STOCK REDUCTION ANALYSIS OF STRIPED MARLIN (*Tetrapturus audax*) 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 striped marlin (*Tetrapturus audax*) caught in the Indian Ocean. Three different assumptions concerning depletion of biomass in 2016 were considered in sensitivity runs. Results and the diagnostic of the status of the stock strongly depends on the assumptions, which might be carefully evaluated by the working group if the intention is to use SRA to assess the status of the stock.

INTRODUCTION

Surplus production models are often used to calculate maximum sustainable yield (MSY) which is a reference point for decision making and management of several fish stocks. Generalized surplus production models with different shapes may be used. In surplus production model framework times series of catch and of estimations of relative abundance are often the input data to estimate intrinsic growth rate (r) and carrying capacity (k) parameters. In some situations both estimations of catches and relative abundance indices are available. Estimations of reliable relative abundance are usually more difficult to obtain than catches, hence for many stocks worldwide only catch time series are available.

Stock Reduction Analysis (SRA) is the denomination of a set of simple methods and approaches to estimate the parameters of production models using catch data only. The methods, which were first proposed by Kimura and Tagart (1982) and Kimura et al. (1984) inspired adaptations (Walters et al., 2006; Martell and Froese, 2012) which become popular, particularly after Martell and Froese (2012) provided a free code. The key issue in the SRA approach is that it request assumptions concerning the biomass depletion in the beginning, in the middle (optional) and in the end of the time series. The depletion in t^{th} year (D_t) is calculated as the ratio between biomass (B_t) and the carrying capacity (k) ($D_t = B_t/k$). After the ranges of plausible depletions in the different parts of the times series were selected, *r*-*k* parameters that meet those assumptions are obtained using computational simulation approaches. Those parameters estimations of r and k are then used to estimate MSY.

In this working paper the SRA approach was adapted to conduct stock assessment of striped marlin (*Tetrapturus audax*) caught in the Indian Ocean. Priors used in previous stock assessments were considered, but biological information concerning growth were also used to estimate a prior distribution of r. Sensitivity runs were conducted to assess the effect of assumptions concerning depletion of biomass in the beginning, middle and end of the time series.

DATA AND ANALYSIS

Depletion of Biomass

Catch time series is the only input data, and it is often used as guide for the choices concerning the depletions of biomass in the SRA approach. For example, Martell and Froese (2012) used as example a rule of the thumb to select the assumption concerning the depletion of biomass based on the ratio between the catch in the end of the time series and the maximum catch. If the final catch was greater than 0.5 of maximum catch, the plausible range of depletion of biomass in the following year after the end of the time series is assumed to be 0.3-0.7, and 0.01-0.4 otherwise. That rule of the thumb was used as example, but the best available knowledge might be used in serious stock assessments (Martell and Froese, 2012). Hence, the inspection of catch time series is of major importance in SRA (and in most of the other stock assessment approaches) in order to choose the assumptions concerning depletion of biomass.

Estimations of catches considered in this analysis are the ones provided by IOTC (Figure 1). Catches increased continuously from 1950 to the end of 1960's, but oscillated very much since 1970's. There were peaks and plunges across the years until 1993, followed by a decreasing trend until 2009. In the end of the time series catches increased and were similar to those of 1970's. Striped marlin has been caught in Indian Ocean by fleets which operate with different gears, hence it worth the effort to split the catches by gear group.

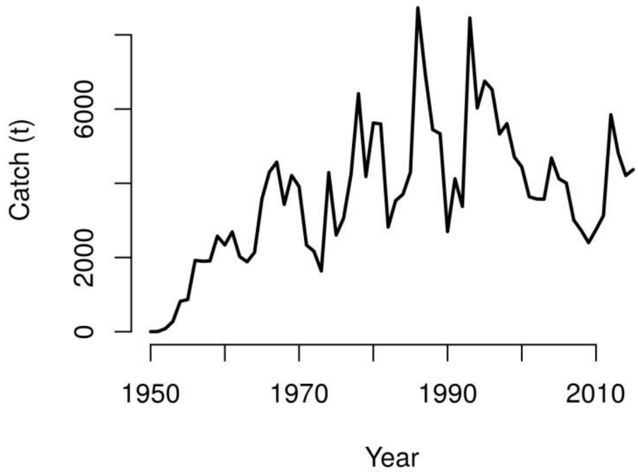

Figure 1 – Total catch of striped marlin (*Tetrapturus audax*) as reported or estimated by IOTC.

Catches split by major gear group and also by secondary gear group are in Figure 2. Most of the striped marlin was caught by longline fleet all across the years (Figure 2 A). However the relative importance of line and particularly gillnet catches have increased in the recent years. Peaks and plunges of striped catches before 2000 were driven by the longline catches. In the recent decades catches of major longline showed another peak (Figure 2 A). Catches of major longline group can be split into two subgroups, longline (LL) and longline fresh (FLL) catches (Figure 2 B). Historically most of striped marlin was caught by LL boats, but notice that the catches of this subgroup decreased fast and steadily since the mid 1990's. Catches series of FLL subgroup starts only in the end of 1980's. FLL catches did not change much from 1990 to 2010, but it increased in the recent years, and in 2014 and 2015 the catches of FLL subgroup were even higher than those of LL subgroup. Catches of major gillnet group can be split into gillnet (GILL) and offshore gillnet (GIOF) subgroups. Catches of GIOF subgroup showed an up and down pattern. Catches of GILL subgroup after 2010 were more two times higher than in the previous years.

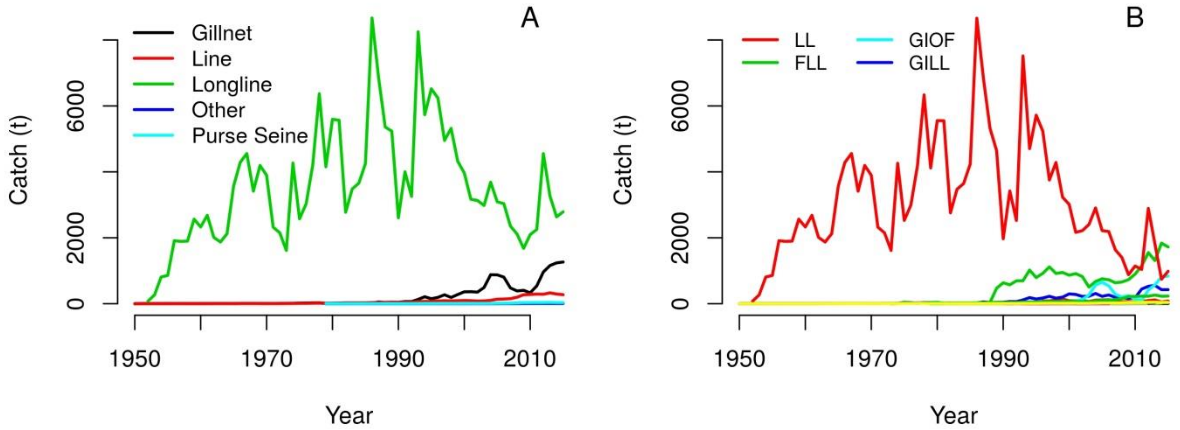

Figure 2 – Catches of striped marlin (Tetrapturus audax) split by majog gear group (A) and by secondary gear group (B). Main secondary gear groups showed in the panel B are: longline (LL), longline fresh (FLL), gillnet (GILL), and offshore gillnet (GIOF).

The complex catch time series leads to important questions. For example, the outstanding decrease of LL catches reflects sampling statistics problems, or collapse of the stock, or changes in fishing strategy and targets, or a decreasing trend of fishing effort? The increasing trend of of catches in the recent years reflect improvement of statistics, or recovery of the stock after the decrease of catches in 1990's and 2000's, or an increasing trend of fishing effort of FLL, GILL and GIOF fleets over areas or fractions of stock which were not explored much in the past? Clarification of these and other questions about catch time series are of major importance to select the assumptions concerning depletions of biomass, which are critical in SRA approach. Therefore the catch time series might be carefully evaluated by the working group during the meeting if the intention is to use the results of SRA to estimate the striped marlin stock status. However, as starting point, in this preliminary analysis I have carried out some sensitivity analysis concerning different assumptions of biomass depletions. The cases considered in this sensitive analysis were defined based on assumptions that the:

a) rule of the thumb used in the example of Martell and Froese (2012) is suitable for striped marlin of the Indian Ocean;

b) overall decreasing trend of catches in 1990's and 2000's (Figure 1), and the outstanding decreasing trend of catches of LL gear subgroup until the end of the time series (Figure 2 B – red line), reflect a collapse of stock. Further, the partial recovery of catches in the end of time series (Figure 1) was assumed to be not a consequence of the biomass recovery. Instead, the increase of catches in the recent years was assumed to be due an improvement of statistics or an increase of fishing effort of fleets which are operating in areas or over fractions of the stock which were not heavily explored before 2010. Under this pessimistic assumption the biomass in 2016 would be lower than the biomass at MSY (B_{MSY});

c) stock may have been strongly depleted until mid 1990's because the catches increased fast since 1950 (Figure 1). However, the catches decreased from mid 1990's until the end of 2000's, hence a partial recovery occurred in the recent years. Under this assumption the biomass in 2016 is more likely lower the B_{MSY}, but there is a possibility that the biomass is equal or slightly higher than the B_{MSY}.

The ratio between the catch at the end of the time series and the maximum catch is the criterion to select ranges of depletion of biomass under the assumption a). Catch times series available in the current stock assessment and in the 2013 stock assessment as well the ratios are in Figure 3. Notice that in the 2013 stock assessment the ratio between the final and the maximum catches were well below 0.5, hence a negative scenario would be selected for the depletion in the end of the time series. However, in the current stock assessment the available dataset showed an increasing of caches in the end of the time series, consequently, the ratio betweem the last and maximum catch is slightly higher than 0.5. Therefore, the range of depletion of biomass selected for 2016 was 0.3-0.7 (case A). This range indicates that the biomass of the stock may be or may be not lower than BMSY. Under the pessimistic assumption b) the biomass in 2016 was lower than B_{MSY}. The range of depletion assumed was 0.01-0.4 (case B). Finally, under the assumption c) the biomass in 2016 may be lower or slightly higher than BMSY. The range of depletion assumed for 2016 was 0.2-0.55 (case C).

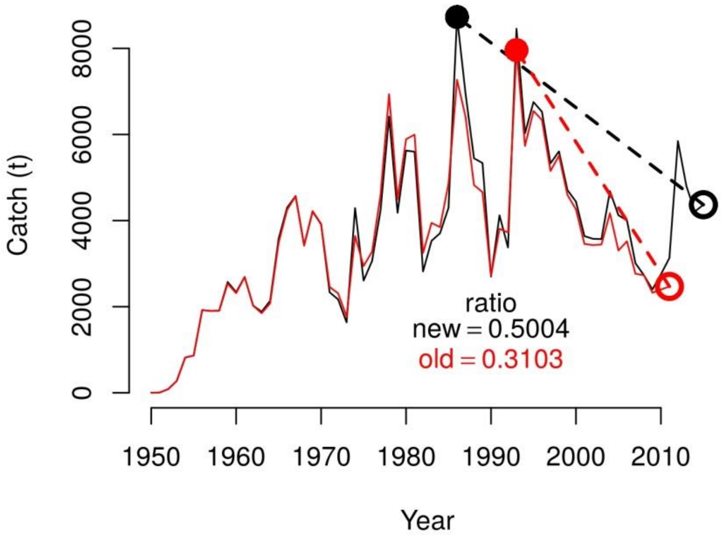

Figure 3 – Catch times series available for in this stock assessment (new – black line) and in the stock assessment held in 2013 (old – red line).

The time series starts in 1950 with low catches. Hence I assumed that biomass at the beginning of time series was close to the carrying capacity. The depletion ranges of biomass in 1950 were equal to 0.8-1.0 for all of the sensitivity runs.

Prior distribution of r and k

The computational procedure starts by randomly drawing *r*-*k* of the prior distributions. The prior distribution used for k was uniform $k \sim U(\max(catch), 20 \times \max(catch))$. 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. The prior distribution of r I have used in this analysis was based on biological knowledge and publications found for striped marlin (*T. audax*) and correlated species. Striped marlin is considered a low resilience species (www.fishbase.org), hence a prior bounded at 0.05 and 0.5 is an alternative (Martell and Froese, 2012; fishbase). These bounds for prior distribution of r were also adopted by Sharma (2013). However, Carruthers and McAllister (2011) have used demographic information and calculated a prior of r for white marlin (*Tetrapturs albidus*) which approximately symmetric with median equal to 0.174 with 2.5% and 97.5% quantiles equal to 0.056 and 0.21 respectively. Atlantic white marlin and striped marlin of Indian Ocean related, and I have also considered this information when selecting a prior distribution of r.

Values of r can also be calculated based on estimations of natural mortality (Zhou and Sharma, 2013) and the scale linking (ω) between fishing mortality at MSY (F_{MSY}) and natural mortality (M) as $r = 2\omega M$. Zhou et al. (2012) punctual estimation of ω for teleosts was 0.87. The methods to estimate M were revised by Then et al (2014), which recommend the use of equation of Pauly (1980) without the temperature term, whenever there are not reliable estimations of maximum age (T_{max}). If T_{max} is available the method of Hoenig (1983) is recommended. In the www.fishbase.org site there is the estimation of T_{max} = 9 years, which was extracted from Paul (1992). If we use this value as input for the Hoenig (1983) equation the solution would be $M = 0.65 year^{-1}$, which is relatively high, and consequently the estimation of intrinsic growth rate is $r = 2 \times 0.87 \times 0.65 = 1.14$ which is high for a "low resilience" species. Hence I have assumed that the available estimation of T_{max} is not useful for the calculation of r. The alternative are the use of Pauly (1980) equation without temperature, which requires estimations of growth parameters (L_{∞} and k) as input. Available estimations I have extracted from www.fishbase.org and other documents are in Table 1. Hoenig (1983) method was used to estimate M based on the estimations of growth available in Table 1. After that estimations of r were calculated based on the Zhou and Sharma (2013) proposition ($r = 2\omega M$).

Table 1: Parameters of the growth curves (L_{∞}, k, t_0) extracted from www.fishbase.org.

L_{∞}	k	t_0	Sex	Locality
221	0.23			Mexico
240	0.81		F	Hawaii
243.8	0.68	-0.69	M	
251	0.73	-0.14	F	
252	0.748		M	South Africa
256.5	0.6	-0.7	F	
264	0.44	-1.07		
275	0.264			Japan
277	0.417	-0.52	M	Hawaii
301	0.22	-0.04		New Zealand
301	0.22			New Zealand
301	0.22	-0.04		New Zealand
312	0.201			Kenya
320	0.61		F	South Africa

Density distributions of r based on "low resilience" (LR) assumption, on prior calculated for white marlin in the Atlantic (Carruthers and McAllister, 2011) (CM), and on growth and M parameters estimations (GMR) are showed in Figure 3. The GMR density which was calculated based on biological information give weight to high values of r, which are not expected for low resilience species. Therefore I have assumed that GMR density is suspect and gave less weight to it when building the gamma prior for r used in this working paper (black thick line – Figure 3), which is a open-minded/vague prior.

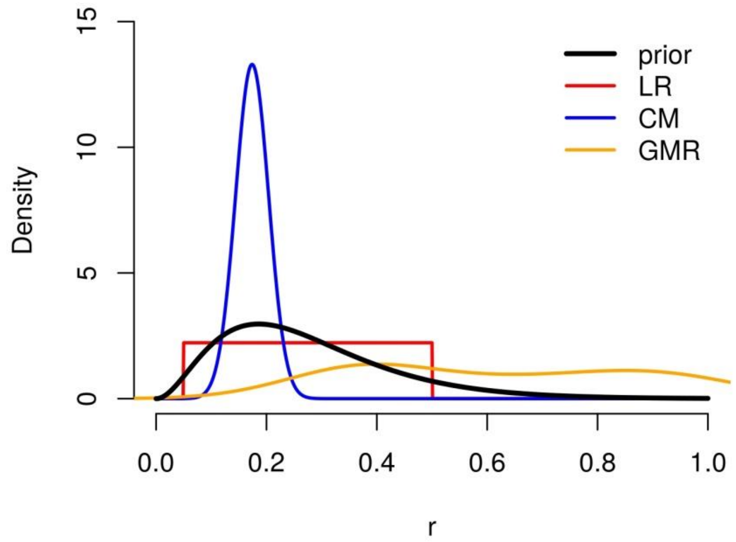

Figure 3 – Densities distributions of r based on “low resilience” assumption (LR), on prior calculated for white marlin in the Atlantic (Carruthers and McAllister, 2011) (CM), and on growth and M parameters estimations (GMR). The prior of r was calculated as a compromise among the three densities.

Stock Reduction Analysis

In this SRA the Schafer (1954) production model was used. In each of the sensitivity cases considered 10,000 r-k values were simulated from the prior distributions the ones that meet the range of depletion levels were retained. Nevertheless, 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). While the prior distribution of *r* was assumed to represent the best available information on the parameter, the upper limit for *k* was chosen subjective. Therefore Martell and Froese (2012) suggest to update the upper limit of *k* after a first run. The new upper limit of *k* 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 (black line – Figure 3) 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

In the case A, after the first 10,000 runs 890 r-k values meet the depletion level range in 2016 (0.3-0.7). The updated prior was calculated as a compromise between the initial prior and the r values retained after the first run. These three densities are shown in Figure 4. In general the retained values of r after the first run were lower than 0.2, hence the updated prior gives more weight to low values of r than the input prior.

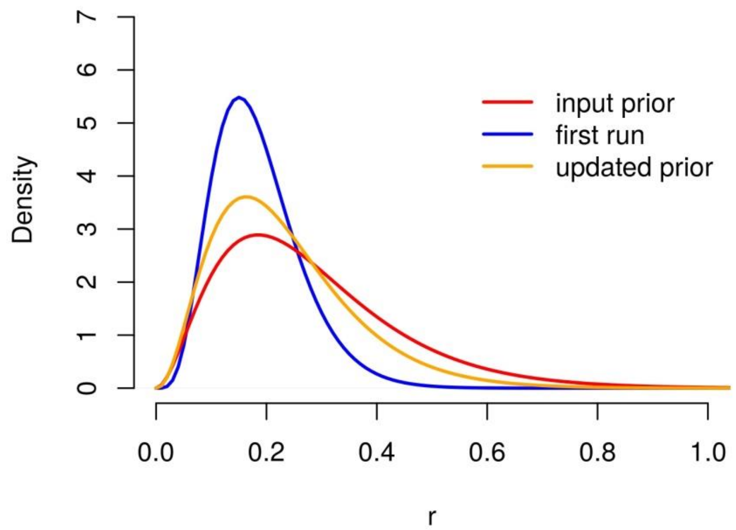

Figure 4 – Initial prior of r (input), the density calculated after the firs run and the updated prior.

Results of SRA are 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 were higher than MSY in the end of 1970, mid of 1980's, during the 1990's, and in recent year. Correlation between r and k estimations is high (top mid and right panels). The r-k estimations are in left side of the space of parameters (top mid panel, which give weight to relatively low values of r and high values of 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. High values of r usually do not meets the depletion ranges, because fluctuations of biomass trajectories 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. The upper limit of the prior of k equal 20 times maximum catch in the first run, and the subsequent approach to update the prior resulted in a final distribution of k bounded at the upper limit (mid bottom panel – Figure 5). The distribution of MSY was also bounded at the upper limit. The geometric mean of MSY is 4,326 t, while the empirical interval of confidence (95%) ranged from 3,251 to 5,050 tons.

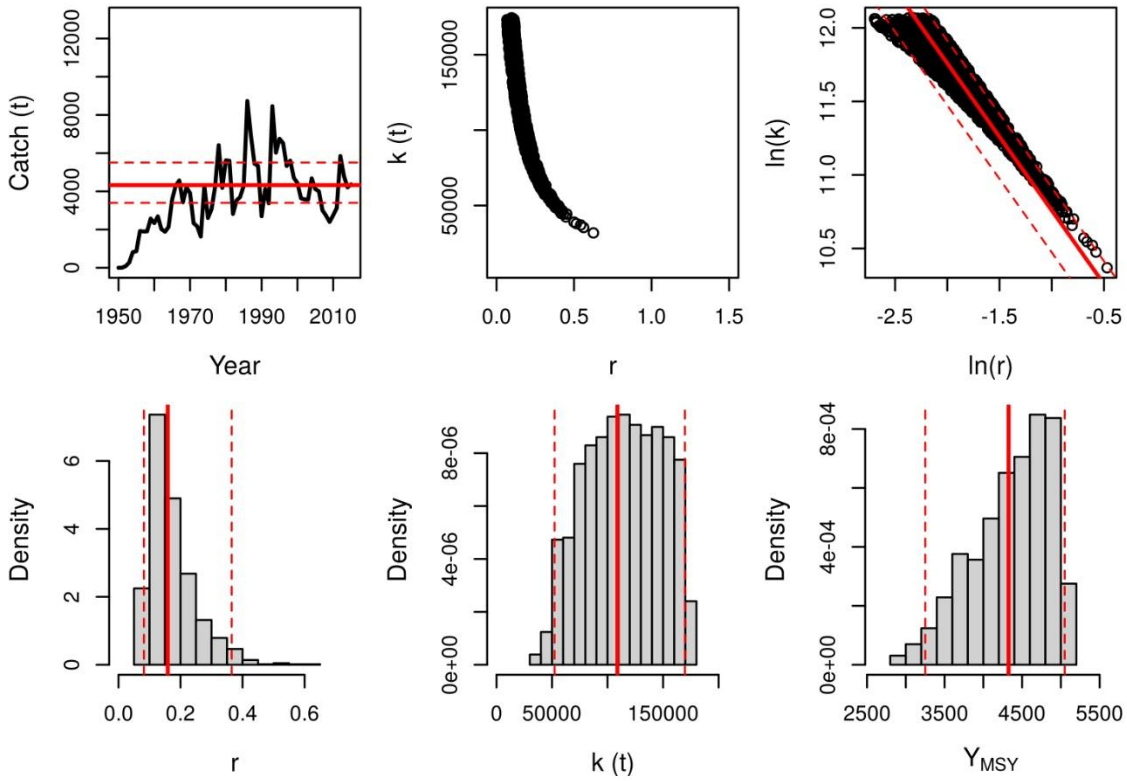

Figure 5 – Estimates of catch of striped marlin (*Tetrapturus audax*) as reported in IOTC database, and estimates of r, k, and MSY calculated using catch only stock reduction analysis.

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 1990. Biomass estimates were very close to carrying capacity in the beginning of the time series because the catches were low in 1950's. Fishing mortality ratio increased continuously since the beginning of the fishery and probably surpassed 1 for the first time in 1986. There were oscillations but F/F_{MSY} was likely higher than 1 in 1990's, but the fishing mortality decreased in 2000's. In the end of the time series the F/F_{MSY} increased and was close to one after 2011. The B/B_{MSY} ratio decreased from 1950 until 2001, when the geometric mean of the distribution was close to one. Biomass was close to B_{MSY} until the end of 2000's, but the B/B_{MSY} ratio slightly from 2008 to 2012.

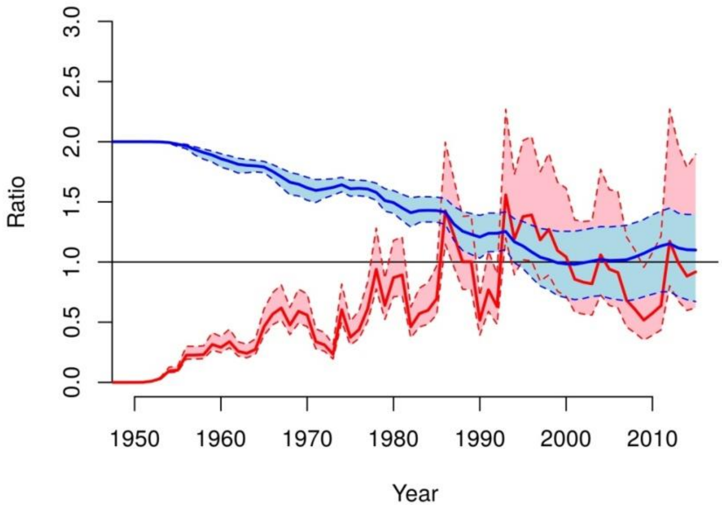

Figure 6 – Trajectories of ratio between fishing mortality and fishing mortality at MSY (F/FMSY) (bluish colors) and between biomass and biomass at MSY (B/BMSY) (reddish color). Solid lines stand for the geometrical means, while dashed lines stand for the bounds of 95% empirical confidence intervals.

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 from green (not overfished) to orange region (subject to overfishing) until the end of 1990's. However, the modes were located back in the green area in the recent years. 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}. Because of the skewness of the distribution the geometrical mean of B/BMSY was close to one from 1998 to 2007 (Figure 6), but the mode was not (Figure 7). Also, because of the skewness the probability that joint values of F/F_{MSY}-B/B_{MSY} were in red zone (overfished) in 2015 was close to 0.3 (30%) (Figure 8), though the kernel (mode) of the joint distribution is clearly in the green zone (Figure 7).

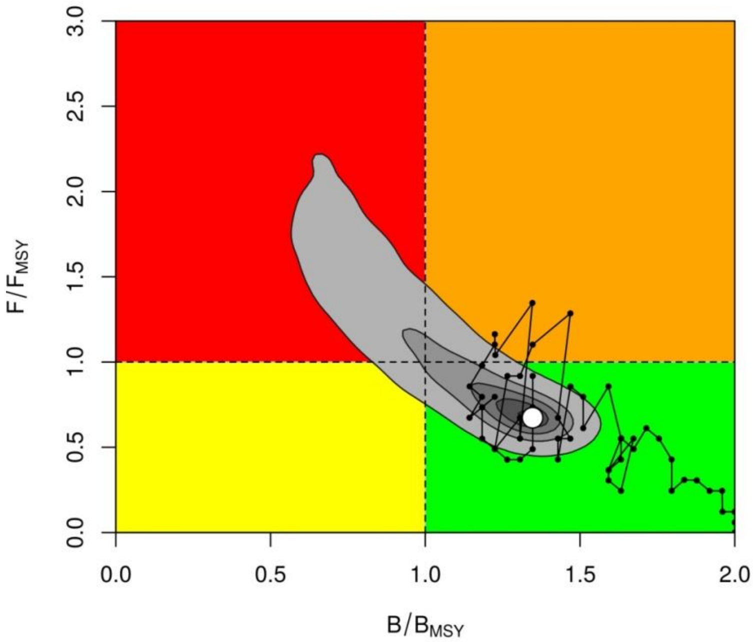

Figure 7 – Kobe plot as calculated based on the analysis of estimates of catch available in the IOTC dataset.

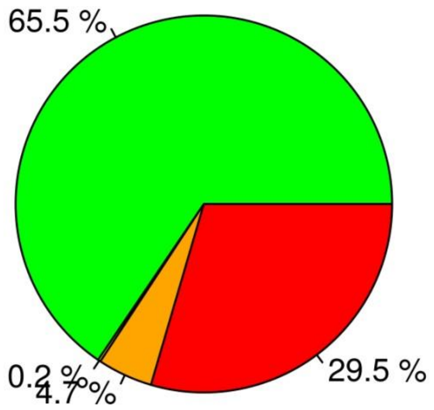

Figure 8 – Probabilities that joint values of ratios F/F_{MSY}-B/B_{MSY} were in green, orange and red zones of the kobe plot in 2015.

The average catch of the last three years to show up in the available time series (2013-2015) is 4,460.19 t. Hence the nine TACs used in predictive analysis corresponding to 60% to 140% of the average catch range from close to 2,676 t to 6,244 t. Joint distribution of the ratios in the predictive calculations for 2016 to 2025 time span were strongly skewed just like in 2015 (Figure 7), hence medians of predictions are showed instead of the mean (Figure 9). Results indicate that the medians of B/B_{MSY} will be higher than one in the end of the 10 years of projections unless the TACs are equal or higher than 5,350 t which is 120% 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 below than one unless the TACs is greater than 110% of the average catch of recent years.

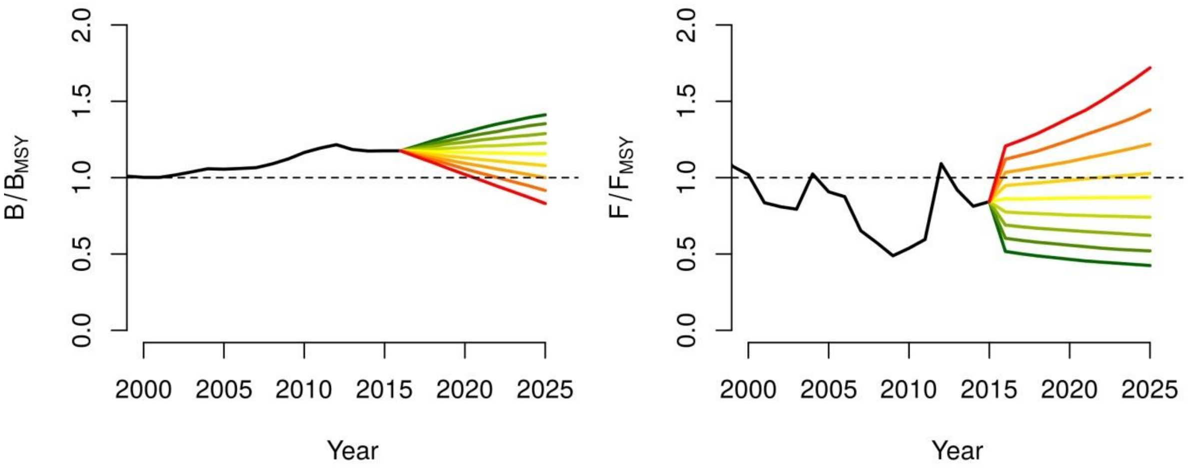

Figure 9 – Predictions of medians B/BMSY and F/FMSY ratios until 2025. Black lines stand for the calculations based on the time span of the available data, while color lines stand for predictions based on nine Total Allowed Catches (TACs). Colors fading from green to yellow to red stand for TACs equal 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 remains close to 0.3 across the years until 2025. If TAC is higher than the recent catches the probability of overfishing increases until 2025. If the TAC is 40% higher than recent catches the probability of overfishing is higher than 0.7 in 2025. In opposition if the TAC is lower than the average of recent catches the probability of overfishing is low.

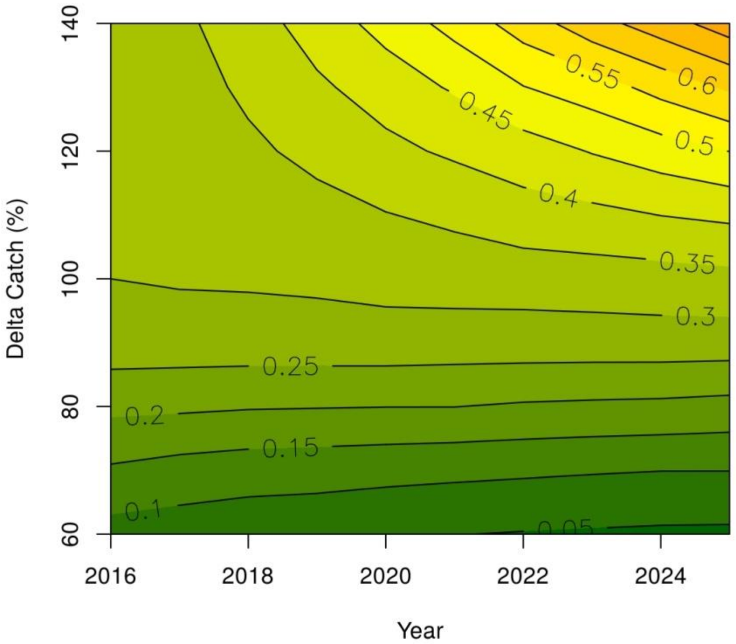

Figure 10 – Probability of overfishing striped marlin in the 2016-2025 time span if the Total Allowed Catch is between 60% and 140% of the average catches of recent years (2013-2015).

Comparisons of all the cases

Detailed results of the other two sensitivity runs (cases B and C) are shown in Appendix to not clutter. However, follow below comparisons of estimations of MSY and of the joint distribution of B/B_{MSY} and F/F_{MSY} ratios for all the three sensitivities runs. Empirical density distributions of MSY calculated for the cases A, B and C are in Figure 11 A. Notice case A calculations give more weight to high values of MSY with mode close to 5,000 t, while case B calculations were pessimistic in the sense the estimates of MSY were low, with mode close to 3,000 t. Case C estimations give weight to intermediate values with mode close to 4,000 t. Therefore the scales of estimations of MSY are quite different depending on the assumptions concerning the depletion range of biomass in 2016.

Ratios between average of catches of recent years and estimations of MSY are in Figure 11 B. Notice that empirical density distributions of the ratios calculated in cases B and C indicate that the recent catches were likely above the MSY. Empirical probabilities that $Y/Y_{MSY} > 1$ were high (>0.9) for both, cases B and C. In opposition, the probability that $Y/Y_{MSY} > 1$ is just 0.5 if we rely in case A, which is not that pessimistic as in cases B and C.

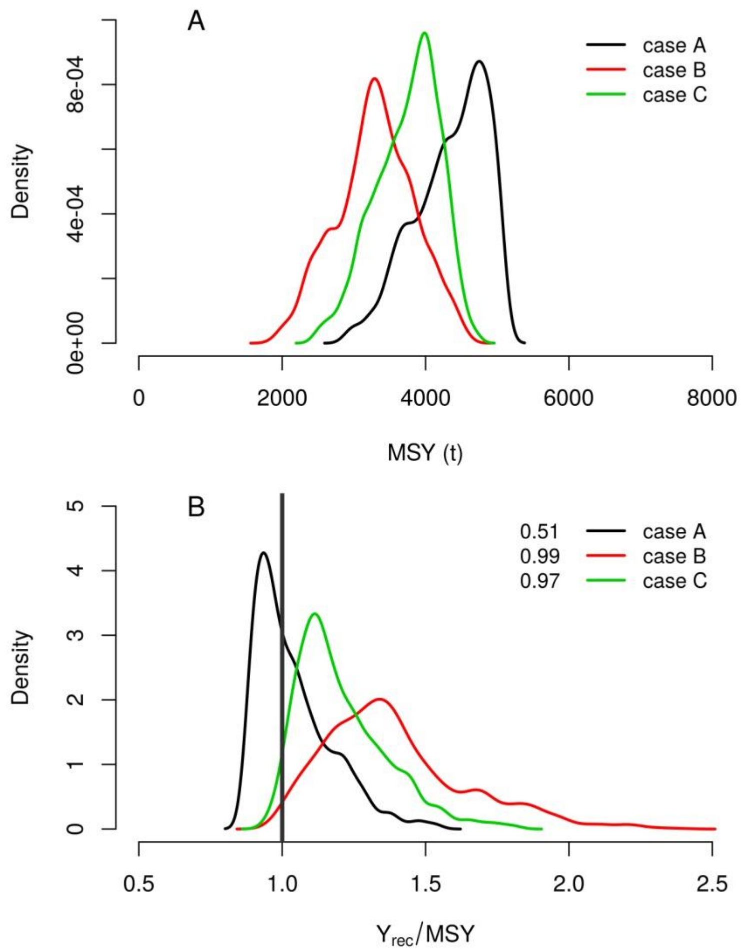

Figure 11 – Empirical density distributions of estimates of MSY of striped marlin (A) and of ratios between the average catch of recent years (2013-2015) and MSY (B) calculated based on three assumptions concerning the depletion of biomass in 2016: Case A – depletion range of 0.3-0.7; Case B – depletion range of 0.01-0.40; and Case C – depletion range of 0.20-0.55.

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 corners of the elliptical polygons. Contour lines and modal values calculated based on the different assumptions concerning depletion of biomass were quite different, which was a expected result. Calculations based on cases A, B and C are conflictive and diagnostic of the status of the stock strongly depends on the case. Results of case A (depletion 03-0.7) were optimistic in the sense the core of the joint distributions of ratios F/F_{MSY} and B/B_{MSY} are likely in the green zone (not overfished). In opposition, results of case B (depletion 0.01-0.40) were pessimistic as it indicates that the striped marlin was overfished in 2015.

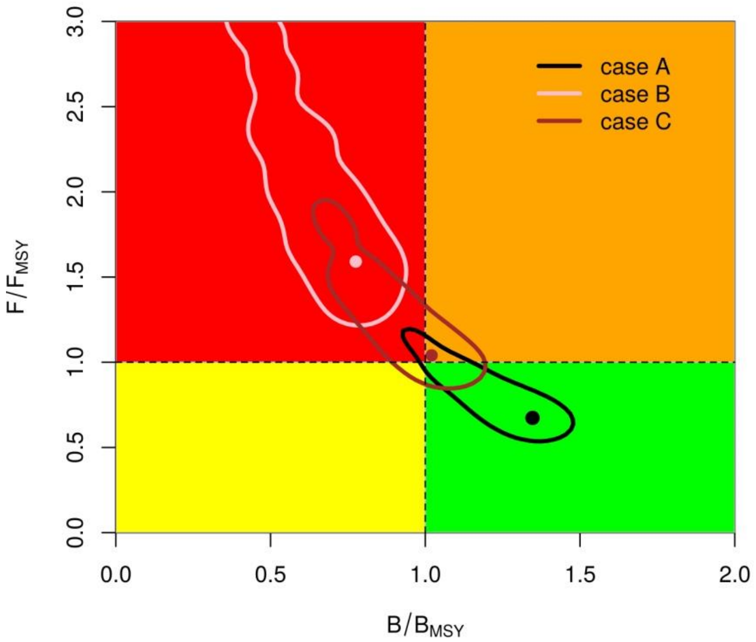

Figure 12 – Contour lines 0.5 of the maximum densities and modes of the joint distributions of B/B_{MSY} and F/F_{MSY} calculated for 2015 based on three different assumptions concerning the depletion of biomass in 2016: Case A – depletion range of 0.3-0.7; Case B – depletion range of 0.01-0.40; and Case C – depletion range of 0.20-0.55.

REMARKS

The conflictive results of case A, B and C stress the importance of the assumption concerning the depletion of biomass in the SRA. Oscillations of catches of striped marlin are high with peaks and plunges. This pattern makes even more difficult to select the depletion ranges to use in the analyses. The assumptions here in this preliminary analyses might carefully discussed by the working group if the intention is to use SRA to assess the status of the stock.

APPENDIX

Case B – depletion range 0.01-0.40

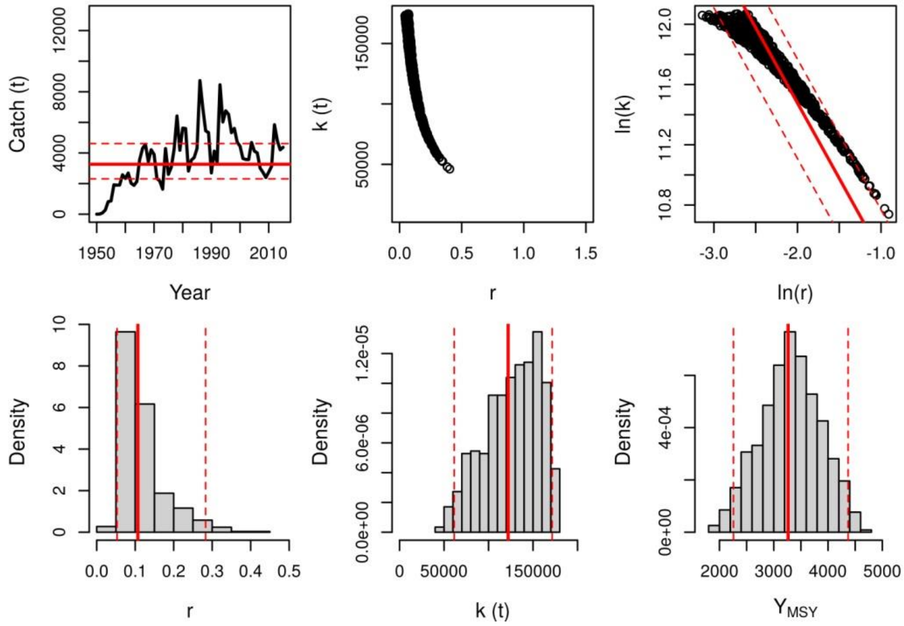

Figure A1 – Estimates of catch of striped marlin (*Tetrapturus audax*) as reported in IOTC database, and estimates of r, k, and MSY calculated using catch only stock reduction analysis.

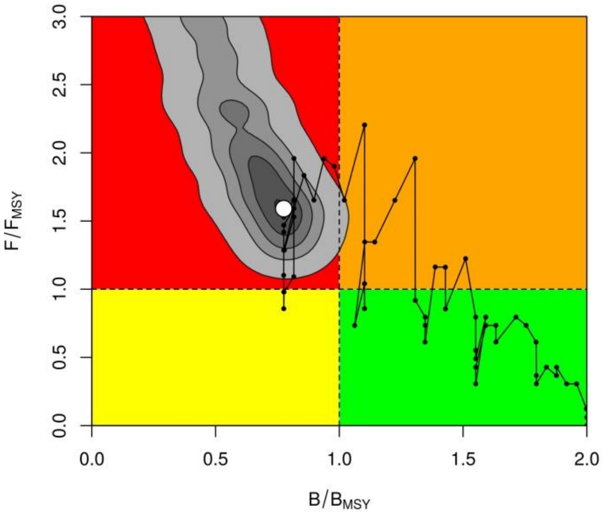

Figure A2 – Kobe plot as calculated based on the analysis of estimates of catch available in the IOTC dataset.

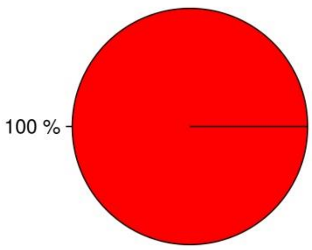

Figure A3 – Probabilities that joint values of ratios F/F_{MSY}-B/B_{MSY} were in green, orange and red zones of the kobe plot in 2015.

Case C – depletion range 0.01-0.40

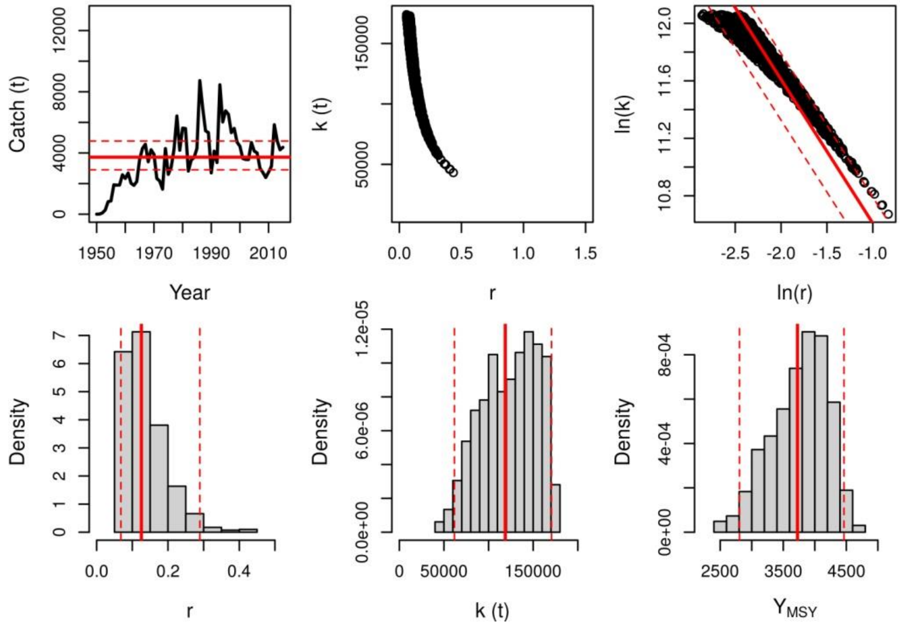

Figure A4 – Estimates of catch of striped marlin (*Tetrapturus audax*) as reported in IOTC database, and estimates of r, k, and MSY calculated using catch only stock reduction analysis.

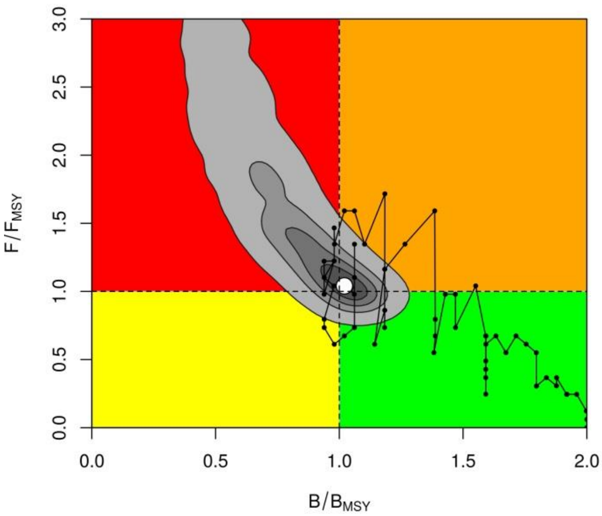

Figure A5 – Kobe plot as calculated based on the analysis of estimates of catch available in the EUPOA dataset.

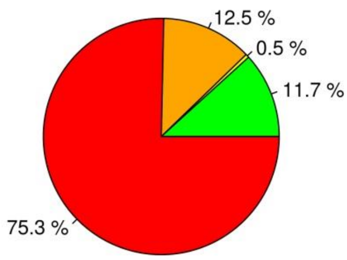

Figure A6 – Probabilities that joint values of ratios F/F_{MSY}-B/B_{MSY} were in green, orange and red zones of the kobe plot in 2015.

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