5873E-02	0.59
zone	3	9.46	1052	798.92	4.48	3.9039E-03	1.10
gear	1	47.27	1051	751.65	67.19	7.2070E-16	5.51
year:zone	8	4.84	1043	746.81	0.86	5.5049E-01	0.56
quarter:gear	1	6.29	1042	740.52	8.94	2.8480E-03	0.73
zone:gear	1	8.15	1041	732.37	11.58	6.9240E-04	0.95
Mixed effects model for log of CPUE (kg * 1E-03 hooks).							
model	*AIC*	*BIC*					
year+quarter+zone+gear+year:zone	2750.70	2865.17					
year+quarter+zone+gear+quarter:gear	**2745.70**	**2860.18**					
year+quarter+zone+gear+zone:gear	2749.34	2863.82					
year+quarter+zone+gear+year:zone+quarter:gear	2747.70	2867.15					
year+quarter+zone+gear+year:zone+zone:gear	2750.01	2869.47					
year+quarter+zone+gear+quarter:gear+zone:gear	2747.20	2866.65					
year+quarter+zone+gear+year:zone+quarter:gear+zone:gear	2748.52	2872.95					
Fixed effects model for presence/absence. AIC best model.							
	Df	*Deviance*	*Resid. Df*	*Resid Dev.*		*Pr(>Chi)*	*% deviance*
NULL			58	1929.5			
year	13	940.87	45	988.63		2.2000E-16	48.76
quarter	3	92.77	42	895.86		2.2000E-16	4.81
zone	3	749.35	39	146.51		2.2000E-16	38.84
gear	1	4.88	38	141.63		2.7250E-02	0.25
year:quarter	13	53.86	25	87.77		6.4000E-07	2.79
quarter:zone	9	59.03	16	28.74		2.0570E-09	3.06
Mixed effects model for presence/absence							
model	*AIC*	*BIC*					
year+quarter+zone+gear+year:quarter	185.63	231.34					
year+quarter+zone+gear+quarter:zone	**175.94**	**221.64**					
year+quarter+zone+gear+year:quarter+quarter:zone	176.71	224.50					

Table 3. Estimated relative abundance index based on a delta-log normal model, standard error, CV, number of observations and confidence intervals (95%) of the Spanish longline fishery. Period: 1998-2011.

Year	Index	Index.SE.	CV	N	Low95%	Upp95%
1998	18.2439	11.9478	0.6549	76	15.5577	20.9301
1999	28.4353	36.9894	1.3008	148	22.4759	34.3947
2000	20.0939	19.9036	0.9905	19	11.1441	29.0436
2001	16.1887	18.3285	1.1322	106	12.6994	19.6779
2002	12.6669	15.1004	1.1921	99	9.6923	15.6414
2003	10.5855	12.8743	1.2162	521	9.4800	11.6910
2004	14.1684	15.9937	1.1288	119	11.2948	17.0421
2005	11.7850	14.1996	1.2049	238	9.9809	13.5890
2006	10.8850	9.6956	0.8907	949	10.2681	11.5019
2007	3.1153	3.7109	1.1912	178	2.5702	3.6605
2008	9.4496	8.5545	0.9053	147	8.0667	10.8325
2009	22.3639	21.2105	0.9484	60	16.9969	27.7309
2010	5.9542	7.4927	1.2584	90	4.4062	7.5023
2011	18.9829	22.1895	1.1689	56	13.1711	24.7946

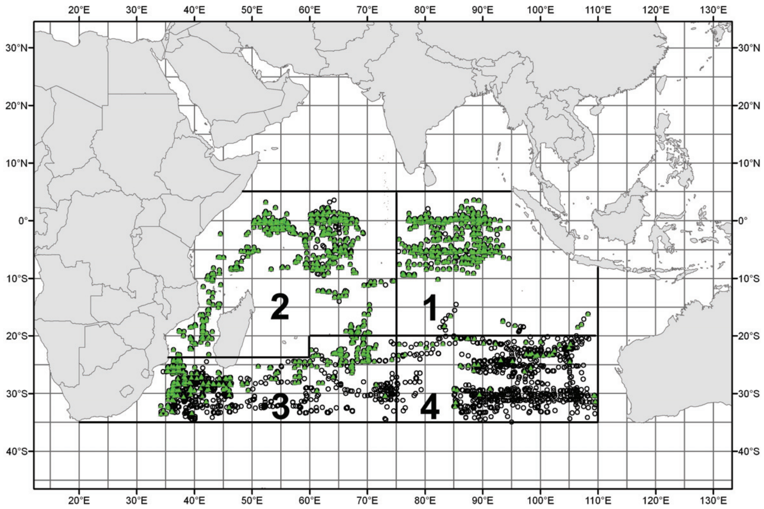

Figure 1. Stratification of geographic zones used for the GLMM analysis of the oceanic whitetip shark in the Indian Ocean as defined by García-Cortés *et al.* 2012 (Green dots= positive catch observations. Black dots: null catch observations). Note that the GLMM analysis was restricted in this case to the continuous period 1998-2011.

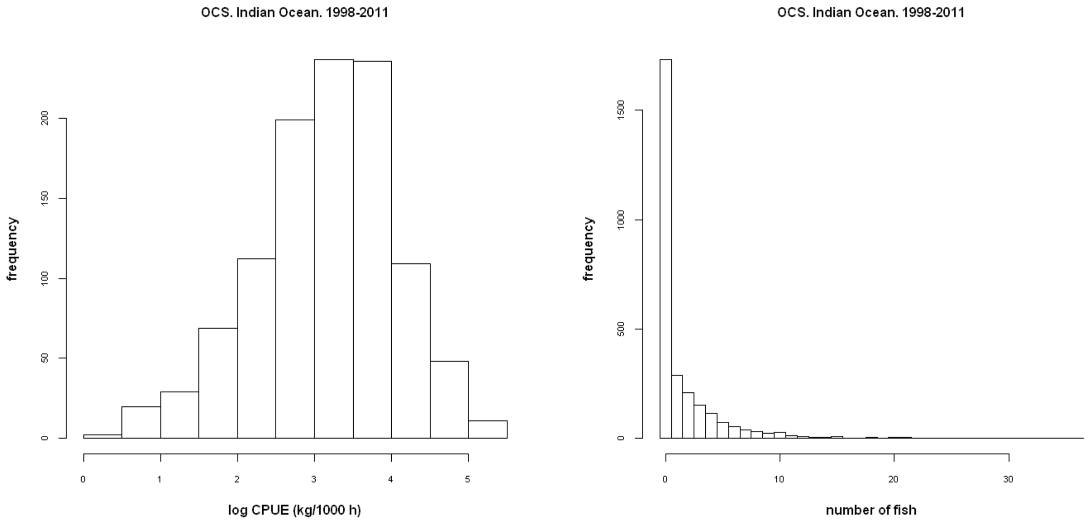

Figure 2. Histogram of log CPUE (kg dressed weight per thousand hooks) for positive catch sets (left panel) and histogram of the number of fish caught by set analyzed (right panel).

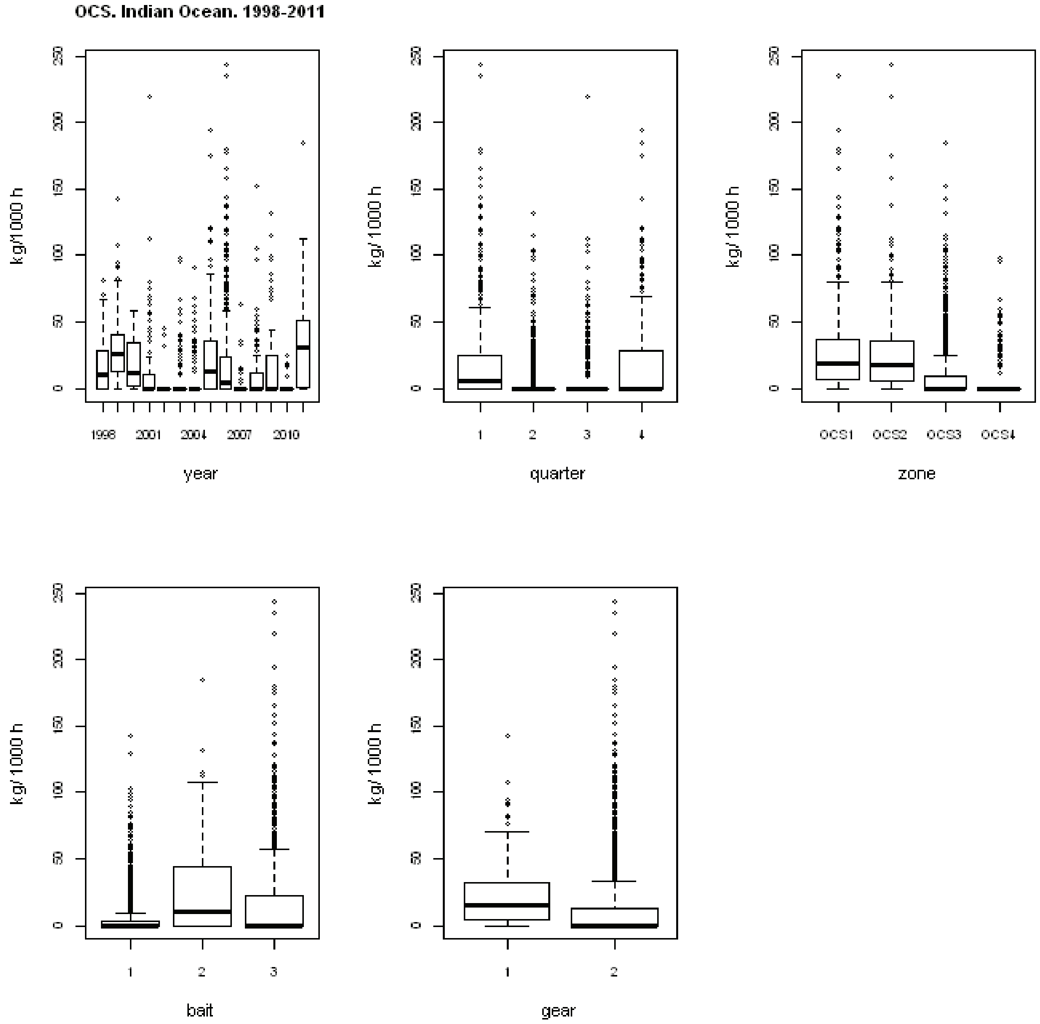

Figure 3. Box-plots of the nominal CPUE observed (kg dressed weight per thousand hooks) per set for each main factor initially considered for the GLMM analysis.

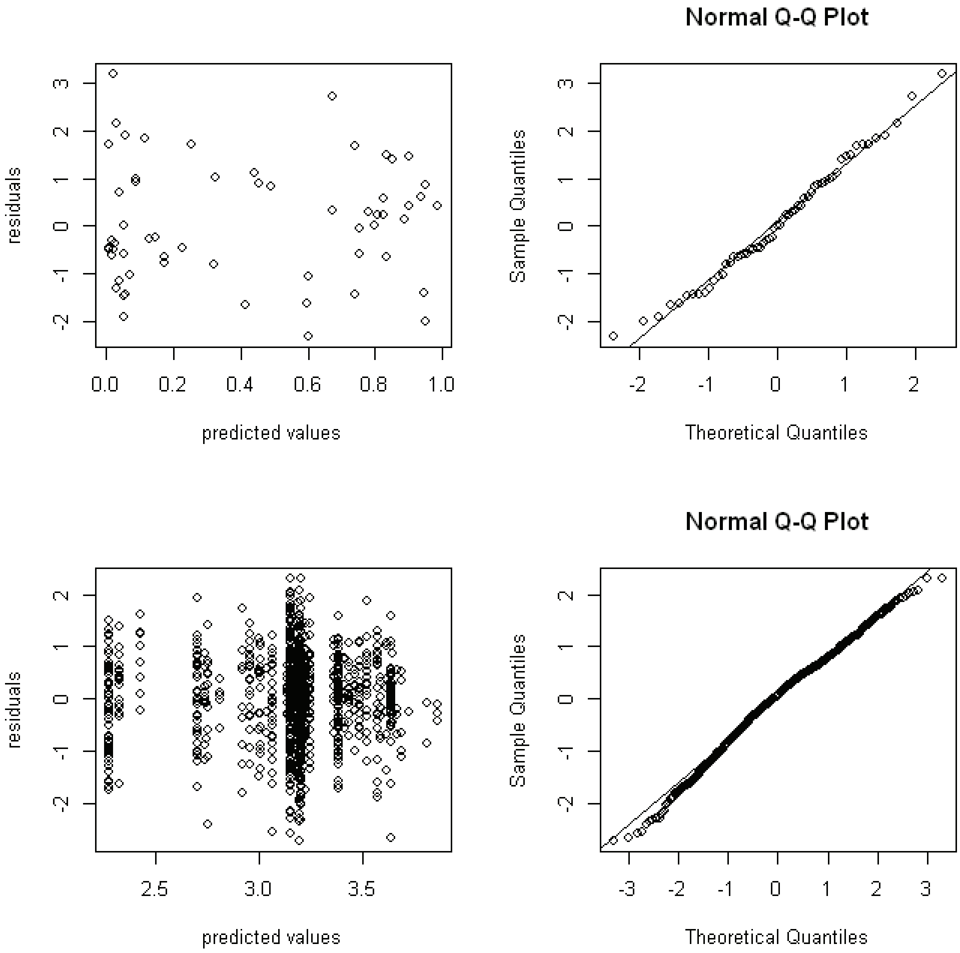

Figure 4. Diagnostics of the final fitted model. Presence/absence model (upper panels); log CPUE model (lower panels); residuals (left panels); qq-plots (right panels).

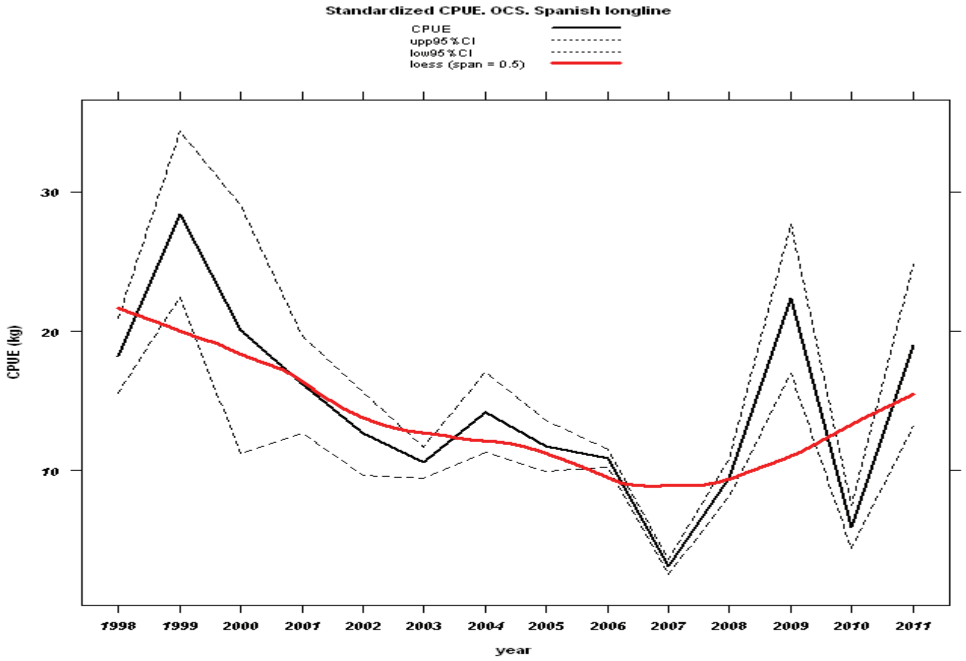

Figure 5. Estimated standardized catch rates (kg dressed weight), corresponding 95% confidence limits (bootstrap percentile method) and loess fit (red line) of the oceanic whitetip shark in the Indian Ocean during the 1998-2011 period.