# USING FADS TO ESTIMATE A POPULATION TREND FOR THE OCEANIC WHITETIP SHARK IN THE INDIAN OCEAN

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**Abstract**

Count data of oceanic whitetip sharks (OCS) associated with Fish Aggregating Devices (FADs) were used to derive a population trend for the species in the western Indian Ocean. Observer data from the French and Spanish purse seine fleets, combined with a historic database from the Soviet Union were used in the analyses. The combined time series spanned from 1986 to 2015. Results indicated a declining population trend. The OCS population in the Indian Ocean was estimated to be three times smaller in recent years (2000-2015) compared to historic years (1986-1999).

## 1. Introduction

The oceanic whitetip shark (OCS - *Carcharhinus longimanus*) is commonly caught as bycatch by a variety of pelagic fishing gears, such as tuna longlines, gillnets, and purse seines (Bonfil et al., 2008). The species is easily distinguishable from other pelagic shark species by the round shape of its long pectoral and dorsal fins, as well as by the white stains in their margins (Compagno, 1984). Their large fins are highly valued in international trade, making them an important target of this market (Camhi, 2009).

Once considered amongst the most abundant pelagic sharks, the oceanic whitetip is now commonly perceived as rare (Backus et al., 1956; Compagno, 1984; Strasburg, 1958). Whereas there is some uncertainty about the precise status of OCS populations worldwide, mainly due to inadequate monitoring, there is a general scientific consensus that populations are decreasing (Baum et al., 2006; Baum and Blanchard, 2010; Bonfil et al., 2008; Clarke et al., 2013). Concerns regarding the conservation of oceanic whitetips sharks have risen substantially in the past few years, leading Tuna Regional Fisheries Management Organizations (RFMOs) from all oceans to implement species-specific banning measures (Tolotti et al., 2015a). However, knowledge gaps concerning OCS ecology and biology are still wide and impose a barrier on the development of mitigation measures for fisheries and accurate stock assessments (Murua et al., 2013).

The oceanic whitetip shark is believed to have been more severely impacted by pelagic longlines, as its catch rates are usually higher in fisheries using this fishing gear (Rice and Harley, 2012). Consequently, most of the few abundance and/or catch-rates estimates for the species were derived from this fishery (Cortés et al., 2010; Semba and Yokawa, 2011;

Tolotti et al., 2013; Walsh et al., 2009). However, abundance trends for the OCS have been heavily questioned due to standardization problems (Baum et al., 2003; Burgess et al., 2005) and, as mentioned above, question marks still remain regarding the species population status. In the Indian Ocean, it is also thought that OCS may have been heavily captured by artisanal driftnet gillnet and small scale longliners (Murua et al., 2013)

Data from the tropical purse seine fisheries has been much less explored to derive population indices for the OCS, although the species is the second mostly bycaught shark in this fishery (Amandè et al., 2012; Santana et al., 1998; Torres-Irineo et al., 2014). Additionally, OCS catch rates are considerably higher on object-associated sets than on free-school sets. Based on a modeling approach on count data (Filmalter et al., 2013; Sempo et al., 2013), this work presents a first attempt to estimate an abundance trend for the oceanic whitetip shark in the Indian Ocean, using information of OCS bycatch in Fish Aggregating Devices (FADs) sets and the associative behavior of the species.

## 2. Databases

Three distinct databases were available for this analysis, including observer's data from the French and Spanish tuna purse seine fleets, as well as data from historic purse seine surveys conducted by the Soviet Union (USSR) (Table 1). Both French and Spanish data come from observer programs, either conducted within the framework of specific European Union (EU) research projects in the 1990s, or since 2003 continuously under the European Data Collection Regulations (Council Regulation no. 1543/2000, Commission Regulation no. 1581/2004, Council Regulation no. 199/2008, and Commission Decision 2008/949/EC). The French database was provided by the *Observatoire Thonier*, while the Spanish database was provided by AZTI. The historic USSR surveys were carried out between 1986 and 1992 and data was collected by scientific observers in the scope of various programs developed by research institutes and affiliated organizations. This database was developed within framework of YugNIRO[1] research activities in the Indian Ocean.

**Table 1.** Databases used in the present study.

| | Number of FAD sets | Period |
|---|---|---|
| French - Observatoire Thoniere | 3152 | 1995 and 96 - 2005 to 15 |
| Spanish - AZTI | 1112 | 1998 and 99 - 2003 to 09 - 2015 |
| Soviet Union - YugNIRO | 259 | 1986 - 1992 |

Fishing sets conducted by the French and Spanish fleets cover a large area of the western Indian Ocean, roughly limited by the latitudes of 10°N to 20°S and by the longitudes of 040°E to 080°E (Figure 1). The historic Soviet Union sets cover a smaller area, but they fall inside the area covered by the EU fleets, roughly ranging from 05°N to 10°S and form 050°E to 070°E. Some Soviet fishing sets were also made in the northeastern portion of the Mozambique Channel. In all databases, sets were divided into two distinct fishing strategies, sets on Free Swimming Schools (FSC) and sets on Fish Aggregating Devices (FAD). Sets on

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both natural and man-made devices were recorded under the same FAD category. Whale-associated sets were treated as free-school sets and sets on whale sharks were pooled with FAD sets. As the occurrence of oceanic whitetip sharks on non-associated sets is rare, all sets classified under the free-school category were excluded from the analysis.

**3. Data preparation**

The total number of oceanic whitetip sharks in each FAD set was analyzed. Bycatch events were classified according to the total number of OCS in a single set, starting from FAD sets with zero OCS occurrences up to FAD sets with 10 OCS. Sets with more then 10 OCS were pooled together under a >10 category. The proportion of each catch event in relation to the total number of FAD sets was then calculated. The time-series was divided into two periods: historic, spanning from 1986 to 1999, and recent, spanning from 2000 to 2015. Each period was analyzed separately for comparative purposes.

**4. Bootstrapping**

The time-series originated after combining the three datasets had gaps and the number of observed sets by year varied considerably (Figure 3). To evaluate the impact of this sampling variability in the proportion of catch events a bootstrap resample analysis (Efron and Tibshirani, 1994) was conducted. Each analyzed period was resampled 1000 times with replacement and a sample size of 1000. For every bootstrapped sample the proportion of OCS catch events was calculated, following the same procedure of the original sample.

**5. Fitting Poisson distribution**

Poisson is a discrete frequency distribution that describes the probability of independent events to occur in a fixed interval (Zar, 1999). Following this definition, the Poisson distribution (Equation 1) was used to describe the pattern observed in Figure 2:

$$P_{(x)} = \frac{e^{-\lambda}\lambda^{x}}{x!} \qquad \text{(Equation 1)}$$

Where $P$ is the probability of an event ($x$) to occur, and $\lambda$ is the average number of events per interval. In this case study, $P_{(x)}$ represents the proportion of FAD sets with $x$ OCS and $\lambda$ is the average number of OCS caught at FADs. The value of $\lambda$ was calculated by $\left|ln(P_{(x)})\right|$. A $\chi^2$ Goodness of Fit test was performed to compare observed and estimated values at 95% confidence level.

**6. Using $\lambda$ as a population index**

Considering that $x_0$ is the proportion of FADs with zero OCS and $x_1$ is the proportion of FADs with 1 OCS (and so forth), their variation through time can be expressed by the following system of differential equations:

$$\begin{cases} \frac{dx_0}{dt} = -\alpha x_0 + \beta x_1 \\ \frac{dx_1}{dt} = -\beta x_1 - \alpha x_1 + \alpha x_0 + 2\beta x_2 \\ \dots \end{cases}$$ (Equation 2)

Where $\alpha$ is the probability of a FAD to "gain" an OCS and $\beta$ is the probability for a FAD to "loose" an OCS. For simplification purposes, $\alpha$ and $\beta$ were assumed to be constant regardless the number of OCS at a FAD (i.e.: non-social behavior). With this assumption, for any value of OCS per FAD $j$ Equation 2 leads to the following solution:

$$x_j = \frac{1}{j!}\left(\frac{\alpha}{\beta}\right)^j x_0$$ (Equation 3)

The sum of the proportion of FADs with $j$ associated OCS must be equal to 1:

$$\sum_{j=0}^{\infty} \frac{1}{j!}\left(\frac{\alpha}{\beta}\right)^j x_0 = 1$$ (Equation 4)

The series expansion of the exponential function ($e^x$) can be substituted into Equation 4, leading to $x_0 = \mathrm{e}^{-\alpha/\beta}$. Equation 3 can then be rewritten as:

$$x_j = \frac{1}{j!}\left(\frac{\alpha}{\beta}\right)^j \mathrm{e}^{-\alpha/\beta}$$ (Equation 5)

Equation 5 actually describes a Poisson distribution (Equation 1) where $\alpha/\beta = \lambda$. As the probability for a FAD to "gain" and OCS ($\alpha$) is directly proportional to the size of the OCS population and the probability for a FAD to "loose" an OCS can be considered independent on the population, $\lambda$ can be used as a population index to derive population trends.

**7. Results**

The proportion of OCS catch events differed slightly between the two analyzed periods (Figure 2). While zero OCS events occurred most frequently on both periods, the proportion of this event was higher for the recent period, reaching 95% of the sets compared to 87% of the historic sets. Similarly, the proportion of events with the occurrence of 1 OCS was higher for the historic period, reaching 6% of the sets compared to 3% of the recent sets. The same pattern is observed for events with the occurrence of >1 OCS.

The bootstrapped samples of both analyzed periods (Figure 4) exhibited the same pattern observed in Figure 2, indicating that the lack of homogeneity in the time-series doesn't seem to greatly impact the analysis. For the historic period, zero OCS occurrences had a median value of 87.4%, while 1 and 2 OCS per FAD occurrences had median values of 6.8% and 2.8%, respectively. For the recent period, zero OCS occurrences had a median value of 95.7%, while 1 and 2 OCS per FAD occurrences had median values of 3.0% and 0.7%, respectively. The upper and lower confidence intervals of these three catch events are shown on Table 2.

**Table 2.** Upper and lower confidence interval for the proportions of FAD sets with the occurrence of OCS derived from 1000 bootstrap resamples.

| | Number of OCS per FAD | | |
|---|---|---|---|
| | 0 | 1 | 2 |
| Historic (1986 - 1999) | 87.33 - 87.47 | 6.14 - 6.25 | 2.77 - 2.83 |
| Recent (2000 - 2015) | 95.65 - 95.74 | 2.96 - 3.03 | 0.68 - 0.71 |

For both analyzed periods, observed and estimated values did not differ significantly ($\chi^2$ Goodness of Fit, p=1). The estimated value of $\lambda$ for the historic period was three times higher then the value estimated for the recent period, 0.1339 and 0.0442 respectively.

Estimates of $\lambda$ were also calculated for each one of the 1000 bootstrap resamples (Figure 5). For the historic period, $\lambda$ mean value was 0.1346 with a confidence interval ranging from 0.1138 to 0.1551. For the recent period, $\lambda$ mean value was 0.0439 with a confidence interval ranging from 0.0327 to 0.0547.

**8. Population trend for the OCS in the Indian Ocean**

The $\lambda$ values obtained in section 7 were significantly higher for the historic period than for the recent period, which indicates a declining population trend for the oceanic whitetip shark in the western Indian Ocean. The mean value of $\lambda$ for the historic years (1986 to 1999) is 0.1364, while the mean value for the recent years (2000 to 2015) is 0.0441. This translates to a population decline of around three times between the analyzed periods. In a more conservative approach, considering the lower confidence interval of historic years (0.1138) and the upper confidence interval of the recent years (0.0547), the OCS population in the Indian Ocean is around two times smaller in recent years.

**9. Remarks**

An ocean wide population trend is lacking for the oceanic whitetip shark, but regional studies on catch rates and abundance trends have shown evidence of substantial population declines in the Atlantic and Pacific Oceans (Baum and Blanchard, 2010; Clarke, 2011; Hall and Roman, 2013; Rice and Harley, 2012). For the Indian Ocean, there is no quantitative stock assessment for the species and only limited fishery indicators are available, making it difficult to determine meaningful abundance trends within this ocean basin (Romanov et al., 2010, 2008; Semba and Yokawa, 2011). The analysis presented here indicates that the OCS population in the Indian Ocean has also followed the trend of the other oceans, suffering a significant decline.

It is important to note, however, that the dataset used in this analysis has some limitations and results should be interpreted with caution. The fishing sets are not uniformly distributed over the study area, which could generate bias in the analysis. Additionally, knowledge regarding the spatial distribution and movement patterns for the OCS is extremely limited for the Indian Ocean (Filmalter et al., 2012; García-Cortés et al., 2012). Another issue is that the division of the time-series into historic and recent years was arbitrary, following a natural break that was actually imposed by the availability of data (see Figure 3). This arbitrary division might mask or exaggerate the estimated population declines. Insights on the associative behavior of OCS around drifting objects, especially regarding continuous residence times (see Filmalter et al., 2015), would also improve the analysis.

In any case, this is an innovative and relatively simple approach to derive and monitor population trends in the absence of data for reliable stock assessments. Fitting Poisson distributions doesn't require complicated modeling and the input data simply consists of count data of OCS around FADs. The simplicity of the data required allows for the integration of many data sources without standardization bias, providing a robust analysis. The oceanic whitetip shark is easily distinguishable from other shark species, which results in low misidentification issues in observers or fisheries logbooks. Taking these facts into account, historic data mining in the tuna purse seine fishery databases could generate a reliable time-series and provide a robust population trend for the oceanic whitetip shark in a global level.

## 10. Acknowledgments

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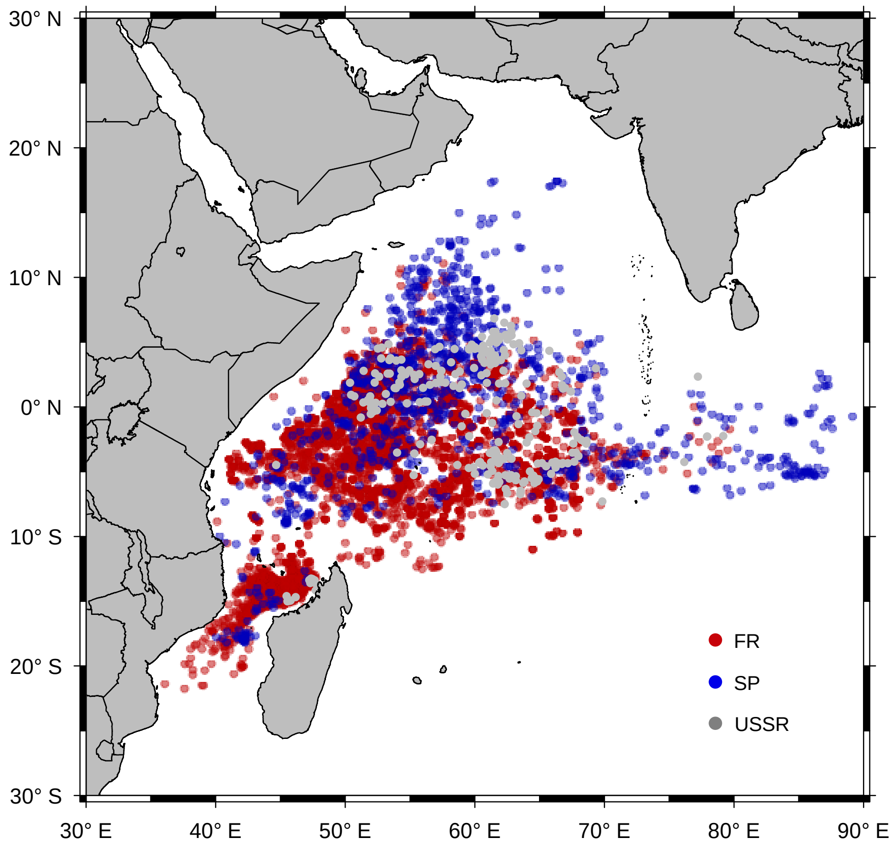


**Figure 1**. Location of FADs sets from the three databases used in this study: French (FR), Spanish (SP) and Soviet (USSR).

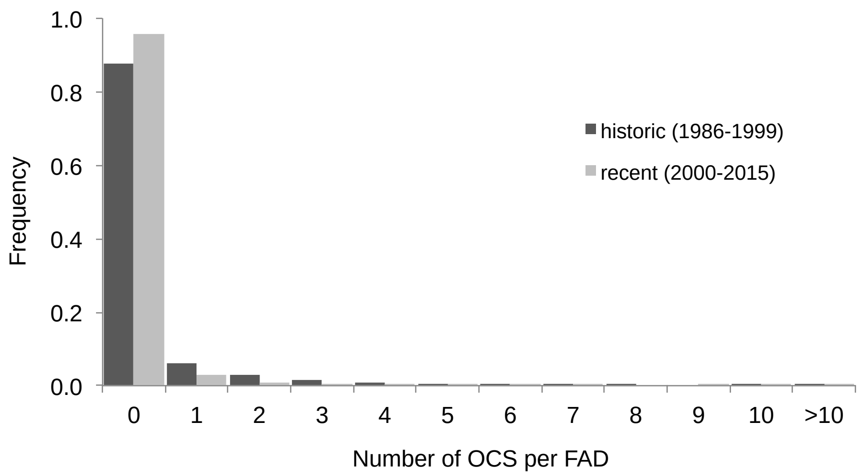


**Figure 2.** Proportion of FAD sets with the occurrence of oceanic whitetip sharks, starting from zero occurrences up to 10 occurrences in a single set.

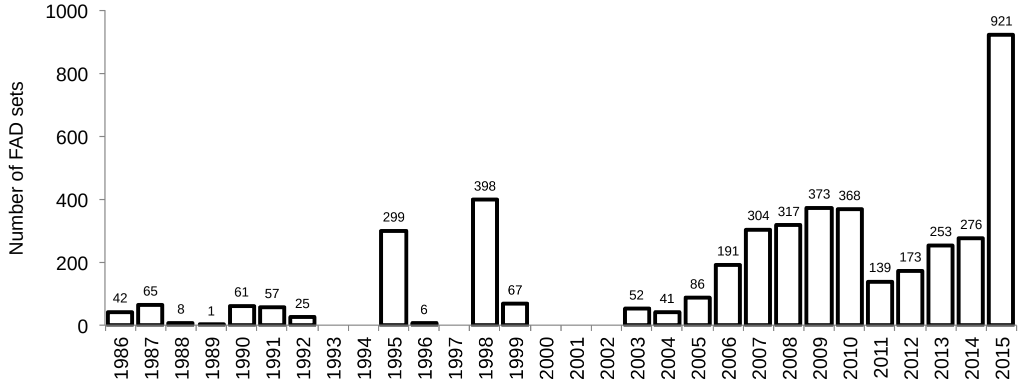


**Figure 3.** Number of observed FAD sets from the three databases used in this study.

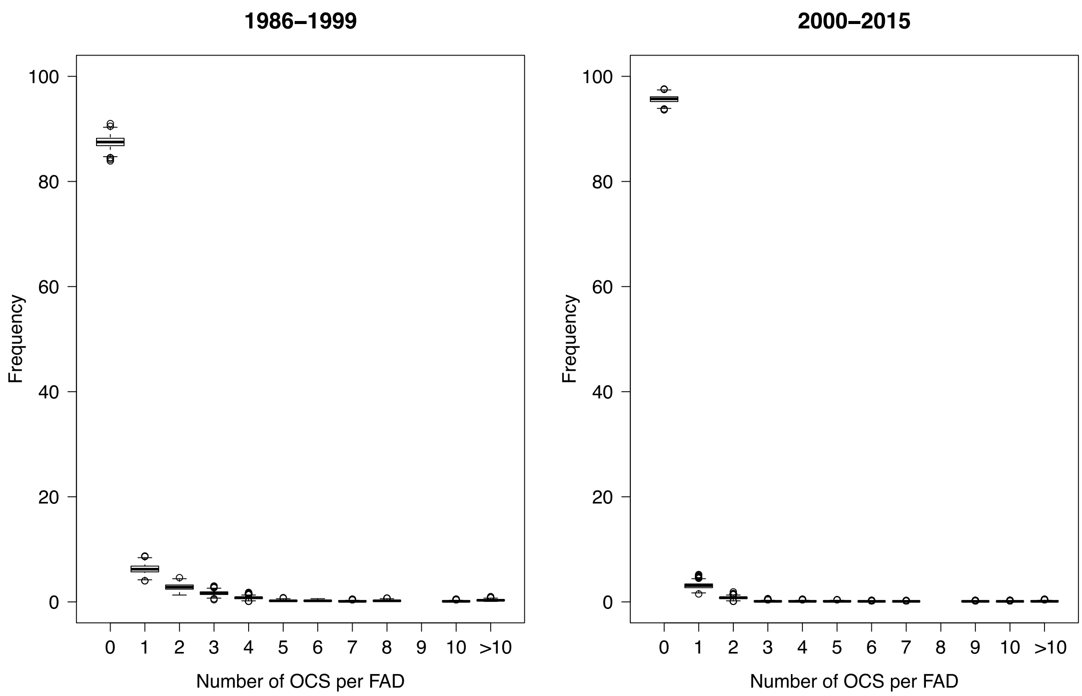


**Figure 4.** Proportion of FAD sets with the occurrence of oceanic whitetip sharks from 1000 bootstrap resamples.

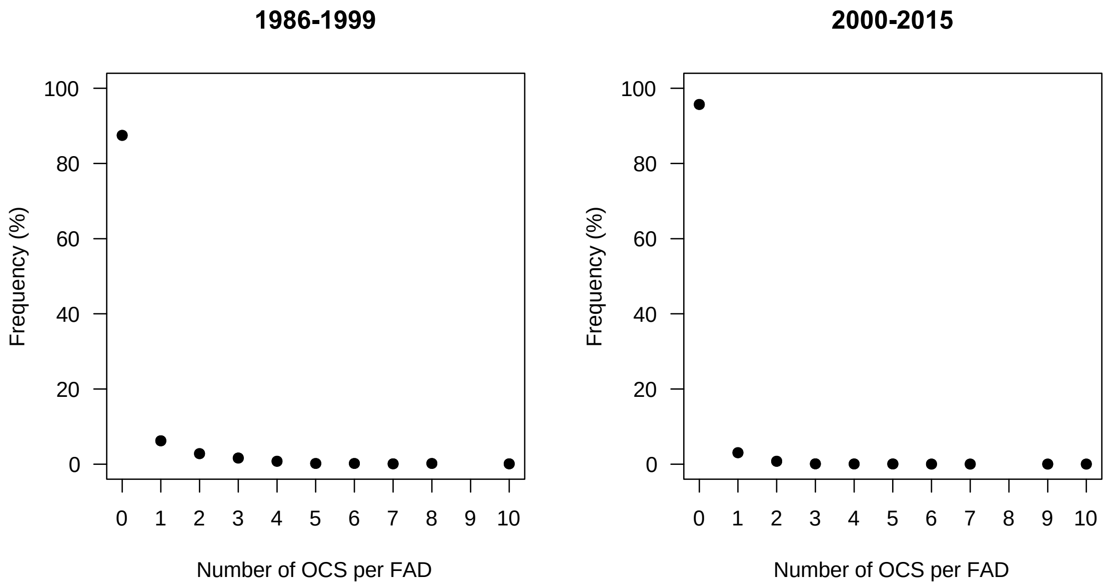


**Figure 5.** Estimated Poisson probabilities of catch events for each of the 1000 bootstraps resamples (red lines). Black dots represent the frequency values of the original sample.