Areas with high bycatch of silky sharks (*Carcharhinus falciformis*) in the Western Indian Ocean purse seine fishery

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Abstract

Catch per unit of effort (number of individuals per fishing set) and numbers of silky sharks (*Carcharhinus falciformis*) caught accidentally by the European tuna purse seine fishery (France and Spain) around floating objects in the Indian Ocean were estimated and mapped for the period 2003-2009. Data were collected by the French and Spanish observer programmes representing a total of 3052 observed fishing sets (1548 on free swimming schools and 1504 on FADs, the term FADs representing here all floating objects, natural and artificial). Kriging interpolations allowed estimating the total FAD-catches of silky sharks at any set performed by the European tuna purse seine fishery (sets declared in the logbooks). The largest catch of silky sharks per unit of effort (mean numbers of silky sharks/FAD set) was observed north off the fishing grounds (centered on 12°N and 60° E). Due to the uneven spatial distribution of the fishing effort, the largest amount of silky sharks caught around FADs did not occur in the area with the highest catch per unit of effort, but in an area centered on 2°N and 53°E. The spatial distribution of silky shark catches was quite constant among years. Effects of potential mitigation measures are discussed.

Keywords: Silky shark, Bycatch, Tuna fishery, Purse seine, Indian Ocean

Introduction

Overexploitation of target and non target marine species is one of the most widespread and direct driver of change and loss of global biodiversity (Gilman, 2011). Mitigating adverse ecological impacts of fisheries requires effective governance of all sources of fishing mortality, including retained and discarded accidental catch (Garcia et al. 2003, Pikitch *et al.* 2004). One of the major operational objectives of an ecological approach to fisheries management (EAFM) is to reduce bycatch, i.e. the incidental catch of non target marine animals and undersized individuals of target species (Davies *et al.* 2009) because bycatch constitutes an important waste and raises conservation, ecological, ethical and economic considerations (Ye et al. 1999, Alverson 1994, Hall 1996; Hall, Alverson & Metuzals 2000; Davis 2002).

Most of the fish species caught incidentally by tuna purse seiners (mainly around FADs, the term FAD being used here to represent all types of floating objects, natural and artificial) are not at risk as they are usually fast growing and highly fertile species. This is not the case for some pelagic sharks which are usually very sensitive to exploitation due to their slow growth, late maturation, and low fecundity. Even though most of pelagic sharks are caught by longliners or other fishing gears (Gilman 2011), there is a need to reduce the incidental catches of sharks made by purse seiners. Silky sharks (*Carcharhinus falciformis*) represented 85% of all sharks caught by the purse seine fishery in the Indian Ocean (IO), mainly dominated by immature individuals (Amandè et al., 2008). The objective of this study was to map the silky shark catches made by the European purse seine fishery and to identify whether some areas appear to represent particular "hot spots" of either shark catches or shark densities. Two indices were considered in this study: catch per unit of effort (numbers of individuals per fishing set), which may be used to define areas with particular high densities of sharks around FADs, and the total numbers of silky sharks caught by the European purse seine fishery around FADs to assess the impacts of this fishery on this species. The spatial variations of each index are computed.

Data

Data were collected by observers aboard European (French and Spanish) tuna purse seiners in the Indian Ocean who observed a total of 3 052 sets during the 2003-2009 period (115 fishing cruises, 4020 days at sea). The coverage rate over the entire period is 4.6 % of the total number of fishing trips, with a regular increase from 2003 (1.7%) to 2007 (9%), before a sharp decreasing (4% in 2009) due to Somali piracy acts which prevented the boarding of observers for security reasons (Chassot *et al.* 2010). The fishing sets were categorized into FAD and free-swimming school (FSC) sets on the basis of direct information reported by observers. The overall observer data comprised 1 548 FSC and 1 504 FAD sets, corresponding to an observed tuna catch (combining skipjack, *Katsuwonus pelamis*, yellowfin, *Thunnus albacares*, and bigeye, *T. obesus*, tunas) of 30 626 t and 42 551 t, respectively.

Methods

The histograms of silky shark catch were characterized by many zero observations and a long right tail (Figure 1). Fishing sets without silky sharks represented 74% of the sets. To assess the number of silky sharks caught per set, we used generalized linear models with or without zero-inflation (ZI) and with Poisson and Negative Binomial distributions (GLMpoisson, GLMnegbin, ZIpoisson, ZInegbin). Predictors used in the regression approaches were detailed in table 1. Models were compared based on the Akaïké Information Criteria (AIC). A geostatistical model was then apply on floating objects sets (responsible for more than 90% of silky shark bycatch) to assess the spatial pattern of the catches of silky sharks made by the European purse seine fishery in the IO. The spatial pattern obtained from observer data was then used to extrapolate the results to all fishing sets on floating objects reported in the logbooks.

Results

A total of 8,808 silky sharks were recorded as bycatch by observers, most of them being caught around floating objects (91.6%). Silky sharks occurred in 26.6% of sets (FAD and FSC combined): 5% on FSC and 48% on FADs, the difference being statistically different (Table 2b, line 3). However, the average numbers of silky sharks when they occur in sets were not significantly different between the two fishing modes (Table 2a, line 3): 11 and 9.7 individuals on average both on FAD and FSC, respectively. No correlation was observed between the number of silky sharks and the total fishing effort (Pearson correlation test, cor=0.043, p-value = 0.5155). The AIC values indicated that the best fit of the silky shark catches was provided by the ZInegbin model. However, this model explained only 17.5% of the total variability present in the data. Available explanatory variables were not sufficient to correctly predict silky shark catches but the species richness appeared to be the main factor affecting both the presence and the number of sharks in a set (Tables 2 and 3).

The catch per unit of effort (number of silky sharks by FAD set) showed a strong heterogeneous spatial distribution (Figure 2b). The “hot spot” of high silky shark densities around FADs appeared to be located at the northern edge of the fishing grounds (centered on 12°N and 60°E). However, the spatial distribution of the total catches was strongly impacted by the spatial distribution of the fishing effort (Figure 2c). Over the period 2003-2009, the largest catches of silky sharks were however performed off Somalia, in an area centered on 2°N and 53°E (Figure 2). Although the numbers of sharks caught by area showed some inter-annual variability, the general spatial pattern of the catches of silky sharks around FADs was similar amongst years (Figure 3).

Discussion

These results may be used to determine key areas to protect in order to reduce the catches of silky sharks around FADs by purse seiners. The area centered on 12°N and 60°E appears to be particularly abundant in small juvenile silky sharks around FADs. Increasing the fishing effort on FADs in this area could then result in a large increase of catches of small silky sharks. This area is right outside the time-area closure (0-10°N, African Coast-60°E) adpoted by the IOTC for purse seiners during the month of November. If the effort of purse seiners moves outside this closed area, in particular in its northern part, this could have very detrimental effects on the silky shark populations. The maps of the total catches of silky sharks clearly shows that the largest catches are not done in the area with the highest catch per unit of effort. This demonstrates that in order to control the total numbers of sharks accidentally caught by purse seiners around FADs, it is important to consider both the catch per unit of effort and the distribution of effort.

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Table 1: Factors used in the analysis of silky shark bycatch per set

Factors	Abbreviation	Type	Description
Richness	Richness	Continuous	The number of different species accounted in each fishing set
Fishing mode	Typbanc	Categorical	The type of fishing sets. 2 levels : FSC=free school sets and FAD=fishing aggregating device sets
Latitude	Latitude	Continuous	Latitude in décimal degrees
Quarter	Quarter	Categorical	The quaters of the year. 4 levels
Fleet	Fleet	Categorical	Fleet origin. 2levels : France and Spain

Table 2: Summary of the Zero-inflated Negative Binomial regression with significant predictors

Count model coefficients (negbin with log link):

Coefficients	Estimate	Std. Error	Pr(>|z|)
Intercept	1.445	0.187	1.22e-14 ***
Fleet.FRANCE	0.161	0.105	0.124
Typbanc.FAD	-0.086	0.166	0.606
Richness	0.094	0.016	2.37e-09 ***
Latitude	0.037	0.007	3.16e-08 ***
Log(theta)	-0.659	0.079	< 2e-16 ***

Zero-inflation model coefficients (binomial with logit link):

Coefficients	Estimate	Std. Error	Pr(>|z|)
Intercept	3.981	0.209	< 2e-16 ***
Fleet.FRANCE	- 0.726	0.196	0.000237 ***
Fishing set.FAD	-1.333	0.223	2.34e-09 ***
Richness	-0.637	0.053	< 2e-16 ***
Latitude	0.016	0.015	0.472752

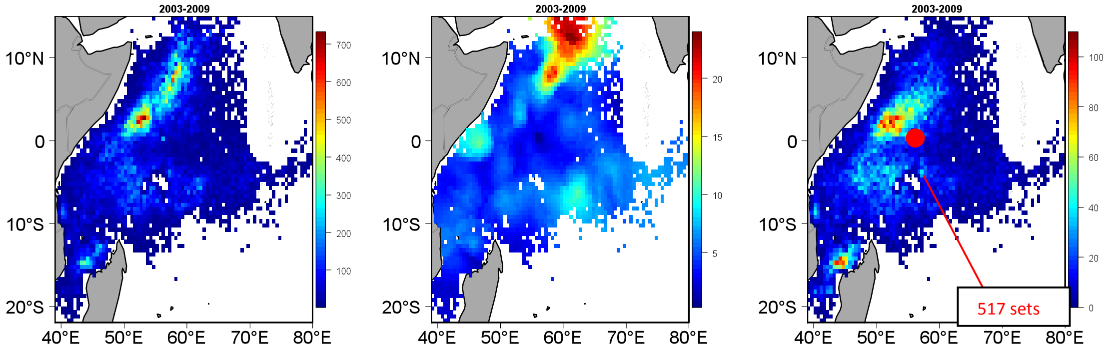

Figure 2: Predicted total number (left, fig. 2a), average number per FAD set (middle, fig. 2b) of silky sharks and total number of FAD sets (right, fig. 2c) during the period 2003-2009 on a 0.5° x 0.5° grid.

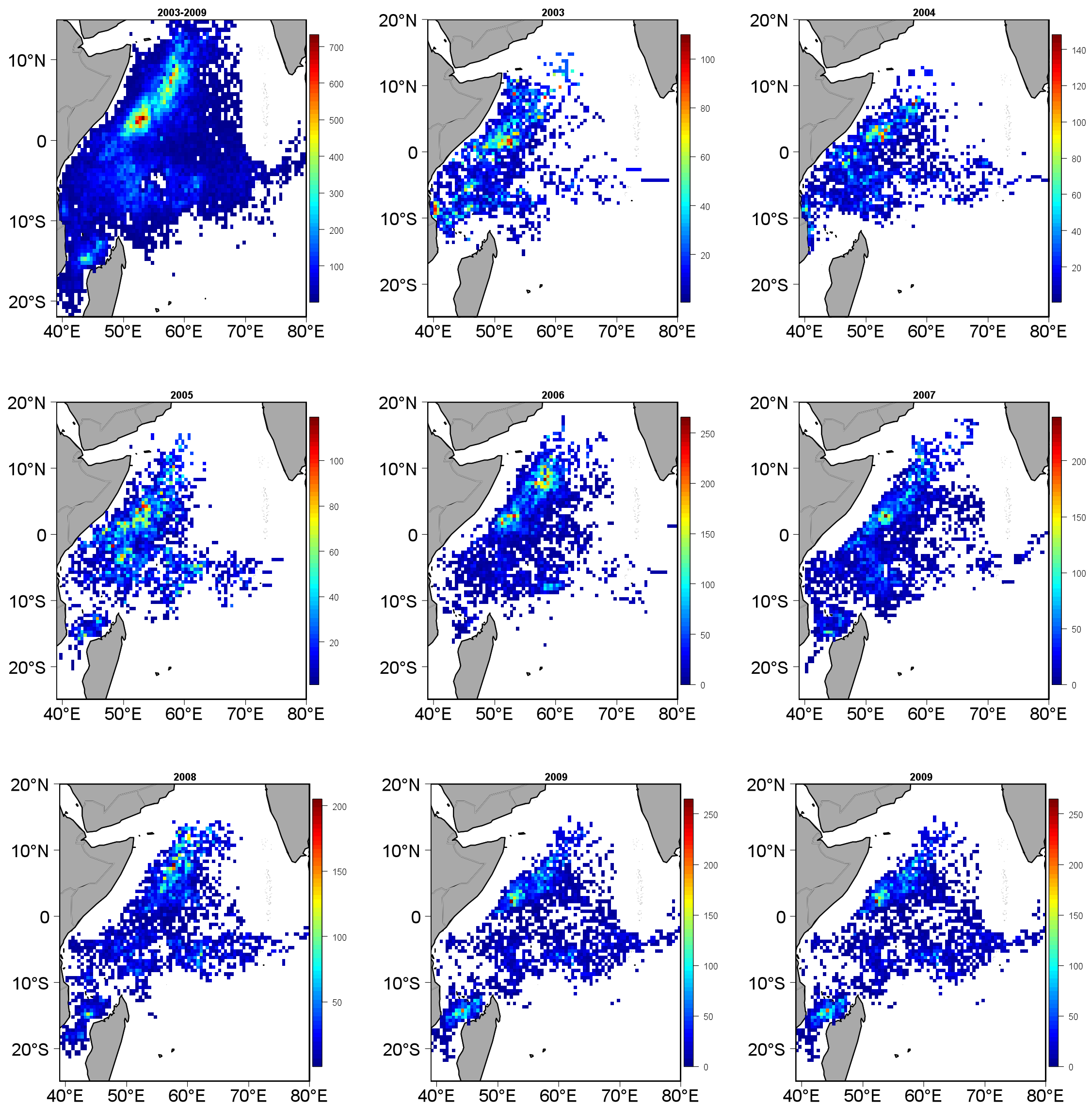

Figure 3: Predicted total number of silky sharks caught by the European purse seine fishery in the Indian Ocean during the period 2003-2009 on a 0.5° x 0.5° grid.