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STANDARDIZED YIELDS OF THE SAILFISH (*Istiophorus platypterus*) 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 sailfish 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 50% of the trips recorded during this period showed a positive catch of these species (at least one fish). Because of the relatively low 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: sailfish, catch rates, abundance, GLM

1. Introduction

The indo-pacific sailfish (*Istiophorus platypterus*) is an epipelagic and coastal to oceanic billfish species more often found above the thermocline. This species is probably one of the least oceanic of all billfishes showing tendency to approach continental coasts, islands and reefs (Nakamura 1985). Geographical-latitudinal limits of sailfish are described from 35º-40ºN to 40ºS or even broader in the western Pacific. However, it mainly is a circumtropical species with scarce occurrence in latitudes above the 25º of the respective hemispheres; distributed in tropical and subtropical waters but some individuals can occasionally reach temperate waters during the respective warming seasons taking advantage of the seasonal strength of the warm currents. Preferences for sailfish appear to be closely associated with the seasonal movement of the 28°C surface-isotherm. Results of some studies indicated that the availability of sailfish is most influenced by sea bottom depth and sea surface temperature (Anon. 2017[a]). Groups of individuals can be found moving seasonally north and south along the inside edge of the predominant warm surface currents. Concentrations of some individuals have been described in highly productive areas, such as areas of convergence and/or upwelling, in interaction with schools of potential preys such as small pelagic bony fish (i.e. clupeids) or squids, in occasions at the same area-time than other taxa also concentrated looking for the same preys. Adult sailfish are apex predators and they opportunistically prey many bony fish species, cephalopods, etc. A big diversity of preys has been described in the literature available.

Sailfish also has anatomical and physiological adaptations for continuous swimming and cranial endothermy which facilitate foraging at different depths. However, tagging studies indicate that sailfish regularly spends most of the time in warm and surface waters above 20 m deep, but it can display short duration vertical dives from surface waters up to 250 m (Hoolihan 2005). So, sailfish seem to be more restrictive in terms of water temperature tolerance than some other Xiphioidei's species such as blue and white marlins or swordfish. Sailfish growth has been studied by means of different methodologies. Results point out sexually dimorphic growth patterns, females growing larger than males. Different seasonal patterns of sex-ratio at size have been also pointed out. Males and females can swim in pairs, or several males chasing a single female, during reproductive events.

Studies carried out in the Atlantic sailfish have displayed relatively restricted horizontal movements based on tagged-recaptured fish, with no transatlantic, trans-equatorial, nor intercontinental movements described. However, based on minimum travelled distance, it was suggested that sailfish could make either cyclic annual movements, exhibit some

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degree of fidelity or some combination of the two (Arocha and Ortiz 2006). Nevertheless, the migratory capacity of sailfish is not fully evaluated because the limited tagging experiments regularly carried out in terms of a low diversity of the geographical tagging designs and uncertainties associated with post-tagging survival, tag shedding and the very different tag reporting rates among areas-fleets-fishermen. So, a complete idea about the migratory capacity and potential mixing was not elucidated so far for the Atlantic sailfish. Preliminary genetic techniques using mitochondrial and nuclear markers revealed no complete evidence of structuring of sailfish within the Atlantic Ocean but suggested a possible genetic stock structure between both the eastern and western Atlantic, and northern and southern hemispheres, but incomplete sampling was considered (Anon. 2017[a]). So, the stocks structure in the Atlantic was pragmatically assumed mostly based on the limited conventional tagging results and the reported fishery data. However, the Indian Ocean can be a special case because their peculiar thermal characteristics versus the characteristics in the two other main oceans where the indo-pacific or the Atlantic sailfishes are present. In the case of the Indian Ocean, a pan-ocean stock structure is assumed.

Because of its coastal habitat preference in warmer waters, the indo-pacific sailfish 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, *sailfish safaris* and many other initiatives done in coastal countries, islands, companies and businesses, regularly for people with high purchasing power. It is considered an exciting luxury fishing experience to create *unforgettable memories* and it catch considered a *prestigious trophy* for recreational fishermen. Recreational fishing trips of sailfish jumps out the water are offered in the coast of many countries and islands of the warm seas of the Indian Ocean.

This species may be also captured as food for human consumption by many coastal driftnets fisheries and many other artisanal gears, so that this species is a source of food for people living near the coastal areas in many countries of the Indian Ocean. The fishing areas where some of the oceanic tuna and tuna-like fisheries operate can also overlap in some cases with areas where sailfish may be found. So, this species can be mainly caught in many driftnets and in other coastal gears, but it is also a minor by-catch in the purse-seine-FAD tropical tuna fisheries and in the oceanic pelagic longliners of the Indian Ocean.

Catches and landings of sailfish have probably not been well documented historically for some fleets. There are estimates for some ocean-going fleets, but there are still gaps in information on many others, such as sports fisheries, coastal driftnets and many artisanal-coastal gears, etc., which probably account for the significant proportion of catches in the Indian Ocean. Scientific estimations of total catches for recent years (Anon 2017[b]) suggest around 25 thousand metric tons/year. Gillnets were considered the main component (around 71% of the total estimated annual catches), other gears such as handline, trolling, baitboat and sport fisheries were considered the second component (around 25%) while longliners represented a minor component (around 4%). 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 overview on which are the most important catch-gear components in the Indian Ocean.

2. Materials and methods

Landing data considered in the present paper as catch of sailfish, 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 49.8% of the trips observed (954 trips, corresponding to 39,625.56*10^3 hooks) was a positive catch of sailfish recorded. Although a part of observation analyzed of some years were obtained during swordfish's surveys done in warmer areas than those where the regular fishing activity is currently carried out (1,592.34*10^3 hooks, during 2005 and 2006) the overall percentage of occurrence obtained was not significantly affected. The sailfish presented greater occurrence in the Indian ocean fishery than observed in the whole Atlantic areas where in roughly 28% of the commercial trips at least one individual belonging to this species was found (García-Cortés *et al*. 2017), probably because the more favourable physical characteristics of the Indian Ocean. However, the sailfish in the Indian Ocean is also a species of low prevalence in this fishery. In average, around 1.34 sailfish individuals were captured for every 100 swordfish individuals caught during the whole period analyzed.

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 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 necessarily represent annual stock abundances but suggest a relatively flat trend throughout the whole period analysed. The usefulness of this indicator may be the interpretation of the overall general trend in the period analysed. Additionally, data from this longline fleet is representing a small component of the total catches in the Indian Ocean and probably a minor part of the areas of distribution of this species in the Indian Ocean. 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 discussed and 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	_	1011.9659			
Year	14	947.9371	64.0288	26.3%	< 0.001
Year Quarter	3	876.3543	71.5828	29.5%	< 0.001
Year Quarter Area	6	854.7902	21.5641	8.9%	0.00145193
Year Quarter Area Quarter*Area	16	828.2907	26.4995	10.9%	0.04739265
Year Quarter Area Year*Quarter	42	795.9162	58.8740	24.2%	0.04357977
Year Quarter Area Year*Area	55	768.9704	85.8198	35.3%	0.00492752

Model factors proportion positives	**d.f.**	**Residual deviance**	**Change in deviance**	**% of total deviance**	***p***
Null	_	844.1415			
Year	14	497.3684	346.7731	61.0%	< 0.001
Year Quarter	3	495.9206	1.4478	0.3%	0.69436938
Year Quarter Area	6	449.1618	46.7588	8.2%	< 0.001
Year Quarter Area Quarter*Area	18	407.2787	41.8831	7.4%	0.00114823
Year Quarter Area Year*Quarter	42	353.0699	96.0919	16.9%	< 0.001
Year Quarter Area Year*Area	66	275.7954	173.3664	30.5%	< 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 SFA/10^6 hooks).

Year	**Nobs**	**Obppos**	**Obcpue**	**Estcpue**	**STDCPUE**	**LCI**	**UCI**
2003	241	0.087	26.217	33.689	0.16018	0.07050	0.36391
2004	195	0.287	107.009	95.074	0.45204	0.24690	0.82761
2005	155	0.555	291.937	312.040	1.48363	0.88700	2.48158
2006	221	0.516	333.729	299.925	1.42603	0.86380	2.35419
2007	132	0.538	218.794	173.080	0.82293	0.46482	1.45693
2008	118	0.593	358.625	311.665	1.48185	0.84930	2.58550
2009	115	0.452	164.282	152.194	0.72362	0.39071	1.34019
2010	65	0.554	270.739	232.586	1.10586	0.56134	2.17858
2011	85	0.647	341.684	328.038	1.55969	0.80544	3.02025
2012	116	0.509	211.615	212.064	1.00828	0.51602	1.97015
2013	139	0.619	264.887	156.806	0.74555	0.42387	1.31136
2014	140	0.671	246.065	201.448	0.95781	0.55600	1.64999
2015	72	0.764	188.860	182.279	0.86667	0.51195	1.46715
2016	61	0.869	302.499	196.255	0.93311	0.54326	1.60273
2017	59	0.780	229.737	267.690	1.27276	0.67457	2.40142

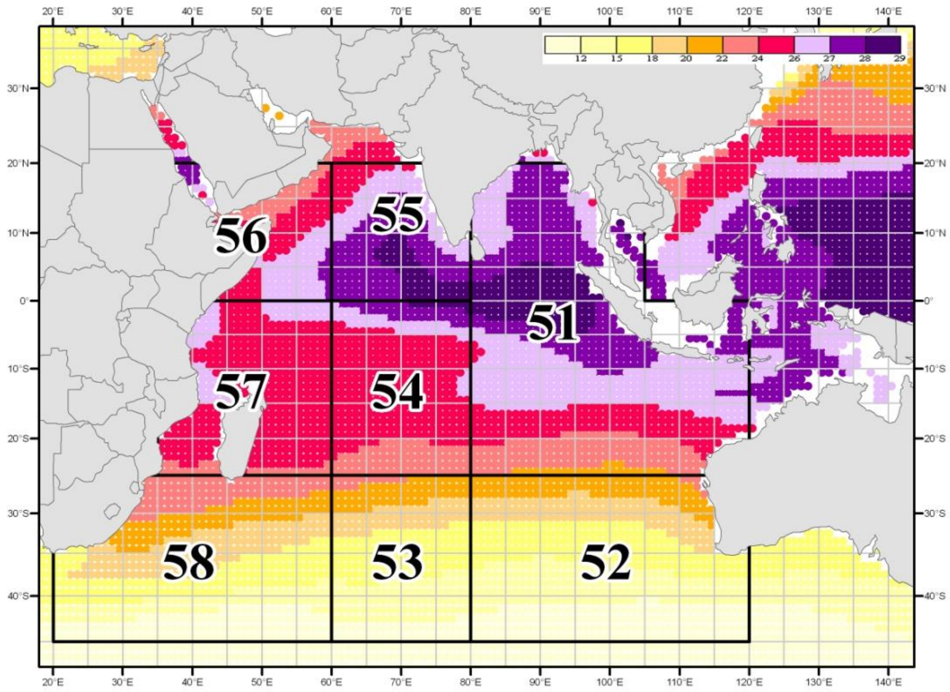
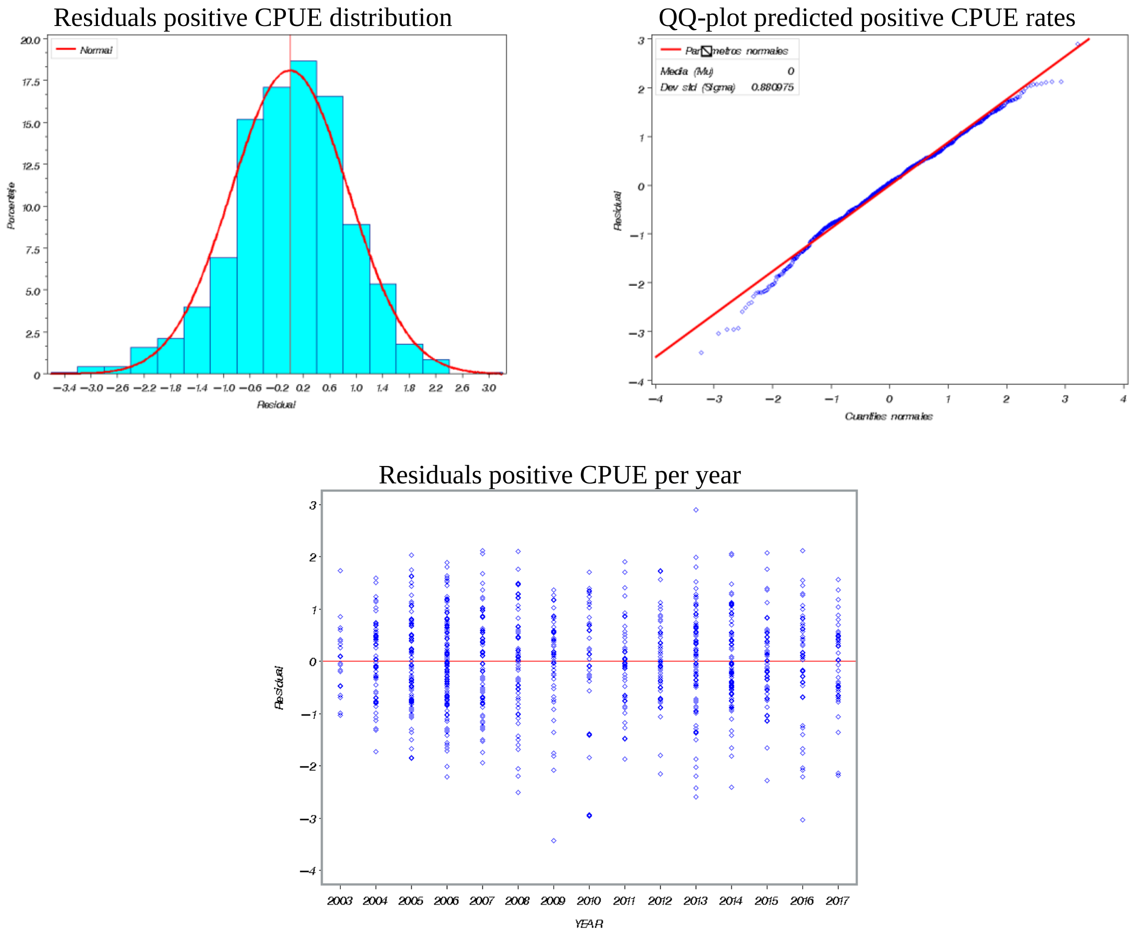


Figure 1. Stratification of geographical regions used for the GLM analysis of SFA in the Indian Ocean.


Residuals positive CPUE distribution

QQ-plot predicted positive CPUE rates

Residuals positive CPUE per year

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

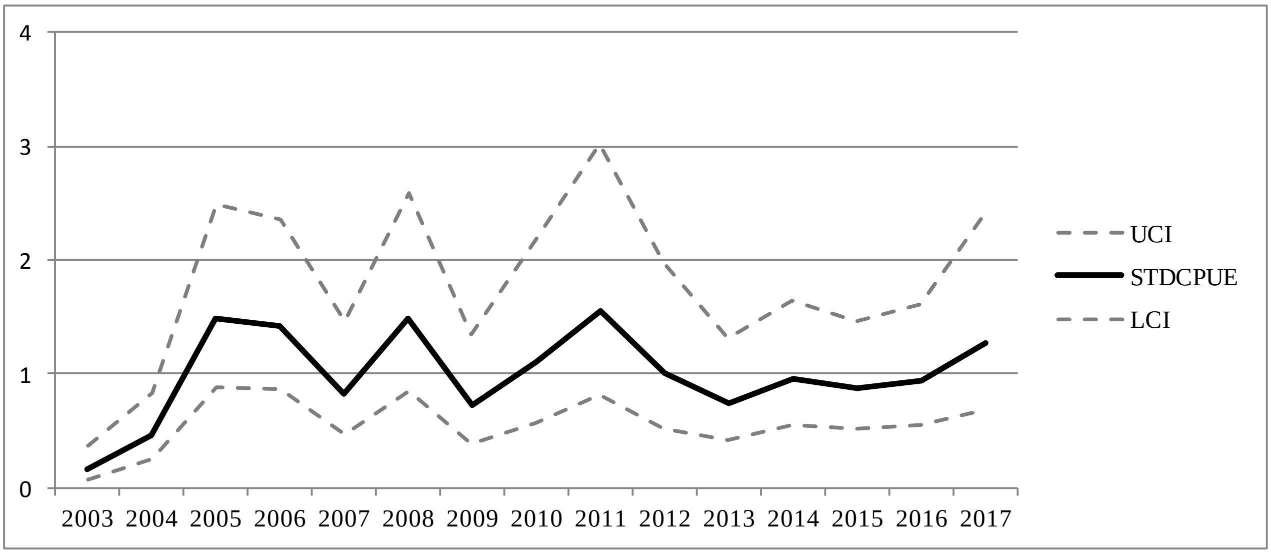


Figure 3. Estimated scaled standardized CPUE in number of SFA and its corresponding 95% confidence intervals during the period 2003-2017.