STOCK REDUCTION ANALYSIS OF BLUE SHARK (*Prionace glauca*) CAUGHT IN THE INDIAN OCEAN

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ABSTRACT

In this paper a Stock Reduction Analysis (SRA) based on catch data and on prior information concerning the intrinsic growth rate (r) was used to estimate maximum sustainable yield of blue shark (*Prionace glauca*) caught in the Indian Ocean. The uncertain concerning catch is high. Five different catch time series were considered. All the results indicate that the stock was not overfished in 2015 which is the end of the time series. However, catches have increased fast after 1990 and were higher than maximum sustainable yield (MSY) after mid of 2000's. Probably the biomass (B) was still B_{MSY} in 2015, but the ratio B/B_{MSY} will be below one in a near future if the catches and the fishing mortality continue to increase. The probability of overfishing blue shark is close to or higher than 0.6 in the near future even if the catches remain close to the average of catches of recent years.

INTRODUCTION

The maximum sustainable yield (MSY) as calculated using surplus production models is currently an important reference point for the management of several fisheries worldwide. Usually the calculation of the MSY and of the parameters of the models demands times series of catch and of estimations of relative abundance. Simple production models of Schaefer type (Schaefer., 1954) can be used to estimate intrinsic growth rate (r) and carrying capacity (k). However, despite estimations of catches are available for most stocks, reliable estimations of relative abundance are often missing. Simple methods for data poor stocks denominated as Stock Reduction Analysis (SRA) has been developed since 1980's (Kimura and Tagart, 1982; Kimura et al 1984). If only catch time series are available SRA is an alternative to estimate r and k, and consequently, reference points related to MSY. After some assumptions concerning the biomass in the beginning, in the middle (optional) and in the end of the time series, a range of r-k parameters are obtained using computational simulation approaches (Walters et al., 2006; Martell and Froese, 2012).

In this paper the SRA approach was used to estimate parameters of a surplus production model of Schaefer type for blue shark (*Prionace glauca*) of the Indian Ocean. Several prior distributions of r have been used in stock assessments of blue shark caught in the Indian and in other Oceans worldwide (ANON., 2015 a; ANON., 2015 b). In addition after the last stock assessment of blue shark of Indian Ocean, another prior of r were estimated by Rosa and Coelho (2016). Those priors were considered to select a distribution of r to be used in the simulation approach.

The uncertain concerning the catches of blue shark are high. Five different catch time series were made available for the stock assessment. The SRA was applied to all the series separated. Estimations of r, k, MSY and kobe plots calculated using each of the five time series were compared.

DATA AND ANALYSIS

Estimations of catches considered in the analyses are the ones: a) provided by IOTC, b) calculated using a GAM approach, c) estimated by researchers (EUPOA), d) calculated using a disaggregation method (DISAG) and e) estimated based on catch ratios of different species (RATIO). The official catch time series provided by IOTC is the base case while the other series were considered in sensitivity analysis. The five time series are shown in Figure 1. Notice that the five times series are monotonous in the sense in most of them the catches have increased continuously at least until 2000's. Most of the catch time series starts in 1950. The EUPOA which starts in 1970 with a relatively high catch is the exception. The main difference among the time series is the scale of the catches, which are relatively low in the IOTC series, while estimations in the EUPOA are higher than in other time series (Figure 1 A). In the end of the time series, IOTC and GAM catches are still increasing, the DISAG and RATIO series drops after peaking in the end of 2000's, and EUPOA oscillates with peaks in the beginning and in the end of 2000's.

In order to make easy comparisons of slopes and the time trends, the differences of scales were eliminated by calculation scores $z = (x - \bar{x})/s$, in which $\bar{x}$, and s are the mean and the standard deviation of the estimations of catch (x) (Figure 1 B). The five time series of scores were similar, but the slope of the EUPOA is higher until mid 1990's, but lower in the end of time series. The scores of IOTC and GAM series are quite similar, and the scores of DISAG and RATIO are also very close each other over the years.

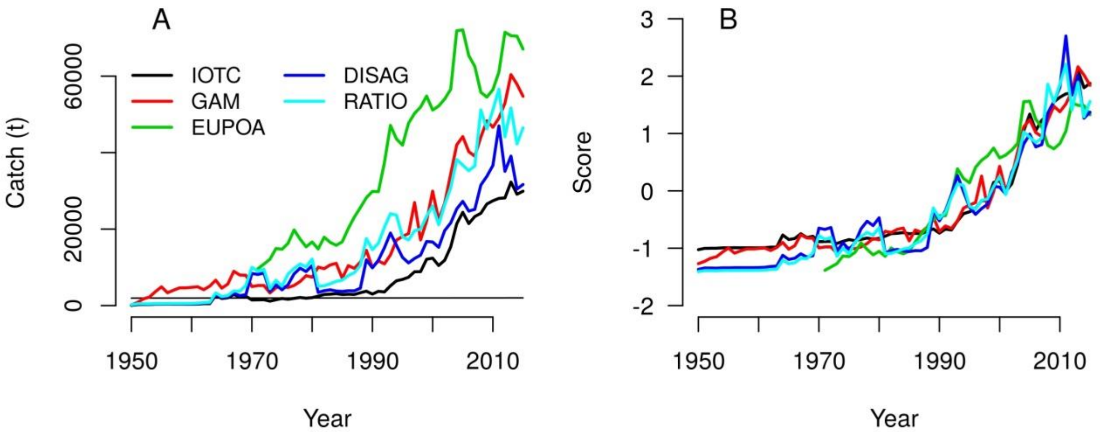

Figure 1 –Estimations of catches (t) of blue shark (*Prionace glauca*) (A), and the scores ((value-mean)/standard deviation) (B).

The depletion of biomass (D) as calculated by the ratio between the biomass (B) and the carrying capacity $D = B/k$ is a key point in the SRA framework. In order to conduct the simulations and calculations it is necessary to assume a range for D in the beginning and in the end of the time series at least. Ranges of D may also be assumed for other parts of the time series. If the first value to show up in the catch time series is relatively low, then one can assume that D is high (close to one) in the beginning of the time series. Because the catches of IOTC, GAM, DISAG and RATIO time series starts with very low values in 1950 I have assumed the range 0.8-1.0 of D for the beginning of the time series (Figure 2). However, the EUPOA starts in 1971 with a catch close to 10,000 t, I have assumed the range 0.7-0.9 of D for the beginning of this time series. I have not assumed a range for the intermediate part of the time series. However the range of D for the end of the time is necessary and critical. The results concerning the status of the stock (*i.e.* overfished) are driven by the D-range assumed for the last year of the time series. Because most of the estimations of the catches of blue shark indicate a monotonous increase, it is not clear if the biomass of the stock is below, above or at the MSY. There are not clear signals of collapse of the stock with a decrease of catches after a phase of high catches and fishing mortality. Hence in this preliminary analysis I have assumed a open-mind D-range of 0.2-0.7 for the end of the time series. In addition, However, this issue might be discussed by the working group in order to select a range for the stock assessment.

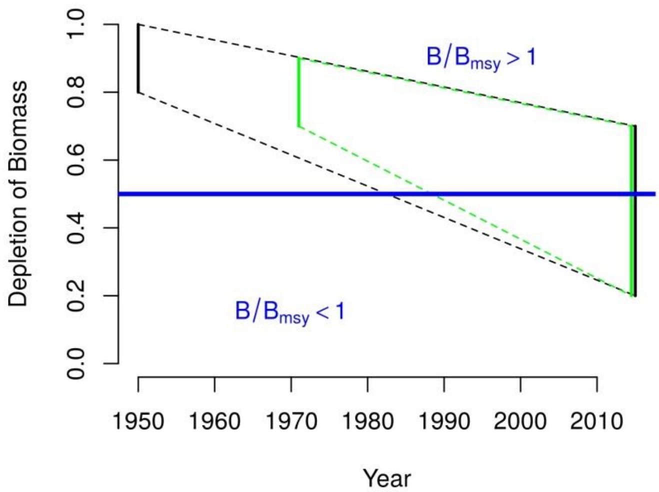

Figure 2 – Depletion ranges considered in the analyses of catch time series IOTC, GAM, DISAG and RATIO (black), and also of the time series EUPOA (green). Horizontal blue line indicate the threshold between the scenarios in which the biomass (B) is below or above the biomass at maximu sustainable yield (B_{msy}).

The computational procedure starts by randomly drawing r-k of the prior distributions. The prior distribution used for k was uniform $k \sim U(\max(catch), 50 \times \max(catch))$. This prior distribution convey very few information about k, and it says that the maximum catch was between 2% and 100% of the carrying capacity, which is non-informative. Priors for r of blue shark can be found in the reports of stock assessments of Regional Fisheries Management Organizations (RFMOs). I have extracted information about prior density distributions from the reports of last stock assessments of blue shark conducteb by the Indian Ocean Tuna Commission - IOTC (Anon., 2015 a) and by International Commission for the Conservation of Atlantic Tunas - ICCAT (Anon., 2015 b). I have also considered the estimations of r of Rosa and Coelho (2016). The priors are shown in Figure 3. Some of the priors are very informative, while others are vaguely informative. In this preliminary analysis I have selected the vague prior used in the last IOTC stock assessment held in 2015 (Anon., 2015 a) which is an open-minded distribution.

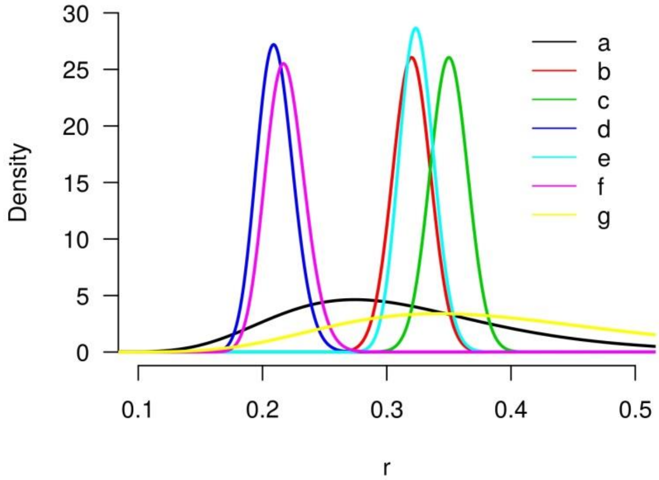

Figure 3 – Prior distributions of r extracted from a report of IOTC (Anon., 2015 a) (a), Rosa and Coelho (2016) (b and c), and from a report of ICCAT (Anon., 2015 b) (d, e, f, g).

After 10,000 r-k values were simulated from the prior distributions the ones that meet the range of depletion levels indicated above were retained. However, the estimations of central values of r and k are very much dependent of the choices concerning the lower limit for r and the upper limit for k (Martell and Froese, 2012). The prior distribution of r was assumed to represents the best available information on the parameter. However, the upper limit for k was chosen subjective. Hence, following the procedure adopted by Martell and Froese (2012), after the first run another upper limit was selected for k which was the smallest k at the lower limit of r ($r < 1.1 \times \min(r)$) or the largest k given the MSY was below the mean of the MSY. In addition I have compared the prior of r and the estimations of r after the first run to verify if they were conflictive. If they were conflictive, another distribution of r would be calculated as a compromise between the prior and the estimations gathered after the first run, otherwise, the new distribution of r would be calculated based only on the estimations gathered after the first run. After the distributions of r and k were updated a new set of 10,000 r-k values were sampled and the values which meet the depletion level ranges were retained as the final solutions.

Estimates of r and k, and the catches were used to calculate MSY, but also fishing mortality (F), biomass (B) and rations between biomass and biomass at MSY (B/B_{MSY}) and between fishing mortality and fishing mortality at MSY (F/F_{MSY}) from 1950 to 2015 which is the time span of most of the five catch times series. Similarly, estimates of r and k were used in predictive analysis of biomass, fishing mortality, B/B_{MSY}, and F/F_{MSY} from 2016 to 2025 taking into account nine Total Allowed Catches (TACs). Values of TACs considered were 60%, 70%, 80%, 90%, 100%, 110%, 120%, 130% and 140% of the average catch of the last three years to show up in the time series (2013-2015).

RESULTS

IOTC catch time series – base case

After the first 10,000 runs 1,214 r-k values meet the depletion level ranges. The parameters of a lognormal distribution were calculated based on the retained values of r-k. The prior lognormal distribution and the updated distribution of r are shown in Figure 4. Note that the two distributions are not conflictive, which indicates that the r values of the prior distribution are not conflicting very much with the depletion levels used in the analyses. The updated distribution of r was assumed as the new prior for a second run and a new set of 10,000 r-k were draw.

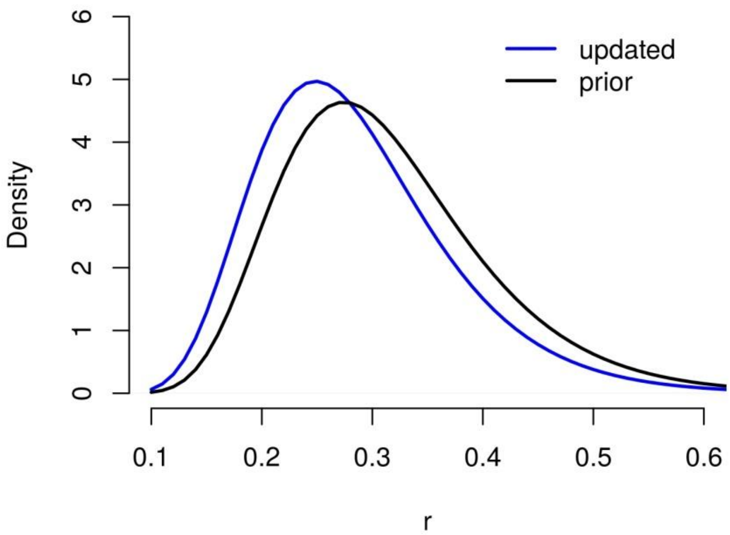

Figure 4 – Prior and updated density distributions of r of the first run.

The typical six panel graphs from the original SRA are shown in Figure 5. In the top left panel there is the catch series and the estimations of geometric mean and quantiles (2.5% and 97.5%) of the MSY. The quantiles range is wide but probably the catches have been higher than the MSY since mid 2000's. Correlation between r and k estimations is high (top mid and right panels). The r-k estimations are in a small corner of the space of parameters (top mid panel, which give weight to relatively low values of r and k. A zoom of the r-k solutions in the logarithm scale are in the top right panel. In that panel the straight solid lines stand for the solutions equal to geometric mean of MSY, while dashed lines for the bounds of r-k combinations which result in MSY between the 2.5% and 97.% quantiles. The triangle shape which is wider in the side where the values of r are low and the values of k are high is typical in this analysis. Biomass trajectories fluctuations are strong if r is high, which increase the probability of extinction or of biomass calculations higher than k (May, 1976).

Marginal distributions of r and k, and the distribution of MSY estimates distributions of MSY estimates are in the bottom panels of Figure 5. Distribution of r is right-skewed but the tail is not heavy. The distribution of k is also right-skewed but the end of the tail was truncated. This pattern appears due to the select the new upper bound of the uniform distribution for k after the first run. The distribution of MSY is symmetric and the geometric mean is 22,704 t. Empirical interval of confidence (95%) is wide ranging from 14,887 to 31,246 tons.

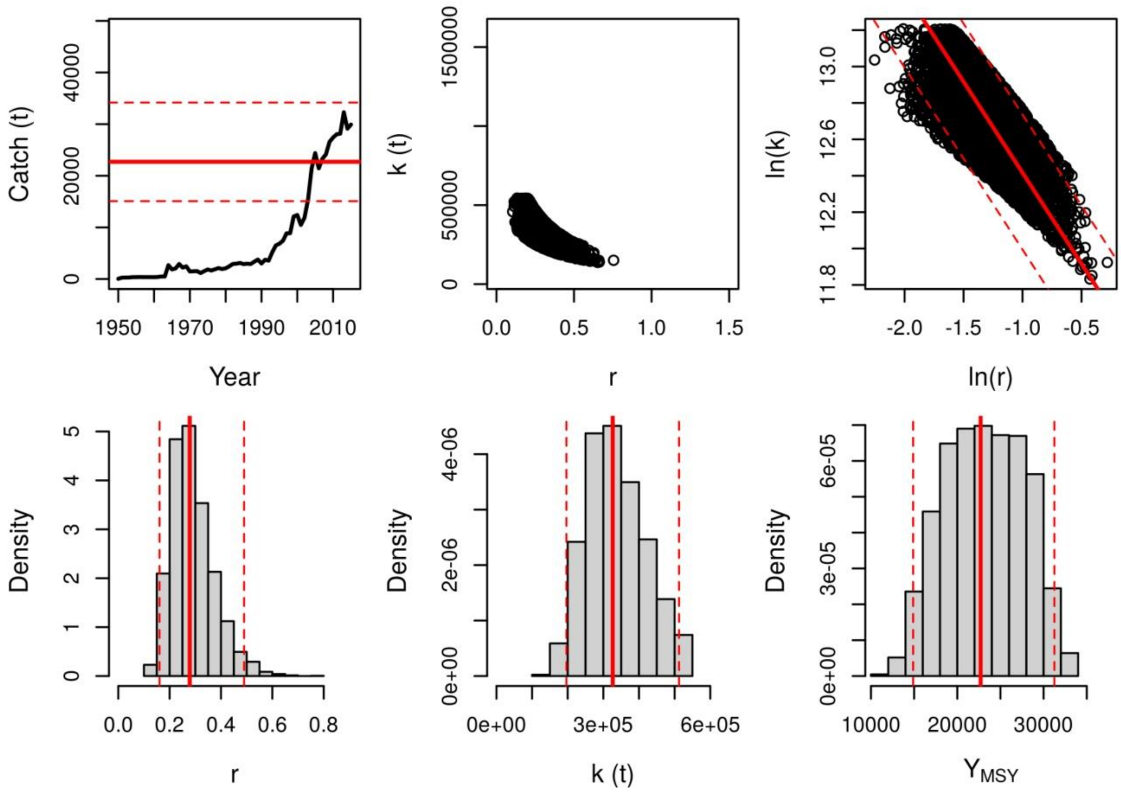

Figure 5 – Estimates of catch of blue shark (*Prionace glauca*) as reported in IOTC database , and estimates of r, k, and MSY calculated using catch only stock reduction analysis.

Estimates of ratio between biomass and biomass at MSY (B/B_{MSY}) and fishing mortality and fishing mortality at MSY (F/F_{MSY}) over the years are show in Figure 6. Overall the empirical confidence intervals of F/F_{MSY} and B/B_{MSY} ratios were narrow in the beginning of the time series but the uncertain is high after 2010. Because the catches are low in the beginning of the time series, biomass estimates are very close to carrying capacity until 1990. After this year the fishing mortality increased continuously and surpassed F_{MSY} in the end of the time series, consequently the probability that biomass is below the B_{MSY} increased. In 2015 the geometric mean of the B/B_{MSY} ratio is above but close to one. Results suggest that the biomass will probably be below the B_{MSY} in the future if the catches and fishing mortality remain high.

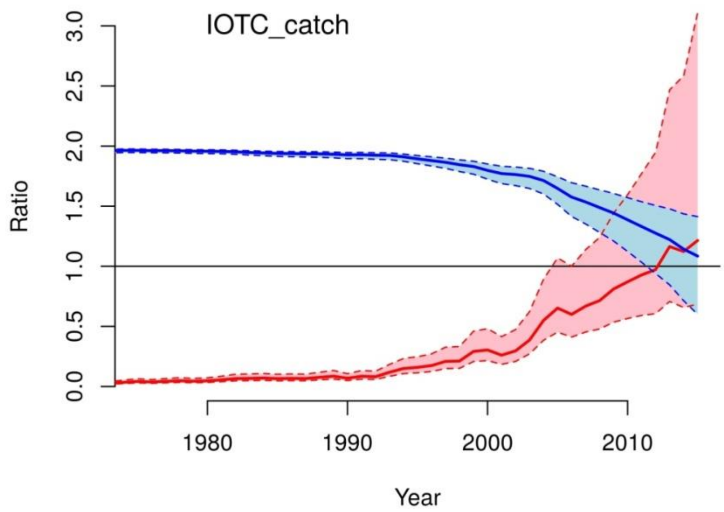

Figure 6 – Trajectories of ratio between fishing mortality and fishing mortality at MSY (F/FMSY) (bluish colors) and between biomass and biomass at MSY (B/BMSY) (reddish color). Solid lines stand for the geometrical means, while dashed lines stand for the bounds of 95% empirical confidence intervals.

Kobe plot is shown in Figure 7. The trajectory of the mode of the joint distribution of F/F_{MSY} and B/B_{MSY} ratios has shifted straightforward to orange (subject to overfishing) and red (overfished) zones, but is still in green region (not overfished) of the space. The joint distribution of F/F_{MSY} and B/B_{MSY} ratios in 2015 is skewed with heavy tail toward high values of F/F_{MSY} and low values of B/B_{MSY}. Note that because of the skewness the geometrical mean of F/FMSY is higher than one in the end of the time series (Figure 6), but the mode is not (Figure 7). Also, because of the skewness the probabilities that joint values of F/F_{MSY}-B/B_{MSY} were in green, orange and red zones in 2015 were all close or above 0.3 (30%) (Figure 8), though the kernel (mode) of the joint distribution is clearly in the green zone (Figure 7).

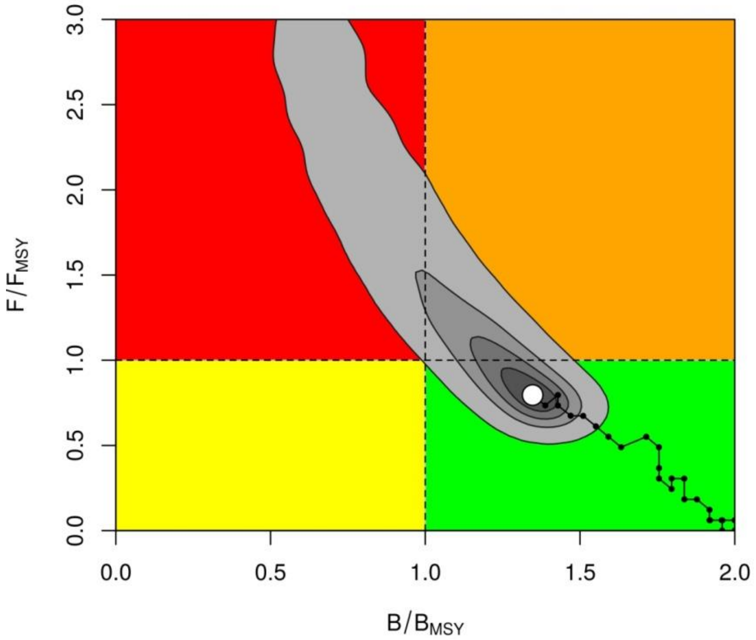

Figure 7 – Kobe plot as calculated based on the analysis of estimates of catch available in the IOTC dataset.

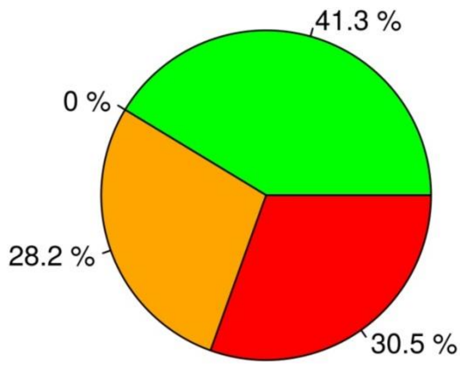

Figure 8 – Probabilities that joint values of ratios F/F_{MSY}-B/B_{MSY} were in green, orange and red zones of the kobe plot in 2015.

The average catch of the last three years to show up in the available time series (2013-2015) is 30,447.47 t. Hence the nine TACs used in predictive analysis corresponding to 60% to 140% of the average catch range from close to 18,270 t to 42,625 t. Because the joint distribution of the ratios are skewed with heavy in the end of time series (Figure 7) and also in the predictive calculations for 2016 to 2025 time span, medians of predictions are showed instead of the mean (Figure 9). Results indicate that the medians of B/B_{MSY} will be below in the end of the 10 years of projections unless the TACs are equal or below 24,358 t which is 80% of the average catch of the last three years to show up in the time series (2013-2015). Similarly, the median of F/F_{MSY} will remain higher than one and continue to increase unless the TACs is bellow the 80% of the average catch of recent years.

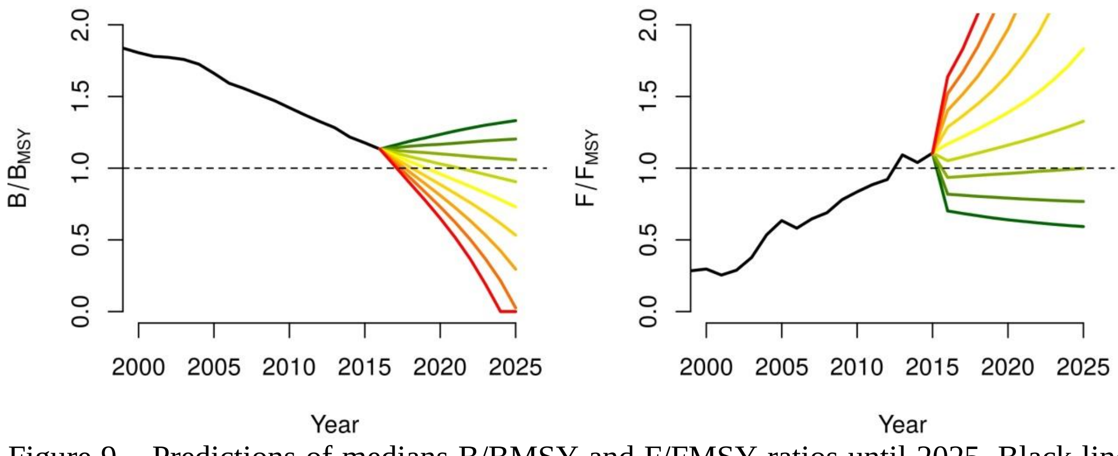

Figure 9 – Predictions of medians B/BMSY and F/FMSY ratios until 2025. Black lines stand for the calculations based on the time span of the available data, while color lines stand for predictions based on nine Total Allowed Catches (TACs). Colors fading from green to yellow to red stand for TACs equal to 60% to 140% (delta of 10%) of the average catches of 2013 to 2015.

Kobe II matrix of probabilities of B/B_{MSY} < 1 and of F/F_{MSY} >1 (overfishing) calculated in the simulations taking into account different TACs are shown in Figure 10. Notice that if TAC is equal to the average of the recent years the probability of overfishing increases continuously until 2025, when it reaches 0.65. If TAC is higher than the recent catches the probability of overfishing increases fast until 2025. For example, if the TAC is 20% higher than recent catches the probability of overfishing is higher than 0.9 in 2025. If the intention is to achieve a probability of overfishing below 0.5 in the near future, TACs can not be higher than 80% of the average of recent catches.

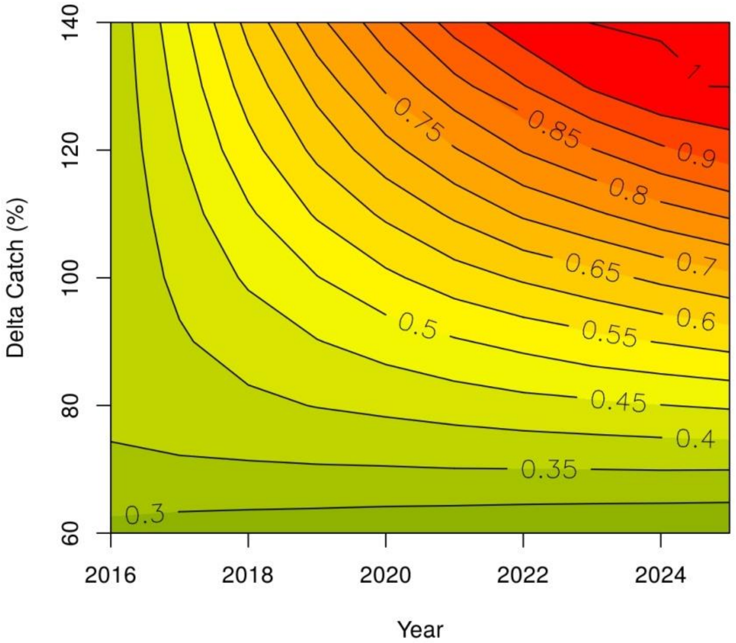

Figure 10 – Probability of overfishing blue shark in the 2016-2025 time span if the Total Allowed Catch is between 60% and 140% of the average catches of recent years (2013-2015).

Comparisons of Base Case and Sensitivity Runs

Overall the results of base case and sensitivity runs point to similar conclusions concerning stock status similar to those showed above for the base case run (IOTC catches). Hence detailed results of sensitive runs are show in the appendix to not clutter. Follow below just some comparisons of MSY estimates and of B/B_{MSY} and F/F_{MSY} ratios of base case and sensitivity runs and general statistic summaries of management benchmarks.

Empirical density distributions of MSY calculated for the five catch time series are in Figure 11 A. Notice that calculations with EUPOA datasets give more weight to high values of MSY around 60,000 t, while calculations with IOTC and DISAG datasets were more conservative in the sense the estimates of MSY were low, close to 25,000 t. Estimations gathered with GAM and RATIO give weight to intermediate values around 40,000 t. Therefore the scales of estimations of MSY are quite different depending on the catch time series used in the calculations. Estimations based on EUPOA series were almost 3 times higher than those obtained by analyzing IOTC and DISAG datasets.

Ratios between average of catches of recent years and estimations of MSY were calculated to minimize the effect of the scale of the five catch time series (Figure 11 B). Notice that empirical density distributions of the ratios calculated using the five catch time series are not conflictive. All of them are skewed to the right and give more weights to values between 1 and 1.5. The probabilities that average caches of recent year were larger than MYS were higher than 0,8 for all time series, particularly in the calculations based on IOTC and GAM catch datasets.

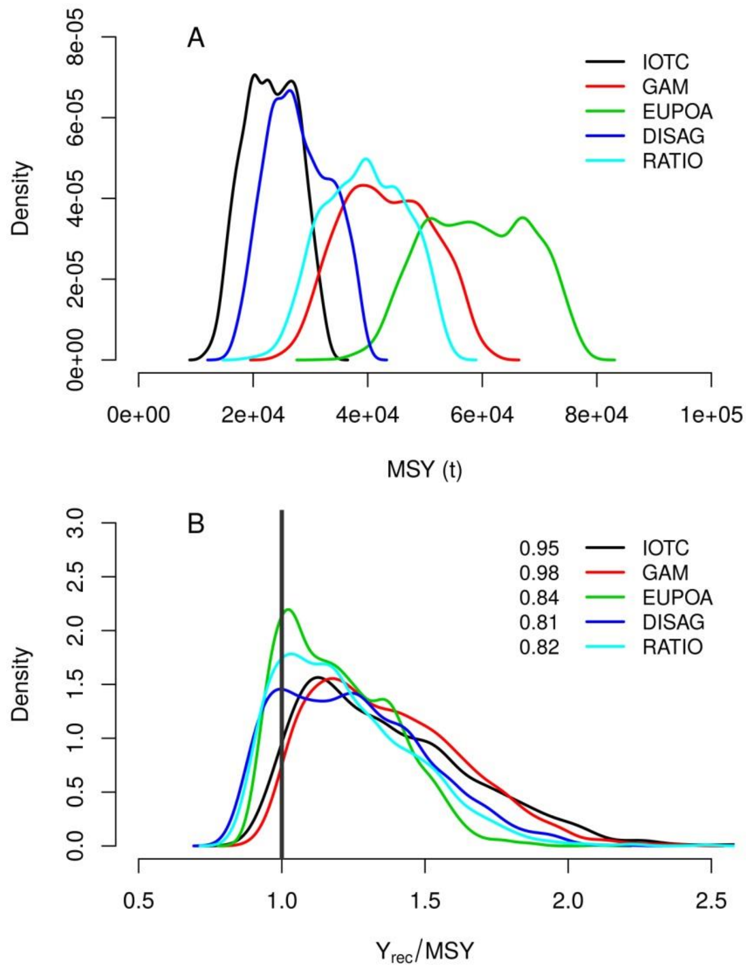

Figure 11 – Empirical density distributions of estimates of MSY of blue shark (A) and of ratios between the average catch of recent years (2013-2015) and MSY (B) calculated based on five catch time series (IOTC, GAM, EUPOA, DISAG, RATIO). Number in panel B stand for empirical probability that average catches were larger than the MSY.

Contour lines at 0.5 of the maximum densities and the modes of joint empirical distributions of B/B_{MSY} and F/F_{MSY} calculated for 2015 are shown in Figure 12. Distributions of those ratios are skewed and the modal values are located in lower corner (green zone) of the elliptical polygons. Contour lines and modal values calculated with the different time series overlay each other. Solutions are not conflictive although the calculations based on EUPOA and RATIO datasets were slight more optimistic in the sense a large part of the polygons are in green zone, while the polygon calculated for the DISAG catch time series has a large part over the red zone. However, in general, all results indicate similar status for the blue shark.

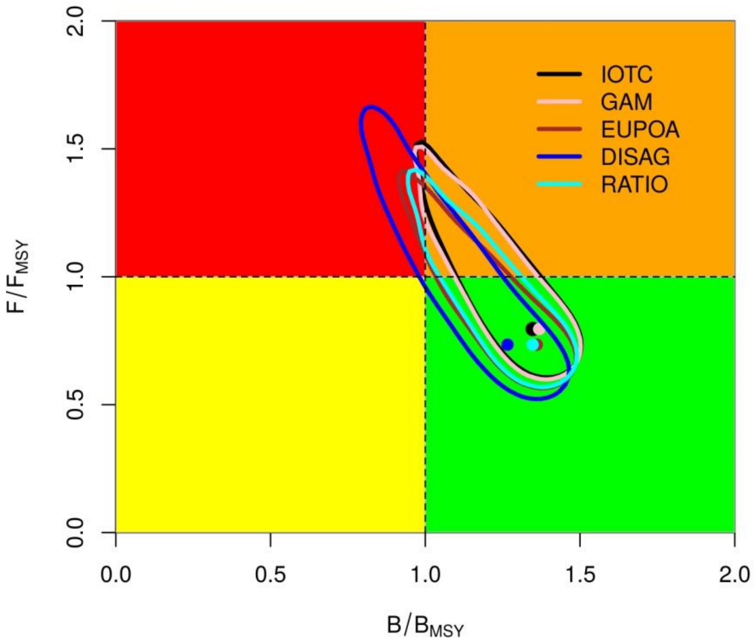

Figure 12 – Contour lines 0.5 of the maximum densities and modes of the joint distributions of B/B_{MSY} and F/F_{MSY} calculated for 2015 based on five catch rate time series (IOTC, GAM, EUPOA, DISAG and RATIO.

CONCLUSIONS

- The SRA results indicate that probably the blue shark of the Indian Ocean was not overfished in 2015.

- Catches and the fishing mortality increased fast the last decades. If catches continue to increase in the next years or if it remain as high as in 2015, the probability that blue shark will be overfished in the near future is high.

- The main difference between the solutions gathered with the five different catch time series is a matter of scale, which is a critical issue for management, but does not change the diagnostic that the recent catches were higher than MSY.

APPENDIX

GAM catch time series

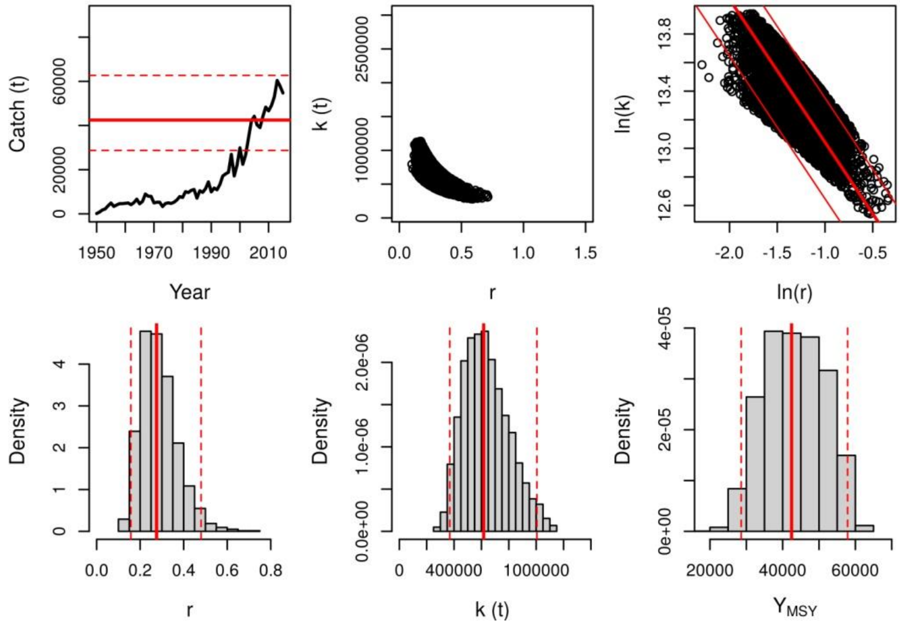

Figure A1 – Estimates of catch of blue shark (*Prionace glauca*) as reported in GAM database , and estimates of r, k, and MSY calculated using catch only stock reduction analysis.

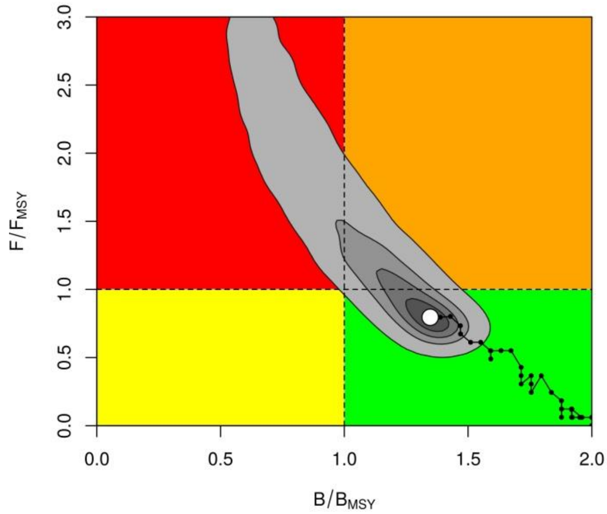

Figure A2 – Kobe plot as calculated based on the analysis of estimates of catch available in the IOTC dataset.

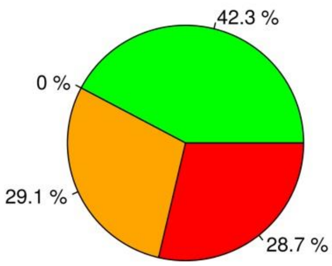

Figure A3 – Probabilities that joint values of ratios F/F_{MSY}-B/B_{MSY} were in green, orange and red zones of the kobe plot in 2015.

EUPOA catch time series

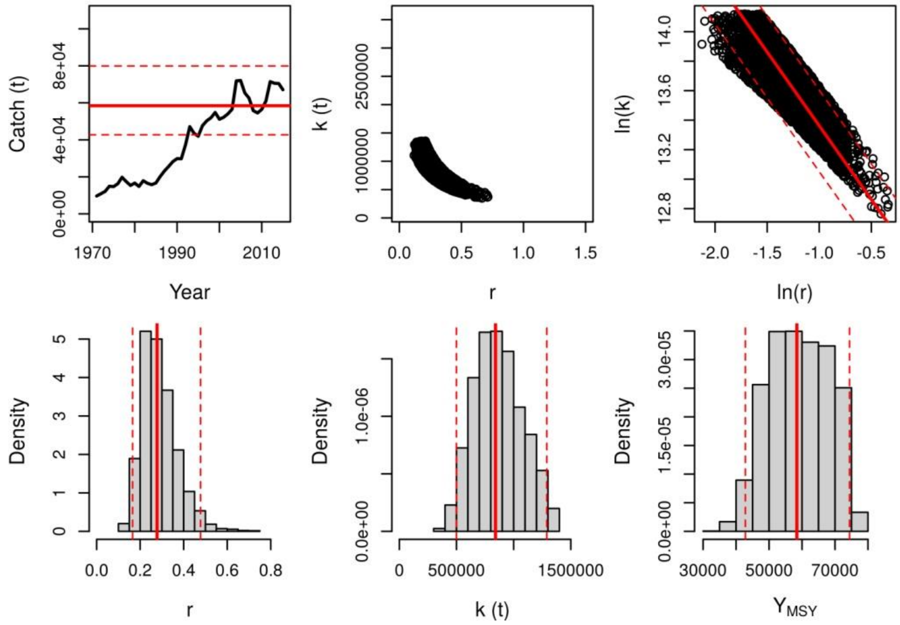

Figure A4 – Estimates of catch of blue shark (*Prionace glauca*) as reported in EUPOA database , and estimates of r, k, and MSY calculated using catch only stock reduction analysis.

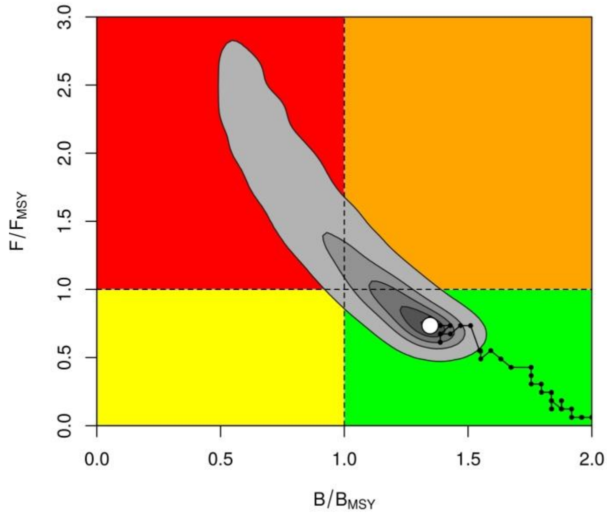

Figure A5 – Kobe plot as calculated based on the analysis of estimates of catch available in the EUPOA dataset.

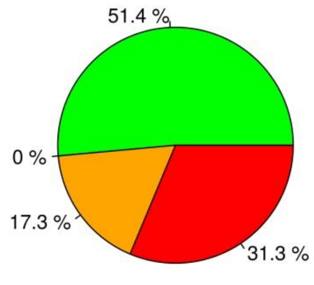

Figure A6 – Probabilities that joint values of ratios F/F_{MSY}-B/B_{MSY} were in green, orange and red zones of the kobe plot in 2015.

DISAG catch time series

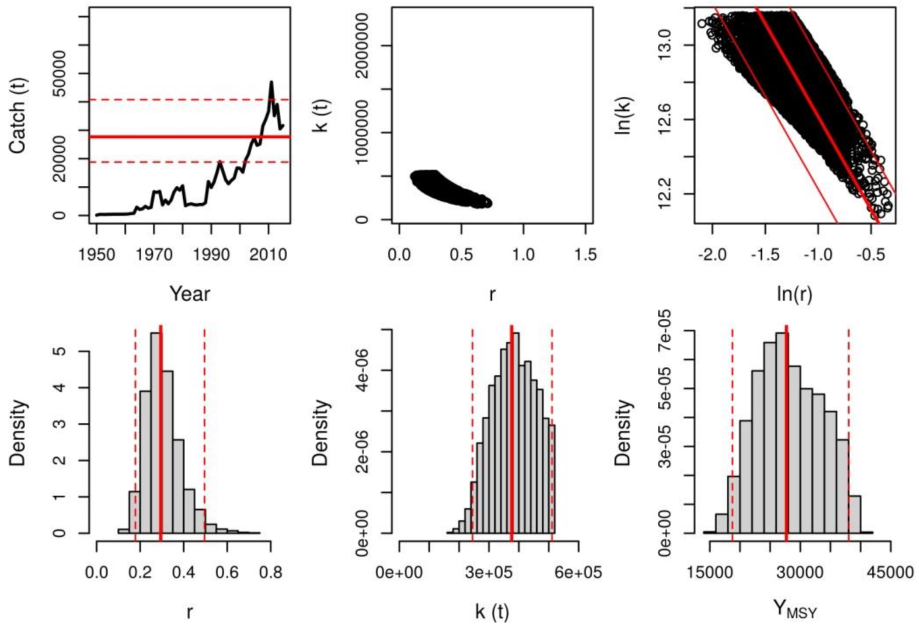

Figure A7 – Estimates of catch of blue shark (*Prionace glauca*) as reported in DISAG database , and estimates of r, k, and MSY calculated using catch only stock reduction analysis.

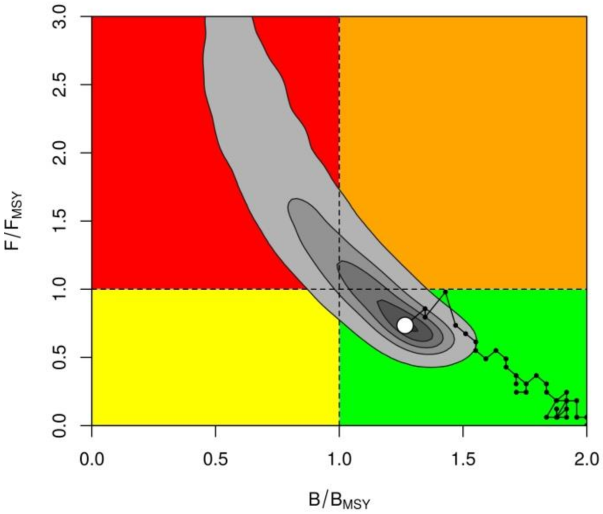

Figure A8 – Kobe plot as calculated based on the analysis of estimates of catch available in the DISAG dataset.

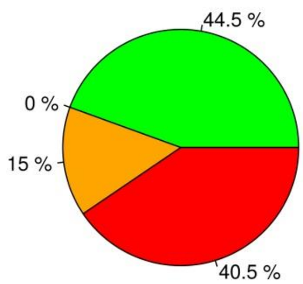

Figure A9 – Probabilities that joint values of ratios F/F_{MSY}-B/B_{MSY} were in green, orange and red zones of the kobe plot in 2015.

RATIO catch time series

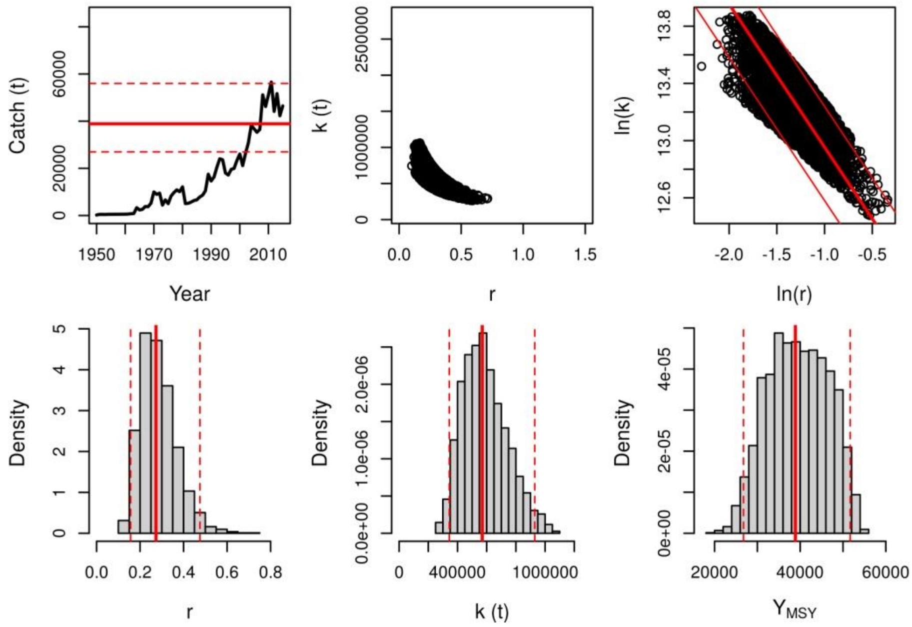

Figure A10 – Estimates of catch of blue shark (*Prionace glauca*) as reported in RATIO database , and estimates of r, k, and MSY calculated using catch only stock reduction analysis.

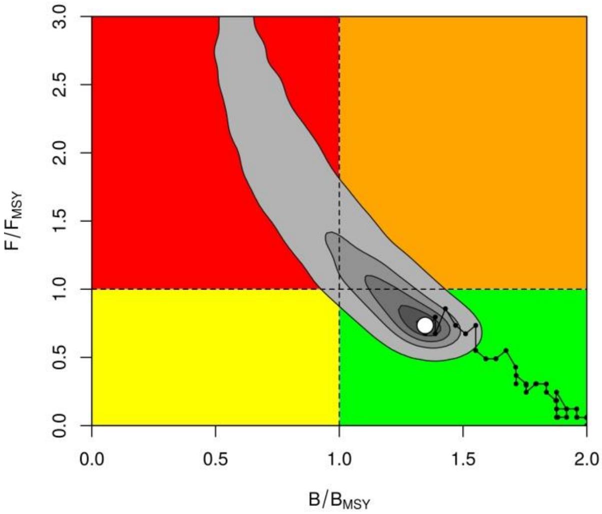

Figure A11 – Kobe plot as calculated based on the analysis of estimates of catch available in the RATIO dataset.

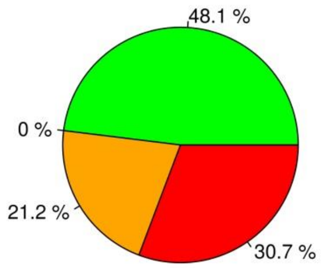

Figure A12 – Probabilities that joint values of ratios F/F_{MSY}-B/B_{MSY} were in green, orange and red zones of the kobe plot in 2015.

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