A PRELIMINARY STOCK ASSESSMENT FOR THE SILKY SHARK IN THE INDIAN OCEAN USING A DATA-LIMITED APPROACH

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SUMMARY

Silky shark in the Indian Ocean can be targeted by some semi-industrial, artisanal and recreational fisheries, and is a bycatch of industrial fisheries such as pelagic longlines and purse seines. Currently there are not stock status estimations, but the WPEB has in its workplan a first assessment of this species in 2019. The objective of this paper is to provide preliminary support for that scheduled assessment, namely by providing: 1) a reconstruction of the time series of catches, 2) explore the possibility to standardize CPUEs for the EU pelagic longline fleets, 3) estimate prior for intrinsic population growth rate (r) and 4) test the feasibility to implement a data-limited assessment model (CMSY) and 5) provide a tentative stock status. From the final CMSY model configuration tested, the catches of silky shark in the Indian Ocean exceeded MSY from 1994 onwards. The exploitation rate for 2015 (last year in the model) was predicted to be well above MSY-level (F2015/Fmsy = 2.07). The estimation of current biomass (B2015) was 1.03 of Bmsy, with a considerable margin of uncertainty in the prediction (0.44-1.39), meaning that at present the silky shark stock in the Indian Ocean is subject to overfishing but not yet overfished. A fishing reduction to the levels observed in the late 1990s and early 2000s (around 9,000 t) would likely be sustainable. However, given the current level of uncertainty, the estimated lower 95% confidence limit of MSY (6,400 t) could serve as a more conservative guidance for total allowable catches. Due to the preliminary nature of this work and considerable uncertainty associated with the estimations, management advice is not clear. However, this work it could serve as a starting point to the scheduled 2019 IOTC silky shark assessment.

KEYWORDS: Data-limited, silky shark, stock assessment, stock status, Indian Ocean, pelagic fisheries.

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1. Introduction

In the Indian Ocean, silky shark can be targeted by some semi-industrial, artisanal and recreational fisheries, and is a bycatch of industrial fisheries such as pelagic longline tuna and swordfish fisheries, and the purse seine fishery.

Prior to the early 1970s the information on the fisheries is scarce. Both unrecording, recording but not reporting shark catches, and lack of species-specific statistics are common for most of the fleets in the region. Significant catches of sharks have gone unrecorded in several countries and many of the available records probably severely under-represent the actual level of catches, since they do not account for discards (unrecording catches of sharks for which only the fins were traditionally kept, or of sharks discarded because of their size or condition) or reflect dressed weight instead of live weight. In addition, shark finning was considered to be regularly occurring for this species. The bycatch/release injury rate is still poorly known, but in all likelihood, high. As regards length composition of the catches, the available information remains mostly anecdotal and grossly fragmented. Additionally, there is also currently limited information on fishing effort, preventing the estimation of nominal and standardized CPUE trends.

Life history traits are reasonably well-known for this species in the Indian Ocean. There is information on age and growth, including estimates on von Bertalanffy growth parameters and longevity, and on reproductive biology. In addition, there are several conversion factors available (length-weight relationships, fins/carcass ratios).

Following the results of a Productivity and Susceptibility Analysis (PSA, a semi quantitative Ecological Risk Assessment) for shark species caught in fisheries managed by the Indian Ocean Tuna Commission (IOTC) silky shark was qualified as potentially being at high risk of overexploitation. Those types of analysis, like the PSA, provide a rank of relative vulnerability of the species but do not provide stock status. Up until now, no quantitative stock assessment has been conducted by the IOTC Working Party on Ecosystems and Bycatch (WPEB); consequently, the stock status for this species remains unknown. Notwithstanding the foregoing, current outlooks would suggest that maintaining or increasing fishing would be likely to lead to declines in biomass, productivity and CPUE.

The key obstacles currently preventing quantitative scientific advice and the provision of a stock status for this species in the Indian Ocean are mainly related with 1) the poor quality and reliability of the recorded catch statistics (grossly underestimated), 2) the lack of reliable and detailed information regarding exerted fishing effort and mortality (with the consequent impossibility of estimating standardized catch-per-unit-effort series) and 3) the total absence of information as regards the composition of the catches.

A stock assessment is envisaged and in the WPEB workplan to take place in 2019. With that goal in mind, the specific objectives of this paper are to provide preliminary

information in support of the future WPEB silky shark assessment, by providing the following:

1) Reconstruct silky shark catch time series for the period 1971-2015.

2) Explore the possibility of estimating catch-per-unit-effort time series based on the EU longline fisheries with bycatch of silky sharks.

3) Estimate a probability density distribution for silky shark intrinsic population growth rate (r) based on biological parameters, that can be used later as a prior in assessment models.

4) Test the implementation of feasible stock assessment models for Indian Ocean silky shark, at this stage mostly a data-limited method based on estimated catches, resilience and qualitative stock status information.

2. Material and methods

2.1. Catch reconstruction

Catches were reconstructed between 1971 and 2015 using a ratio based method. This method was originally developed for the EUPOA - EU Plan of Action for sharks (see Murua et al., 2013; Coelho et al., 2018). It has been since then already applied and used as sensitivity scenarios during the latest (2017) stock assessments of blue shark in IOTC (Coelho and Rosa, 2017a) and shortfin mako in ICCAT (Coelho and Rosa, 2017b).

2.2. CPUE series

The available information on silky shark catches by EU pelagic longline fleets (Portuguese, Spanish and French longliners) fishing in the Indian Ocean was compiled. Following a preliminary analysis, it was concluded that the available data are very scarce and clearly insufficient to meet the needs for estimating standardized catch rates.

2.3. Demographic analysis

A stochastic population dynamics model (demographic analysis) using age-based Leslie Matrices was carried out to estimate the population intrinsic growth rate (r) (Caswell, 2001). Since only females produce off-spring, the demographic analysis was carried out exclusively for the female component of the population (Simpfendorfer, 2004). The age-structured model conceived was a pre-breeding survey model, where reproduction and natality take place first, followed by the probability of survivorship-at-age. Thus, the age-specific fecundity values of the Leslie matrix (Fx) were calculated as the products of the age-specific fertilities (mx) and the first-year survivorship (s0):

Fx=s0.mx. In terms of survivorship, the age-specific survivorship was estimated based on several indirect life history equations, specifically on Pauly (1980), Hoenig (1983), Jensen (1996), Peterson and Wroblewski (1984), Chen and Watanabe (1989).

Two different scenarios were analyzed and compared (**Table 1**). These scenarios accounted for different possible alternatives that can be used to estimate fecundity (either a 1 or 2-year reproductive cycle, still uncertain for the species).

Table 1. Biological inputs for the demographic analysis under various scenarios.

Parameter	Scenario 1	Scenario 2	References
Theoretical maximum length (L_{inf}, cm)	320.4		
Growth coefficient (k, year^{-1})	0.057		
Theoretical age at length zero (t_0, years)	-5.12		Hall et al., 2012
Median age for knife-edge maturity (years)	15		
Litter size (nr of embryos)	7.2		
Sex ratio at birth	1:1		
Lifespan (years)	35		Joung et al., 2008
Scalar coefficient of weight on length	0.0000118		Romanov &
Power coefficient of weight on length	2.97417		Romanova, 2009
Reproductive cycle (years)	1	2	

Uncertainty in the analysis was introduced in the survivorship and fecundity parameters. Uncertainty in the survivorship parameters was introduced by generating age-specific random survivorship values from a uniform distribution with support defined between the minimum and maximum empirical age-specific estimates. For the fecundity parameters, uncertainty was considered by generating random age-specific fertilities based on a normal distribution, with the expected values and standard deviations based on the fertility-at-age values. Each scenario was simulated using 10,000 Monte Carlo replicates varying each input parameter (survivorship and fecundity) based on the previously assumed distributions. The resulting 10,000 Leslie matrices were analysed, and the distributions of the output parameters summarized as the mean r values and the corresponding 95% confidence intervals (0.025 and 0.975 quantiles).

2.4. Assessment model

Considering the information available, effort was focused on the implementation of the CMSY model developed by Froese et al. (2017).

In essence, the model implements a stock reduction analysis using default priors for the intrinsic rate of population growth (r), based on resilience; for the carrying capacity or unexploited stock size k based on maximum observed catch and estimated priors for r; and start, intermediate, and final year depletion levels (B/K), based on a set of simple rules.

This model framework allows for the inclusion of priors for the input parameters (r, K and depletion) based on expert knowledge or estimated by any other feasible methods. The stock reduction analysis uses a Schaefer biomass dynamic model and an algorithm for identifying feasible r-k combinations to estimate biological and management quantities (r, K, MSY, BMSY, FMSY) as well as time series of biomass, fishing mortality, and stock status benchmarks (B/BMSY, F/FMSY).

It is worth noting that in its current version CMSY addresses the overestimation of productivity at very low stock sizes (general shortcoming of production models) by implementing a linear decline of surplus production when biomass falls below 1/4 K.

2.5. Model configuration and range of parameters explored

Estimated catches for the period 1971 to 2015 were used. No abundance index was available for this stock.

Using the stochastic Leslie matrix model, a distribution of r values was computed with a mode at 0.064 and a 90% confidence interval in the range 0.050 – 0.077. By using this quite narrow range we assume a very precise idea about this parameter, which would strongly restrict the space of parameters r and K explored by the model. In order to explore a wider range of plausible r values, no range was specified, and the resilience value available on Fishbase was used (Froese & Pauly, 2015).

As a note, and comparing to the default used values, for silky shark resilience is estimated to be very low (Froese & Pauly, 2015), which for CMSY defaults corresponds to values of r in the range 0.015-0.100. The median estimate is very similar and only the ranges modestly wider than the first implemented option described before.

As regards the range of depletion rates (B/k), at the start of the time series (1971), the stock is believed to be already exploited, but at a light level. An initial depletion rate (B/k) of 0.7-0.9 was therefore used. In order not to constrain too much the estimated stock trajectory, a wider range, between 0.2 and 0.7, was used for the final year (2015) depletion rate.

By default, CMSY uses an intermediate depletion rate (10 years before the end of the available time series) with values in the range 0.2-0.6. Preliminary runs using this default option showed that the range is very restrictive. The estimated trajectory goes just under the upper limit of this intermediate range, which shows that this default value strongly constrains the model. In order to give the model more freedom, a larger range was set (0.1-0.9, for year 2000 in the available time series).

Further model configuration involved both the choice of variance for the catch data (observation error), and variance of the process error. For both the default value was 0.1, which seemed considerable low (especially given that the catches were estimated by using a model); hence, higher values (0.2) were tested. This was found to have no effect on the output of CMSY.

3. Results

3.1. Catch reconstruction

There are differences in the reported versus estimated silky shark catches along the entire time series. Before the mid 1980s there are very few reported catches of silky shark. From then on there is a rapid increase in both series. However, in the estimated time series the catches continued to increase until the mid-2000s, while in the reported catches there is a peak in catches in the 1990s followed by an abrupt decrease. Between 2005 and 2015 there are some oscillations in both series but at very different catch levels (**Figure 1**).

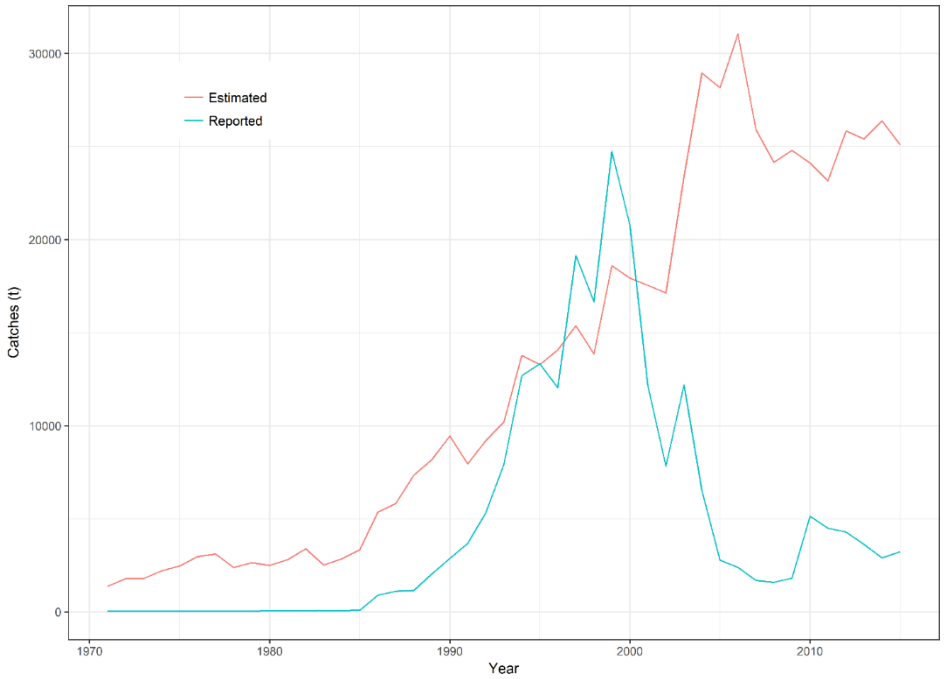

Figure 1. Time series of reported and estimated silky shark catches, between 1971 and 2015, for the Indian Ocean.

3.2. Standardized catch rates

After preliminary runs using Portuguese and Spanish observer data, the very limited interactions/catches with this species precluded any advancement on this issue. Therefore, at this point only catch based assessment models were tested. The French pelagic longline data from the fleet based on La Reunion was also explored but at this point it was also not possible to produce standardized CPUEs.

3.3. Demographic analysis

Using different biological scenarios, either a 1 or 2-year reproductive cycle, had an effect on the estimated r (**Figure 2**). When assuming a 1-year reproductive cycle (Scenario 1) the estimates of r were higher than when assuming a 2-year reproductive cycle (Scenario 2). The estimates of r were 0.064 and 0.026 for Scenario 1 and 2, respectively.

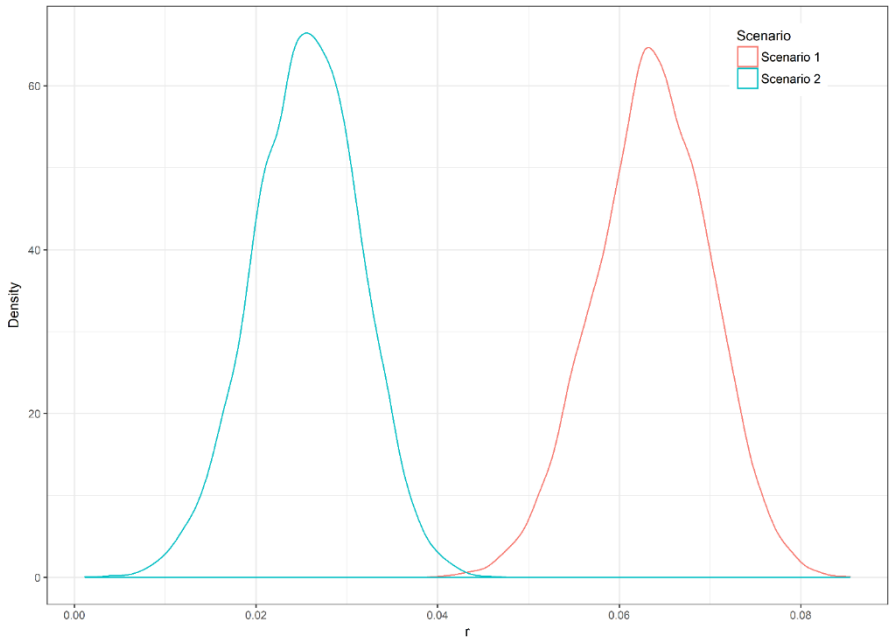

Figure 2. Plot of intrinsic rate of growth (r) estimates from stochastic demographic analysis for the different biological scenarios.

3.4. Stock assessment model

3.4.1. Influence of the choice of the prior on r

The two options tested for the prior on r did not have a marked impact on the outcome of CMSY. This is probably due to the fact that although the range based on the resilience (CMSY default value) is slightly wider than the one based on the Leslie matrix model, the central value for both ranges is similar. The estimated r and k are therefore

very similar: Leslie scenario: r = 0.069, k = 727 (thousand tonnes); resilience scenario: r = 0.062, k = 765 (thousand tonnes) (**Figure 3**).

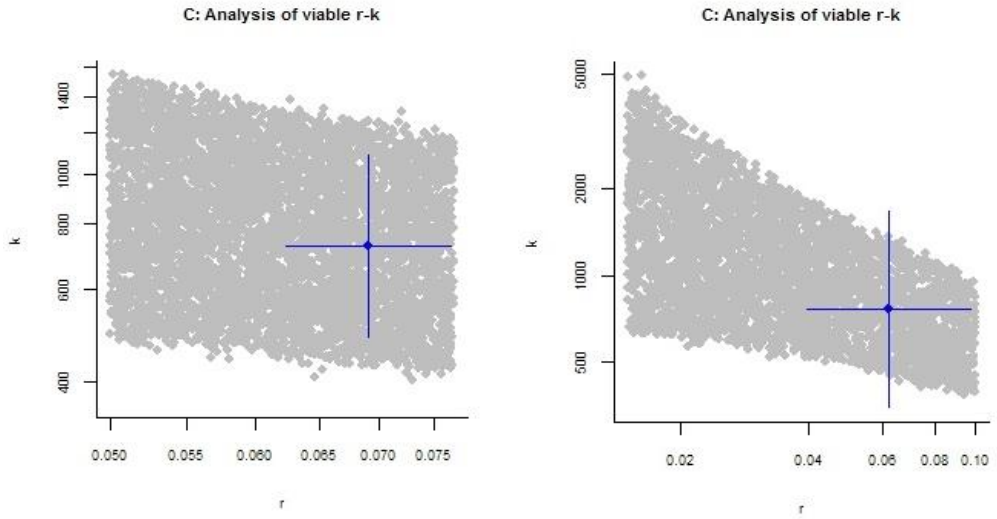

Figure 3. Viable r/k pairs (grey dots), and "best estimates" (and associated uncertainty), blue crosses, for the runs of CMSY using the Leslie based priors on r Leslie based (0.050 – 0.077; left panel) and the resilience based priors on r (0.015 – 0.1; right panel).

3.4.2. Run with default settings for depletion rate in intermediate year:

Using the default setting resulted in a trajectory strongly constrained by the depletion rate in the intermediate year (**Figure 4**). The trajectory goes close to the upper limit in the intermediate year, and close to the lower limit in the final year. This suggests that a less constraining range should be used for the intermediate depletion range.

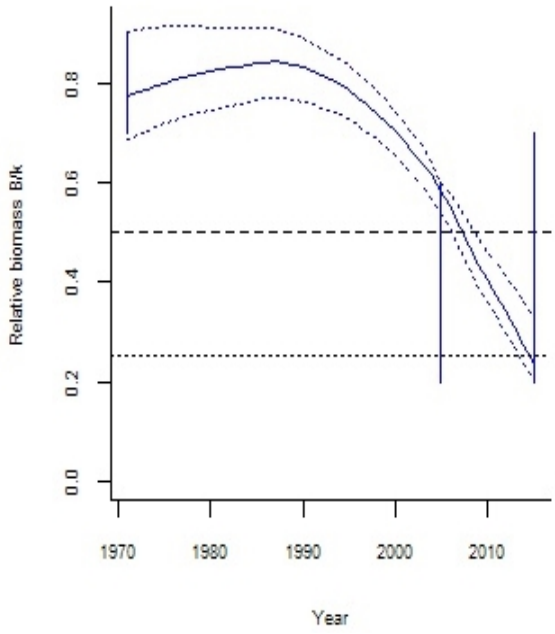

Figure 4. Estimated stock biomass using the expert knowledge on initial and final depletion rates, and the default setting for intermediate depletion rates.

3.4.3. Output of the final CMSY configuration

The agreed final configuration of the model included the resilience based r prior (as the Leslie based estimate was considered excessively restrictive), the expert knowledge based initial and final depletion rates (with the assumptions of light depletion in the first year of the time series and a wide range, from light to strong depletion, in the last year of the time series), and a very broad range of depletion for the intermediate year (with a view to minimizing the impact in the CMSY results). Final model configuration estimates of r, k and related quantities are given in **Table 2**.

Table 2. Final model configuration estimates from CMSY.

Parameter	Estimate	95% CI
r	0.062	0.0397-0.0970
k	765 (1000 t)	351-1666 (1000 t)
MSY	11.9 (1000 t)	6.19-22.7 (1000 t)
Relative biomass on last year (2015)	0.528 k	0.215-0.695
Exploitation F/Fmsy on last year (2015)	2	1.54-4.90

The stock is believed to have been at almost pristine state in 1971 (B/k around 0.8), started declining in the 1990s to close to BMSY in 2015. The exploitation rate was low in the early years, increasing strongly since the early 1990s to a value of 2 times FMSY currently.

Therefore, the results give the perception that the stock biomass is still above BMSY (stock is not overexploited), but the current fishing mortality is high, around 2 times higher than FMSY (stock is currently under over-exploitation).

4. Discussion

4.1. Stock status and management recommendations

Catches exceeded maximum sustainable yield from 1994 onwards, with an upward trend until the end of the reconstructed time series (2015) (**Figure 5**).

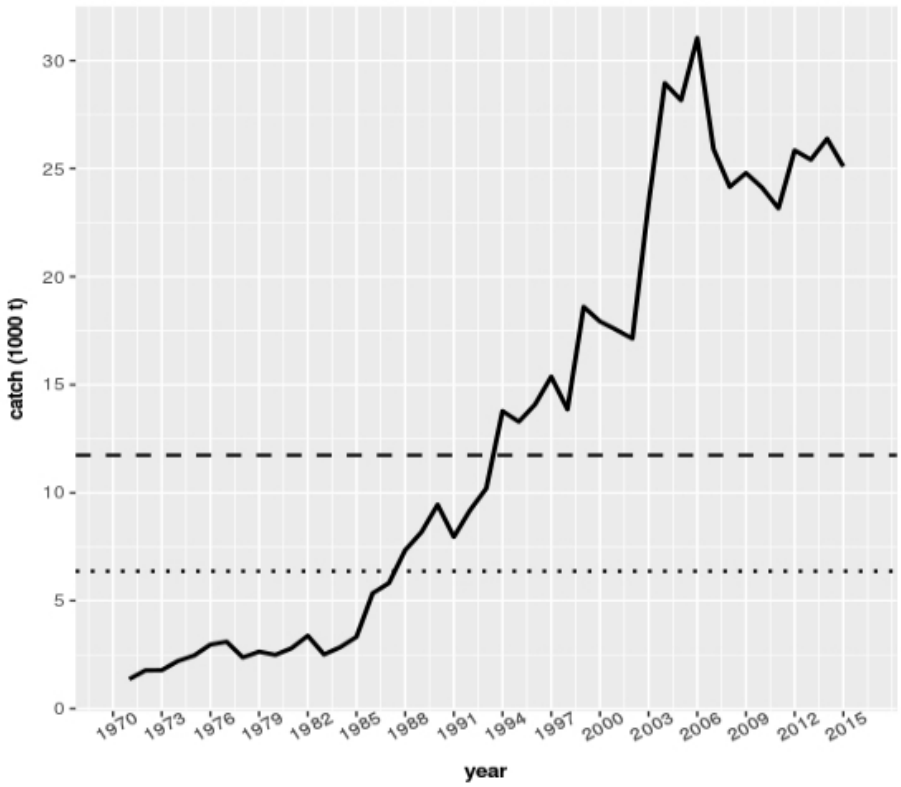

Figure 5. Reconstructed catch time series (1971-2015). Horizontal dashed line indicates MSY, and the dotted line indicates the lower confidence limit of MSY.

As regards exploitation, it was below the MSY-level in the years before 2003; from then on, the exploitation increased beyond the levels compatible with maximum sustainable yield. The exploitation rate for year 2015 (last in the available time series)

was predicted to be well above the MSY-level (F2015/FMSY = 2.07) with a wide margin of uncertainty around that prediction (1.54-4.90) (**Figure 6**).

CMSY predicts biomass above BMSY from the beginning of the time series up to year 2007; from then on, biomass would be between half BMSY and BMSY. The estimation of current biomass (2015) was 1.03, with a considerable margin of uncertainty in the prediction (0.44-1.39) (**Figure 7**).

According to the CMSY predictions, at present the silky shark stock would be subjected to overfishing but not overfished (**Figure 8**).

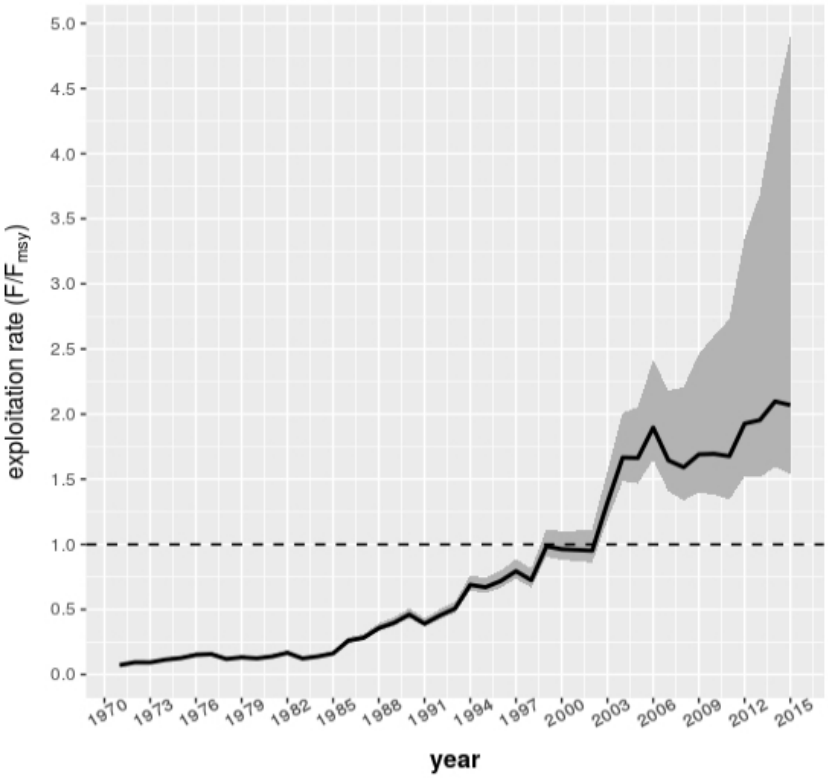

Figure 6. Exploitation rate (solid line) and associated uncertainty (grey shaded area). Dashed horizontal line indicates exploitation compatible with MSY.

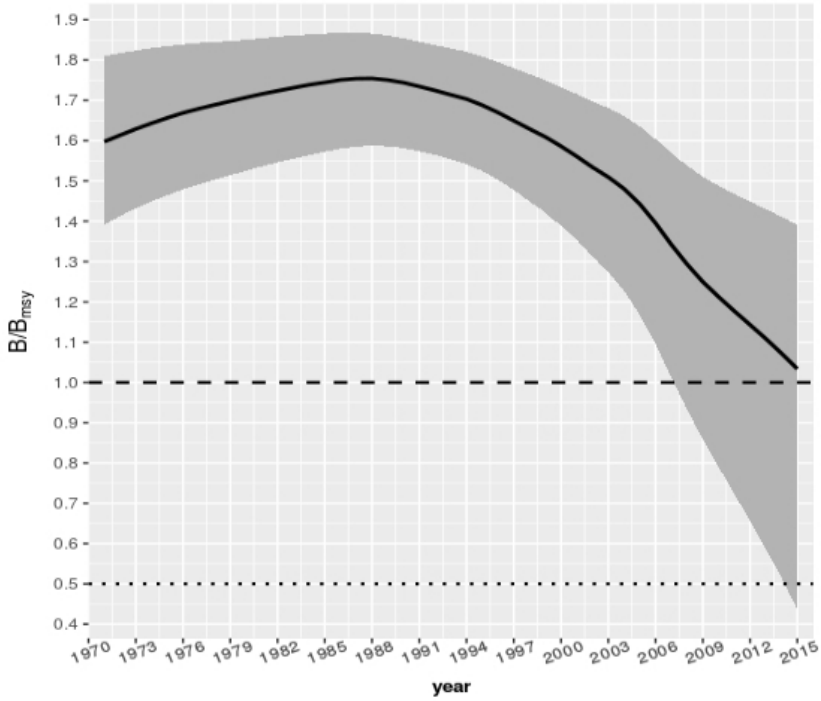

Figure 7. Biomass predicted by CMSY (solid line), with confidence limits (grey shaded area). Horizontal dashed line indicates BMSY and the dotted line indicates half of BMSY.

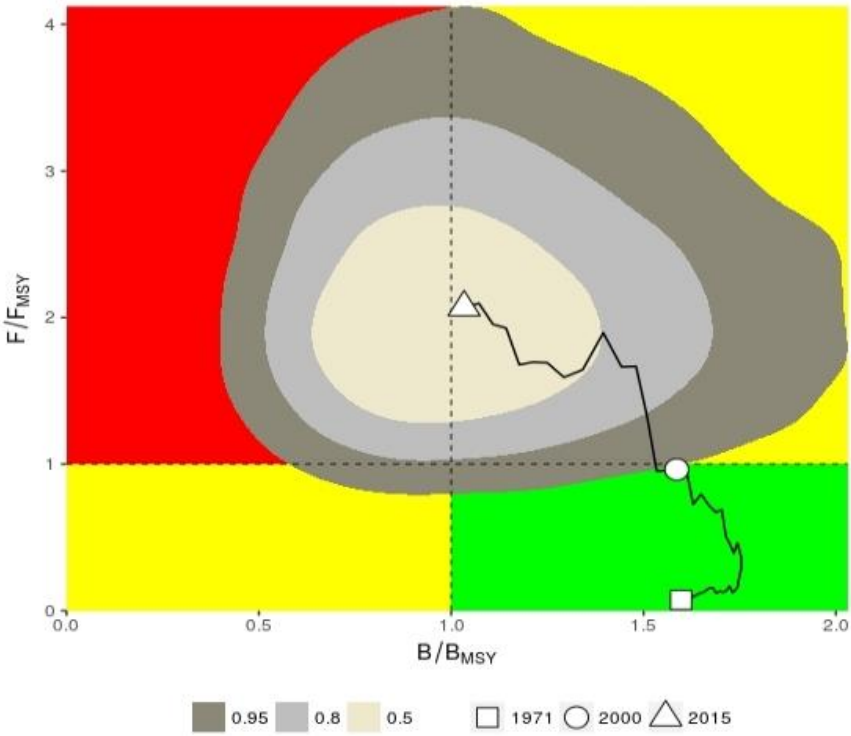

Figure 8. Temporal evolution of biomass and exploitation relative to BMSY (vertical dashed line) and FMSY (horizontal dashed line), respectively. Bivariate empirical confidence intervals correspond to the last year in the available time series (2015).

4.2. Final remarks

Due to the considerable amount of uncertainty in the estimates, management advice is not clear. Recent fishing mortality levels appear to be likely in excess of FMSY. Fishing reduction to the levels observed during the last years in the 1990s and early years in the 2000s would likely be sustainable. Precautionary management may restrict catches at levels observed in late 1980s and early 1990s (9,000 t) until additional information (for instance, CPUE data) that should allow for a more detailed analysis. However, given the current level of uncertainty on the estimates, the estimated lower 95% confidence limit of maximum sustainable yield (6,400 t) may serve as a more conservative guidance for total allowable catches. Management measures designed to reduce catch and effort directed at Indian Ocean silky shark should be implemented.

4. Acknowledgments

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