STANDARDIZED YIELDS OF THE BLUE MARLIN (*Makaira nigricans*) CAUGHT AS BYCATCH OF THE SPANISH SURFACE LONGLINE FISHERY TARGETING SWORDFISH (*Xiphias gladius*) IN THE INDIAN OCEAN

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SUMMARY

*Standardized yields of blue marlin were obtained from 1,914 recorded trips (65.1*10*^{6} *hooks) by the surface longline fleet targeting swordfish in the fishing areas of the Indian Ocean during the period 2003-2017. The observations represent about 90% of the total fishing effort of this fleet during this combined period. Roughly 7% of the trips recorded during this period showed a positive catch of these species (at least one fish). However a part of the observation analyzed were obtained during scientific surveys done in warmer areas where occurrence of this species is more likely but in which the fishing activity was sporadic and it is not currently carried out. Because of the low occurrence and prevalence of this species in this fishery, the standardized yields were calculated using a Generalized Linear Mixed Model, assuming a delta-lognormal error distribution. An overall flat trend was predicted for the whole period considered, with some annual fluctuations. Some other considerations are also discussed.*

Key words: blue marlin, catch rates, abundance, GLM

1. Introduction

Blue marlin (*Makaira nigricans/M. mazara)* is one of the largest billfish species, widely distributed in epipelagic layers but mainly of tropical and subtropical waters with surface temperatures between 22-31°C. Geographical latitudinal limits are regularly assumed between 50ºN to 45ºS, but individuals are less frequently observed in eastern regions of the respective oceans because the thermal characteristics of their epipelagic layers versus the more active circulation of the main warm superficial currents in western regions. Seasonal warming waters can produce sporadic of seasonal occurrence of individuals of this species to some temperate areas near the limits of the distribution. Large individuals can appear in temperate, subtropical and tropical waters, while small individuals are more frequently described in tropical waters.

Blue marlin is primarily a solitary species but sporadic local “concentrations” of this species can be found across some equatorial areas of the Atlantic and Pacific. However, the Indian Ocean can be a special case because the different oceanic characteristics of the Northern system versus the characteristics in the two other main oceans. Blue marlin is an efficient apex predator that regularly feed near surface, but also in deeper water than other Istiophoridae species. A large number of potential preys have been described in literature depending on the area of each study, suggesting an opportunistic feeding behaviour taken advantage of the availability of potential preys.

No enough information on stock structure is currently available in the Indian Ocean. It is not currently clear, but Indian and Pacific stocks are considered so far different for assessment and management. Migrations of the blue marlin have displayed extensive horizontal movements in the Atlantic Ocean, as revealed by the release-recovery data of tagged fish which indicated trans-equatorial movements, but also some inter-oceanic mixing from the Atlantic into the Indian Ocean (Ortiz *et al.* 2003). Nevertheless, blue marlin migration routes and mixing rates are uncertain because the limited tagging experiments carried out, inadequate geographical tagging designs and uncertainties associated with post-tagging survival, tag shedding and the different tag reporting rates among areas-fleets-fishermen. However, despite these limitations, the conventional and electronic tagging studies carried out to date, with a relatively low number of releases and very little diversity of areas considered in the experiments, show evidence that this species can realize huge horizontal migrations. Detailed genetic analyses carried out in the Atlantic have shown no evidence of genetically based stock structure within this ocean because the analyses did not reveal significant heterogeneity (Graves and McDowell

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2003). Therefore, geographically wide stock structures are initially suggested and should be assumed for blue marlin based on these and other evidences.

As it happens in the case of other Xiphoidei's species, studies carried out in different oceans and areas revealed that blue marlin also display differential growth and spatial and seasonal sex-ratio patterns. A physiological adaptation for continuous swimming and cranial endothermy is also a characteristic of this species to facilitate foraging at different depths for a variety of preys. However, studies suggests the blue marlin is mainly associate with the epipelagic layers and spends over 80% of its time in water temperatures ranging from 26-31°C, although short duration dives allows them to cross in some cases temperature 14°C (Saito *et al.* 2004) or similar minimum thresholds of tolerance according to other tagging experiments also carried out. This probably explains why the blue marlin is a minor bycatch species in this swordfish fishery currently carried out in temperate waters of South Indian Ocean. Results of several electronic tagging studies indicate that most of their dive descents ranged from 100-200 m, sporadically reaching depths >300 m, and in some rare events below 800 m deep (Arocha and Ortiz 2006).

The blue marlin is targeted by recreational fleets in many coastal countries and around many oceanic islands with warm sea waters of the Indian Ocean. This species is an important attraction for tourism activity related to big-game fishing and high-end charter cruises, "*blue marlin safaris*" and other similar initiatives done in many coastal countries, islands, companies and businesses, regularly for people with high purchasing power. It is a catch considered a prestigious trophy for recreational fishermen.

This species may be also captured as food for human consumption by driftnets and coastal-artisanal gears, so that this and other species of istiophorids can provide a source of food for people living near the coast in many countries of the Indian Ocean. Artisanal and local fisheries using surface-drift gillnets could be an important component of the catches in the case of some areas of the Indian Ocean. The fishing areas where some of the oceanic tuna and tuna-like fisheries operate can overlap in some cases with areas where blue marlin may be found, because of their biological characteristics (García de los Salmones *et al.* 1989, González and Gaertner 1992, Dickson 1995, Goodyear 2002). In summary, the blue marlin can thus appear as a target species in some fisheries/activities, but also as a bycatch species in tuna fisheries such as surface-drift gillnets, deep and surface longliners, in purse seine-FAD fleets targeting tropical tuna (Anon. 2018[a,b], Delgado de Molina *et al.* 2001, Gaertner *et al.* 2003) and in other fishing gears.

Catches and landings of blue marling have probably not been well documented historically for some fleets and gears. There are estimates provided for some of the ocean-going fleets, but there are still important gaps in information on many others, such as sports fisheries, many artisanal and coastal, etc., which probably account for a significant proportion of catches in the Indian Ocean. So the relative importance of each catch's component by flag or gear is hard to be estimated only considering the reported catches which could provide a false view on which are the most important capture components in the Indian Ocean.

2. Materials and methods

Landing data considered in the present paper as catch of blue marlin, and the nominal fishing effort per trip were recorded during the period 2003-2017 from research activity. Eight geographical regions were defined for preliminary runs (**Figure 1**) but areas 56 and 57 were finally combined for model convergence. Yearly quarters were defined as follows: Q1 = January, February, March; Q2 = April, May, June; Q3 = July, August, September; Q4 = October, November and December. The gear used was 'American style' (Ramos-Cartelle *et al.* 2011).

The standardization of yields in number of fish landed per million hooks (CPUE) for the Indian Ocean was carried out using a Generalized Linear Mixed Model (MIXED procedure, SAS 9.4) assuming a delta-lognormal model error distribution. Under this model, both the catch rates of positive records and the proportion of positive records were fitted separately (Lo *et al.* 1992, Ortiz and Arocha 2004). The proportion of positive components serves to model the probability of capturing these species (at least one fish) in a trip. The factors tentatively considered were year, area, quarter and their interactions. The final models were selected based on the analysis of deviance, including the main factors and factor-interactions that reduce overall deviance ≥ 5% of the null model and provide a solution. Since the objective is to provide a relative annual index of abundance, the interactions that involve the year factor could not be included as a fixed interaction in the 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 final models were:

Model positive catch rates = year + quarter + area + quarter*area and random interactions year*quarter + year*area, assuming a lognormal error distribution.

Model proportion of positives = year + quarter + area, assuming a binomial error distribution.

3. Results and discussion

The analysis covered a total of 1,914 trips (65,059.81*10^3 hooks analysed) made in the swordfish fishing grounds of this fleet in the Indian Ocean as a whole for the period 2003-2017. This effort represented around 89.78% of the total fishing effort of this fleet during combined period. In 7.05% of the trips (135 trips, corresponding to 2,219.41*10^3 hooks) was a positive catch of blue marlin recorded. However a part of observation analyzed (1,592.34*10^3 hooks) of some years (2005 and 2006) were obtained during swordfish's surveys done in warmer areas than those where the regular fishing activity is currently carried out. So the percentage of occurrence obtained in the present study could be higher than achieved in the regular commercial fishing areas. Anyway, the data analysed confirm the generally low occurrence and prevalence of this species in this longline fishery targeting swordfish in the Indian Ocean fishing areas combined.

The analysis of deviance (**Table 1**) highlights the main factors and factor-interactions that reduce the overall deviance (≥ 5%) of the null models, in both the positive only observations model and the proportion of positive model components.

Figure 2 shows the residual pattern of log-transformed catch rates, the normal probability, *qq*-plots and residuals by year of the positive catches. **Figure 3** and **Table 2** show the standardized CPUE (number of BUMs/10^6 hooks) obtained for the series analysed.

The low prevalence of this species in this fishery, possible environmental variations between years and/or access to certain areas with more or less local occurrence/availability of this species in specific years, and other factors such as misidentification or incomplete records over the years, etc., are some elements that could affect the inter-annual CPUE variability obtained. In this sense, the standardized CPUE obtained probably do not represent annual stock abundances but suggest a relatively flat trend throughout the period analysed. The usefulness of this indicator may be the interpretation of the overall general trend in the period analysed. Similar uncertainties may affect the analysis of different fleets and types of gears with smaller coverage and/or where the prevalence of these species as bycatch is usually lower or misreported (Ramos-Cartelle *et al.* 2019), although such limitations are rarely described.

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Table 1. Deviance table analyses of the factors tested, for positive catch rates and for proportion of positives, respectively. Highlighted are the factors with ≥ 5% deviance explained.

Model factors positive catch rates values	**d.f.**	**Residual deviance**	**Change in deviance**	**% of total deviance**	***p***
Null	_	102.8488			
Year	14	81.5276	21.3212	46.4%	0.09368011
Year Quarter	3	79.5085	2.0191	4.4%	0.56845191
Year Quarter Area	6	68.6868	10.8217	23.5%	0.09404581
Year Quarter Area Quarter*Area	9	62.8711	5.8157	12.6%	0.75821275
Year Quarter Area Year*Area	8	61.2499	7.4369	16.2%	0.49030914
Year Quarter Area Year*Quarter	7	56.853	11.8338	25.7%	0.10615863

Model factors proportion positives	**d.f.**	**Residual deviance**	**Change in deviance**	**% of total deviance**	***p***
Null	_	497.9882			
Year	14	349.831	148.1572	35.2%	< 0.001
Year Quarter	3	321.606	28.2250	6.7%	< 0.001
Year Quarter Area	6	203.46	118.1460	28.1%	< 0.001
Year Quarter Area Quarter*Area	18	180.0255	23.4345	5.6%	0.17444076
Year Quarter Area Year*Area	66	100.7568	102.7032	24.4%	0.00257264
Year Quarter Area Year*Quarter	42	77.4146	126.0454	30.0%	< 0.001

Table 2. Number of trips (Nobs), probability of positive catch (Obppos), observed mean CPUE (Obcpue), estimated standardized CPUE (Estcpue), scaled standardized CPUE (STDCPUE) and its 95% confidence intervals (LCI, UCI) by year. (CPUE=number of BUM/10^6 hooks)

Year	**Nobs**	**Obppos**	**Obcpue**	**Estcpue**	**STDCPUE**	**LCI**	**UCI**
2003	241	0.046	8.7578	2.942	0.21370	0.02044	2.23420
2004	195	0.015	1.8862	0.245	0.01776	0.00185	0.17090
2005	155	0.090	34.4633	12.449	0.90426	0.07104	11.50950
2006	221	0.285	84.5344	32.413	2.35440	0.63020	8.79600
2007	132	0.053	8.1330	15.403	1.11888	0.23180	5.40070
2008	118	0.042	12.0859	15.874	1.15305	0.20133	6.60380
2009	115	0.009	0.2811	0.230	0.01672	0.00120	0.23340
2010	65	0.092	11.7171	16.205	1.17713	0.14892	9.30440
2011	85	0.024	5.3763	13.742	0.99816	0.09220	10.80670
2012	116	0.009	5.7873	1.571	0.11408	0.00325	3.99860
2013	139	0.065	19.6800	40.766	2.96116	0.68617	12.77890
2014	140	0.014	0.9140	1.432	0.10405	0.01082	1.00080
2015	72	0.042	6.5788	7.188	0.52209	0.07851	3.47210
2016	61	0.066	9.8615	6.962	0.50568	0.05106	5.00790
2017	59	0.068	25.7711	39.082	2.83886	0.35343	22.80250

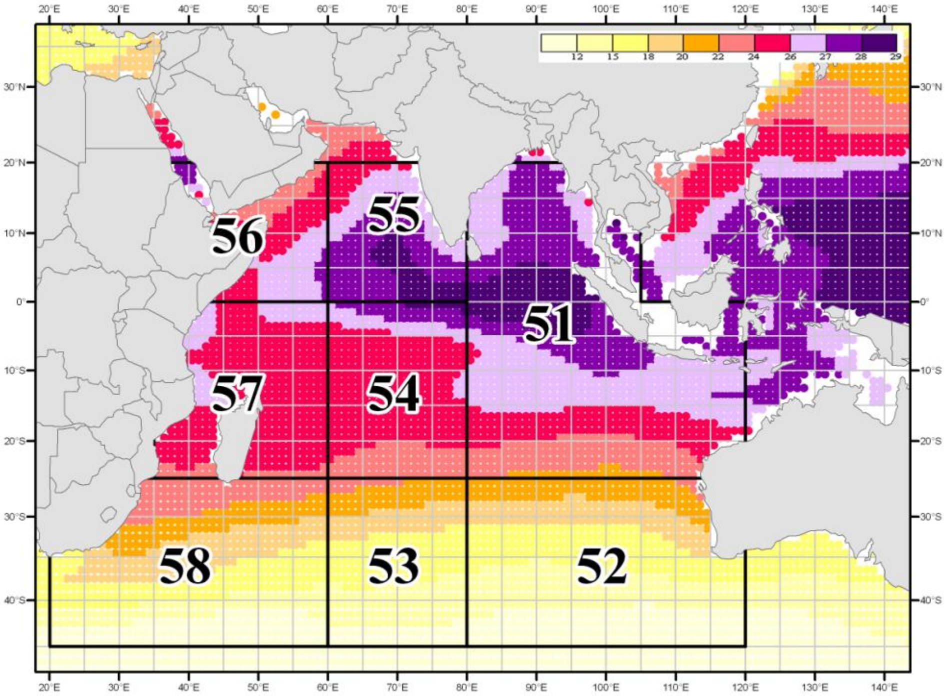
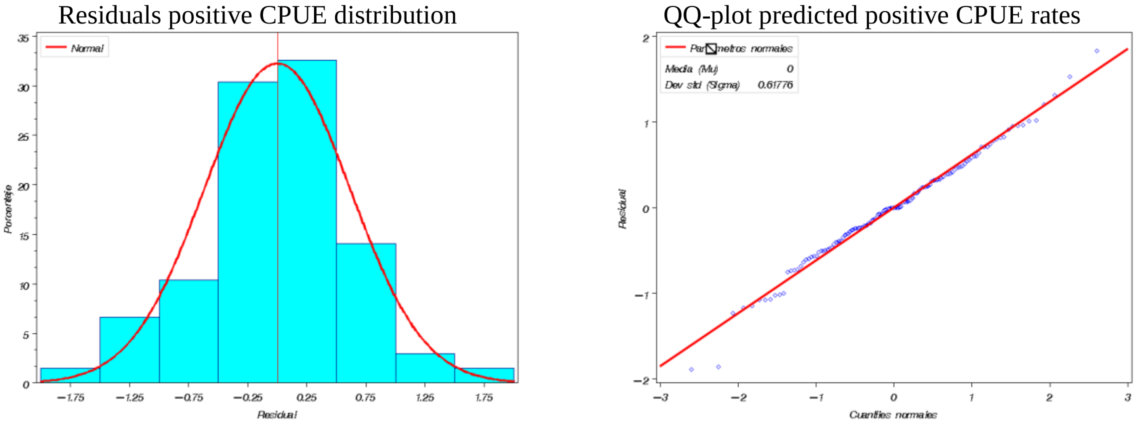


Figure 1. Stratification of geographical regions used for the GLM analysis of BUM in the Indian Ocean.


Residuals positive CPUE distribution

QQ-plot predicted positive CPUE rates

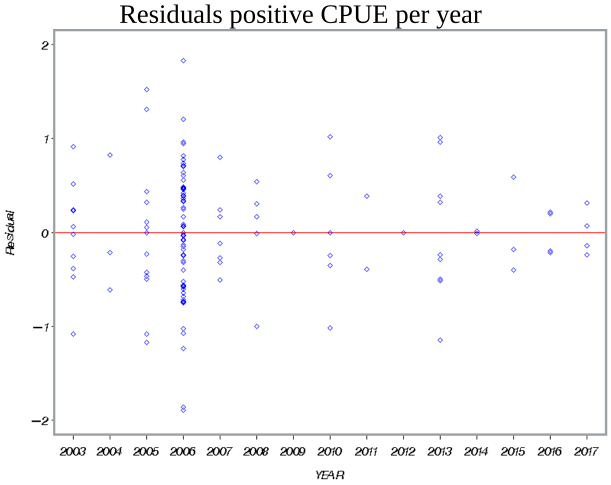

Residuals positive CPUE per year

Figure 2. Distribution of the standardized residual of BUM CPUE, normal probability *qq*-plots and residuals of positive CPUE by year.

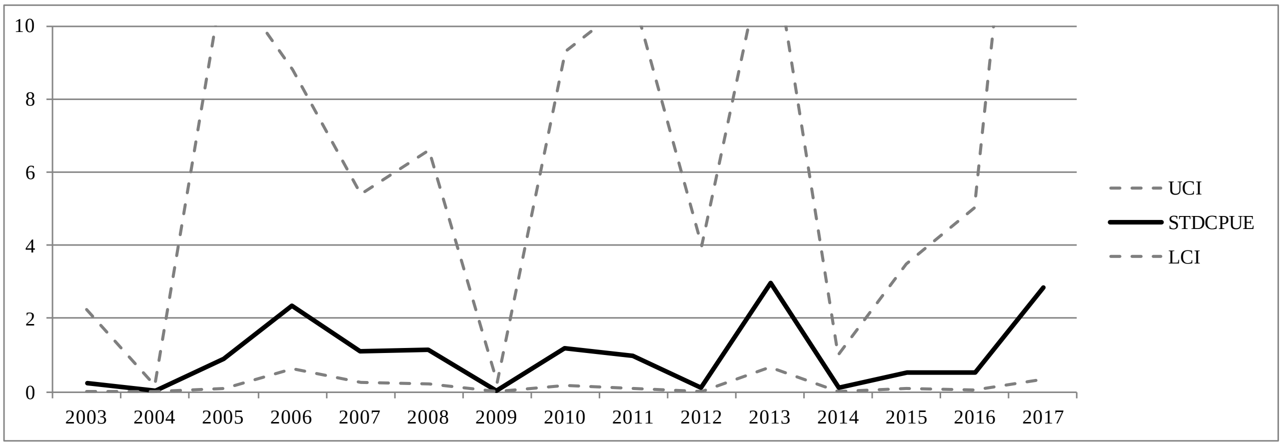


Figure 3. Estimated scaled standardized CPUE in number of BUM and its corresponding 95% confidence intervals during the period 2003-2017.