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Assessment of Indian Ocean bigeye (*Thunnus obesus*) using a biomass dynamic model

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Abstract

In the 17th session of the Indian Ocean Tuna Commission's (IOTC) Working Party on Tropical Tunas (WPTT), the stock status of bigeye was based on the 2013 stock assessment, which estimated that the stock was in the green area of the Kobe diagram (i.e. not overfished and overfishing was not occurring). On its 20th session (S20), the IOTC Commission requested a stock assessment of this stock. In 2013, the stock status was provided using Stock Synthesis (SS3), an integrated age structured statistical model, and in 2016 it is expected to be assessed again by SS3. In this paper we present a stock assessment for Indian Ocean bigeye using a biomass dynamic model and two modelling scenarios that aim at supporting the work of the WPTT. Overall, using the new information made available by the Secretariat with the two scenarios, we estimate that the stock is not overfished and not undergoing overexploitation with a 61% of probability. However, some differences are found between logistic and skewed production functions. We present a full set of diagnostics for each run, including residuals, retrospective analyses, bootstrapped and jackknife estimates and likelihood profiles, in order to facilitate the selection of modelling choices. Such diagnostics can be applied to a wide variety of models. We also present the results of catch projections and their impact through Kobe 2 Strategy Matrices (K2SM). According to these, catches as high as 130 thousand tons (40% more than in 2015) would allow the stock being above its B_{MSY} with more than 50% probability in 2020 but not further in time. However, with catches of 120 thousand tons, the stock would be at $B>B_{MSY}$ with more than 50% of probability in 2030. If current catches of 92,736 tons are maintained, the probability of the stock being above B_{MSY} would be as high as 70% in 2030. Finally, we show the results of projections with alternative Harvest Control Rules through K2SM and catch matrices.

Introduction

In 2013, all the model runs (except two extremes) used to assess the stock status of Indian Ocean bigeye estimated that the stock was above B_{MSY} and all runs estimated the fishing mortality was below F_{MSY}. The IOTC Commission requested the SC and WPTT to conduct a new stock assessment of the status of the bigeye stock using all available information in 2016. The new information available for stock assessment is a reviewed series of catch statistics and six CPUE series made available by IOTC Secretariat. How this new information may change the estimation of the overview of bigeye using SS3 is yet to be assessed but here we present a stock assessment using all the updated information and a biomass production model (Kell, 2016), which has not been applied to IOTC stocks, but that has been used to assess tropical and temperate stocks in the International Commission for the Conservation of Atlantic Tunas (ICCAT).

As the complexity of models increases, diagnostics become more important to understand the robustness of estimates and how they propagate through to advice. Diagnostics also make the stock assessment process more transparent (Kell and Merino, 2015). In this paper we show a series of diagnostics that aim at facilitating the modelling choices required to conduct a stock assessment. In this case, we use the available information to fit two surplus production models (logistic and skewed) in alternative ways: The six CPUE series made available by the Secretariat are used in isolation and in combinations (regions, type and all combined). The results shown in this paper refer to fits using the six CPUE series together in both logistic and skewed models. However, all the individual fits are also prone to be analyzed in the WPTT if requested. The diagnostics shown here may suggest using one or other modelling set-up, but the overall results are shown averaging across the two options with the combined indices. This may be modified at request during the WPTT too.

In IOTC, management advice is provided through projections of constant catch and their impact is analyzed on the estimated future status of stocks through K2SM. Here, we follow a similar procedure with the K2SM averaged from the projections of the two modelling scenarios. In addition, the results of projections through a series of HCRs are shown through K2SM and catch matrices.

Material and Methods

Data

In prevision of the new stock assessment of bigeye, the IOTC Secretariat made available series of catch and CPUE. The catch statistics made available in 2016 show that the recent catch has decreased steadily since 2012 (~20%, Figure 1), which was the last year used for the 2013 stock assessment.

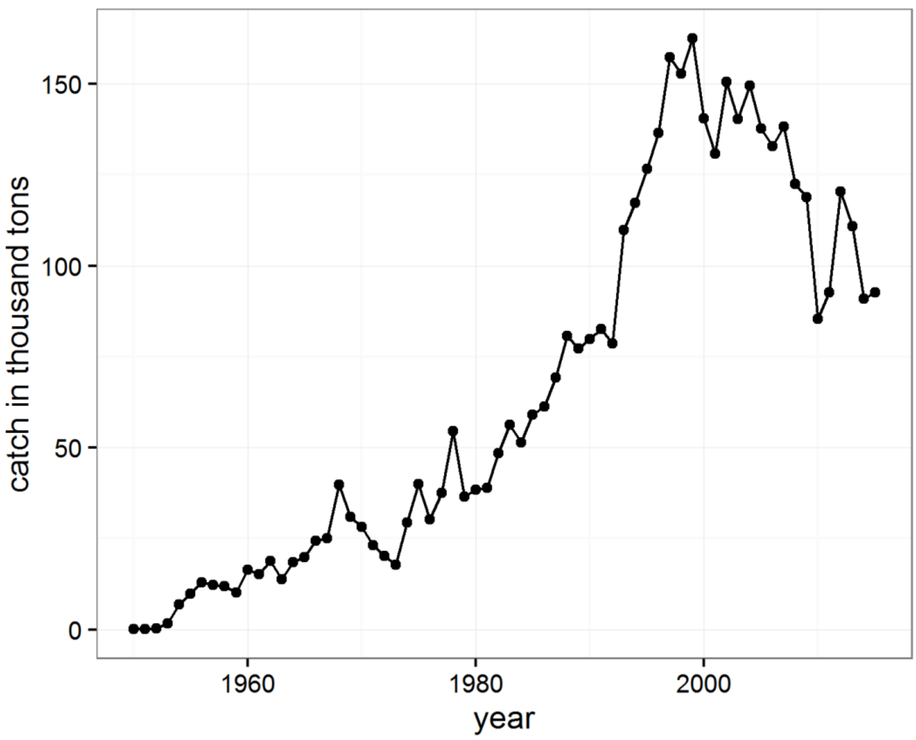


Figure 1. Catch series made available by IOTC Secretariat for the 2016 assessment of bigeye.

With regards to the CPUE series, six series were made available (Figure 2). The series correspond to regions 1 (*R1,* Western Indian Ocean) and 2 (*R2,* Eastern Indian Ocean), see Figure 1 from (Langley et al., 2013), with and without boat identification (*Boat* and *NoID)* and the years used for standardization (all years except 1979-2015 in the indices 7915).

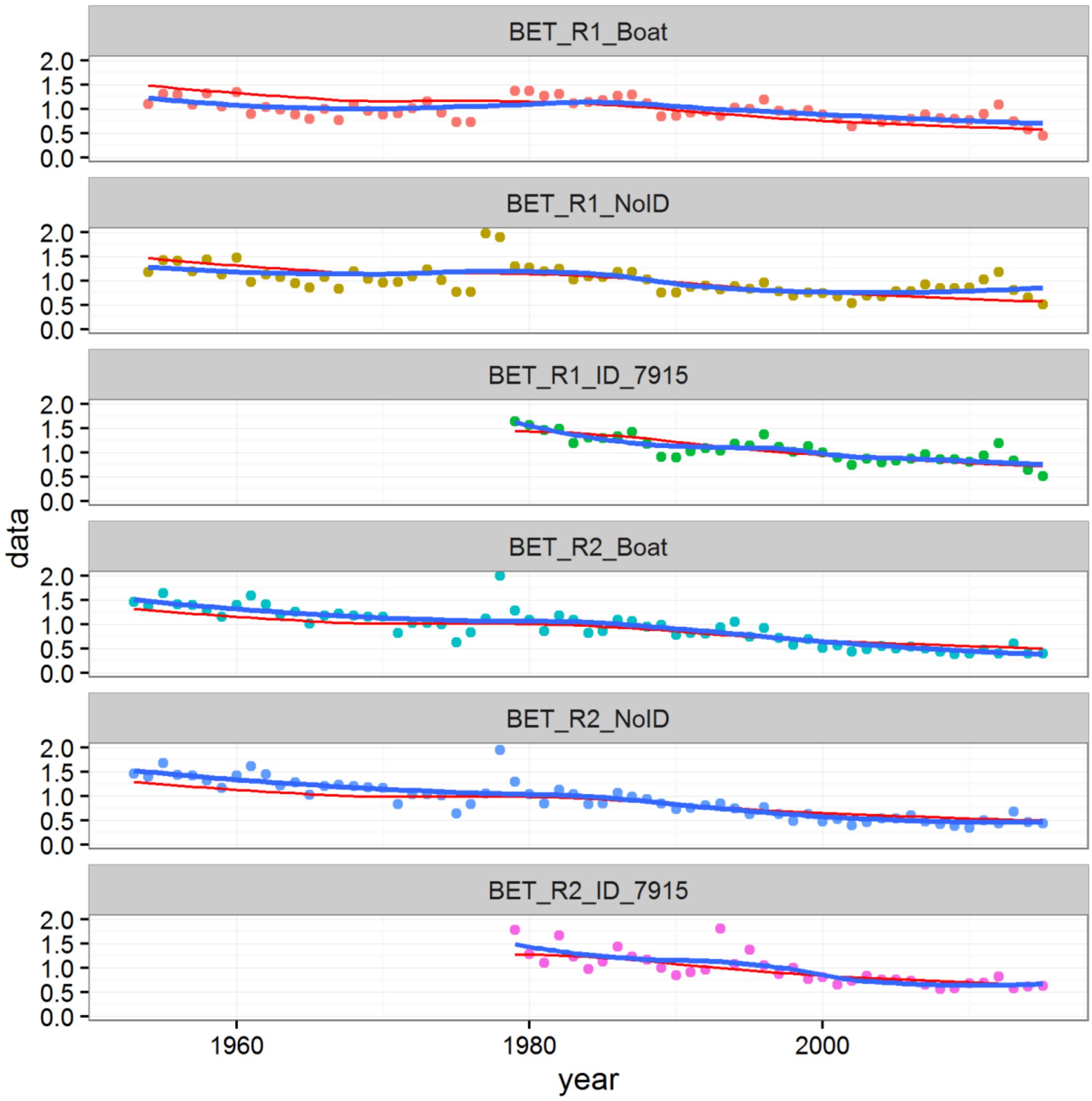


Figure 2. CPUE Series used in the biomass dynamic stock assessment as potential proxies for stock abundance; points are the standardised values, lines the prediction from a GAM fitted either to all the indices with year as a smooth term and index as a factor (red) and by index individually (blue).

The six series are notably correlated as shown in Figure 3:

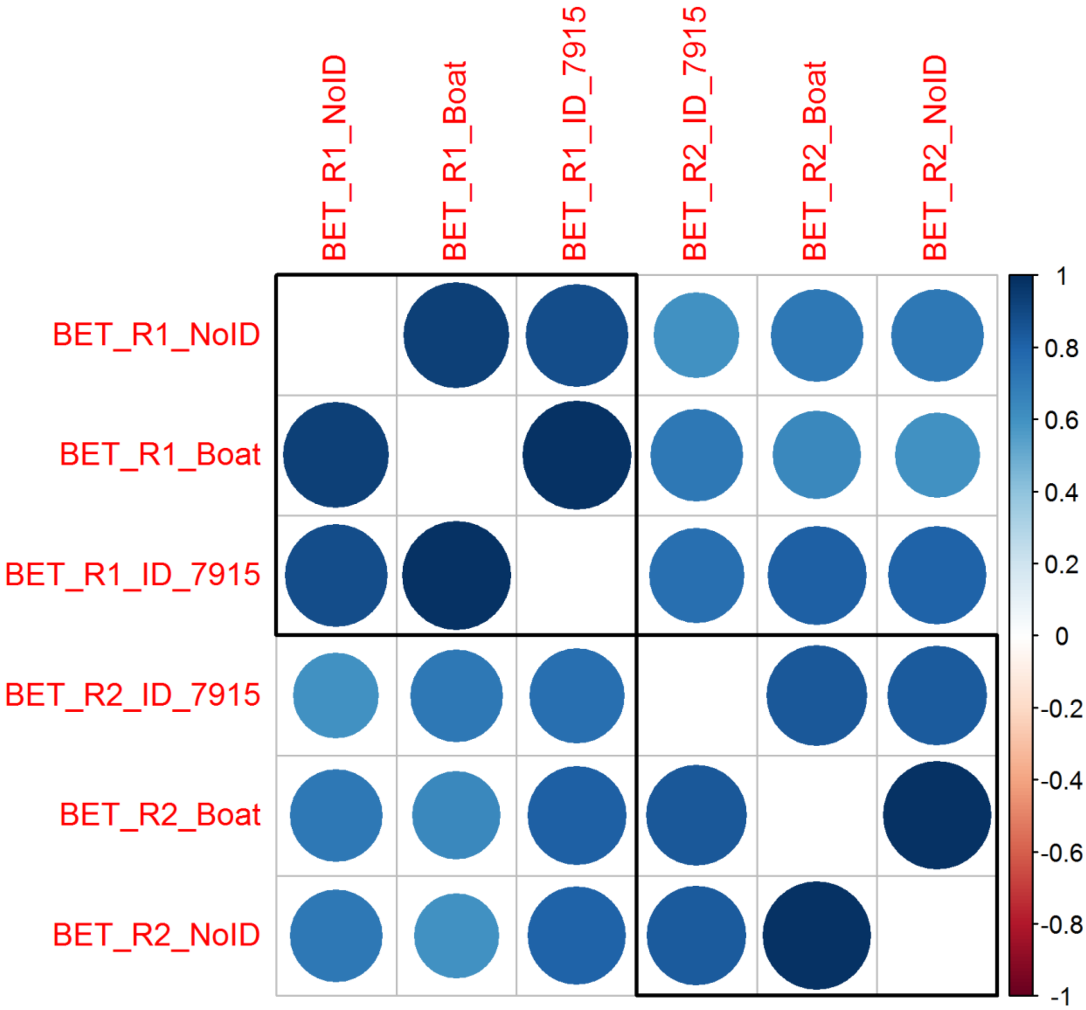


Figure 3. Correlation matrix for the indices; blue indicate positive and red negative correlations, the order of the índices.

Model

In a biomass dynamic model the stock next year (B_{t+1}) is the sum of the current biomass (B_t) less the catch (C_t) plus the surplus production (P_t) i.e.

$$B_{t+1} = B_t - C_t + P_t$$

There are various forms of production functions (P_t), e.g. the symmetric logistic (Hassel, 1975) or the generalized (Pella and Tomlinson, 1969) forms. The logistic production function is probably not appropriate for tuna species, due to high steepness (Maunder, 2003) and a Pell-Tomlinson form with $B_{MSY} < 0.5B_0$ is perhaps more realistic, e.g.

$$\frac{r}{p} \cdot \ B(1-(\frac{B}{K})^p)$$

where (*r*) is the intrinsic rate of increase, (*K*) the carry capacity (*p*) the shape of the surplus production function. If *p<1* then the curve is skewed to the left. The dynamics, i.e. productivity and reference points and the response of the stock to perturbations, are determined by *r* and the shape of the production function *p*. If *p* = 1 then MSY is found halfway between 0 and K, as *p* increases MSY shifts to the right. Here, we fitted the available data to two production functions: logistic and skewed to the left (*p*=0.001, Fox).

The software used to apply the models is *mpb* (Kell, 2016), an R Package for modelling Management Procedures, based on biomass dynamic stock assessment models and empirical harvest control rules. In order to facilitate the modelling choices required for the assessment of this stock, a series of diagnostics were also estimated (Kell and Merino, 2015) using *mpb.*

Results

The estimated parameters for the four main fits are shown in Table 1 (all runs' in the Appendix).

1950	MSY	Fmsy	Bmsy	r	k	p	B0
Log combined	107489.345	0.10422116	1031358.21	0.20844231	2062716.42	1	1
Fox combined	114870.505	0.13601553	844539.64	0.13615154	2294549.96	0.001	1

Table 1. Estimates of Reference Points and parameters from fits to the two models.

Patterns in the residuals from the fits to the CPUE, may indicate biased estimates of parameters, reference points and stock trends. Therefore when fitting a model, the residuals should be checked to identify violations of the assumptions. Initially, the residuals of a fit should be distributed normally and a similar way in the entire time series. The residuals estimated for the four runs are the following:

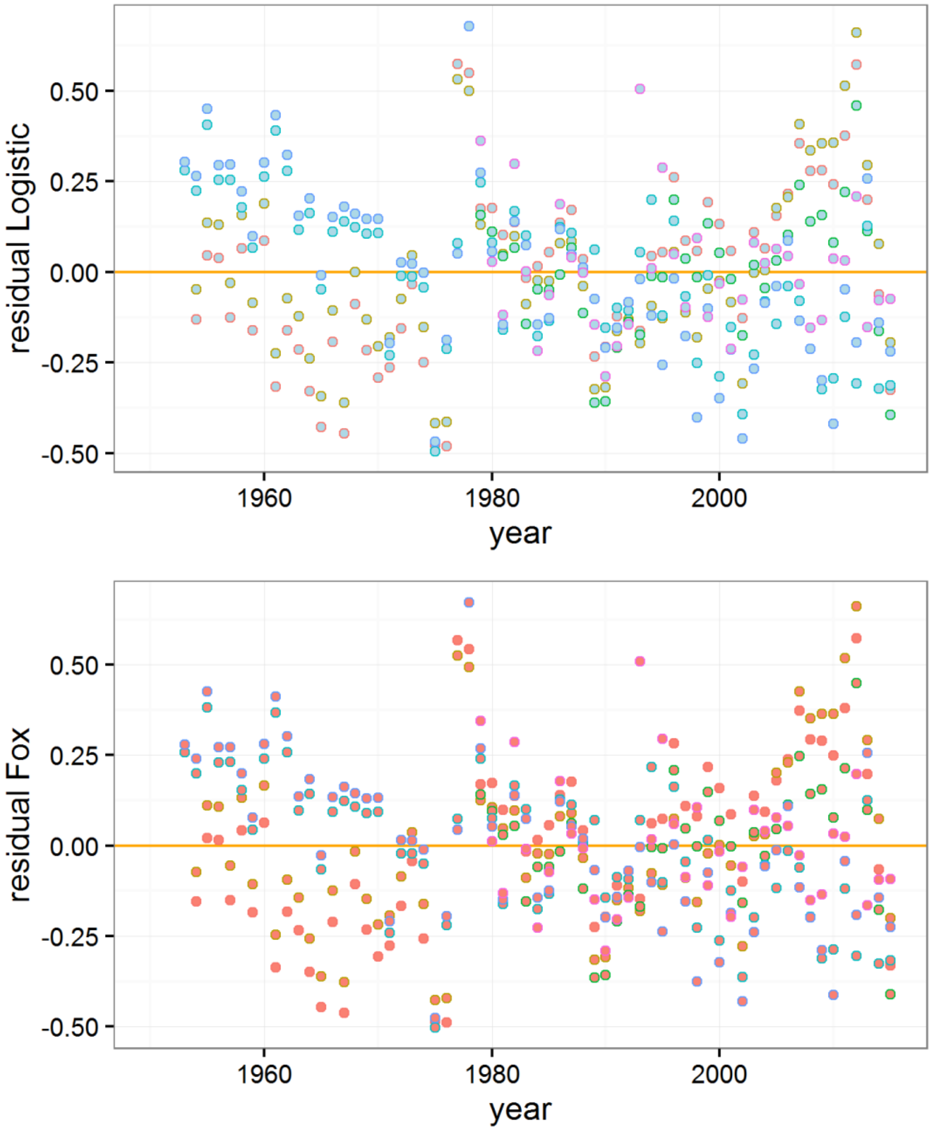


Figure 4. Residuals by year. The different colors in the outer of the points represent each of the CPUE series used; the color of the inner part of the points and in the y=0 line represent each of the four runs.

And the estimated differences between observed and predicted indices of abundance:

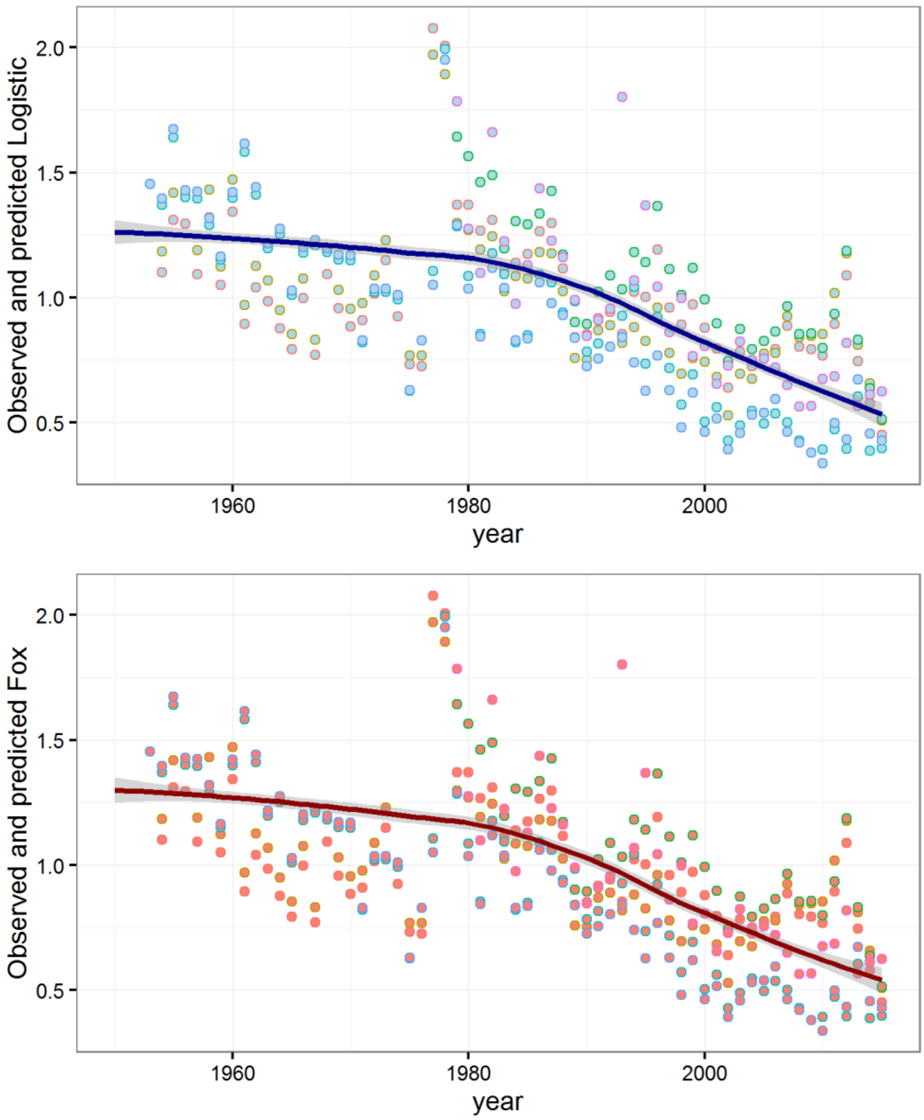


Figure 5. Model predicted and observed abundance. The color of the innter part of the poitns and in the lines represent each of the two runs. The outer colors of the points are the six indices used.

From Figures 4 and 5, it is noted that the residuals from both the logistic and Fox models are evenly distributed in all periods.

Simulation methods such as the jackknife or bootstrap identify problems with the data and model specifications; e.g. due to highly correlated or ill-defined parameters. Results of the jackknife analyses were made to check for influence of individual CPUE points are shown in Figure 6:

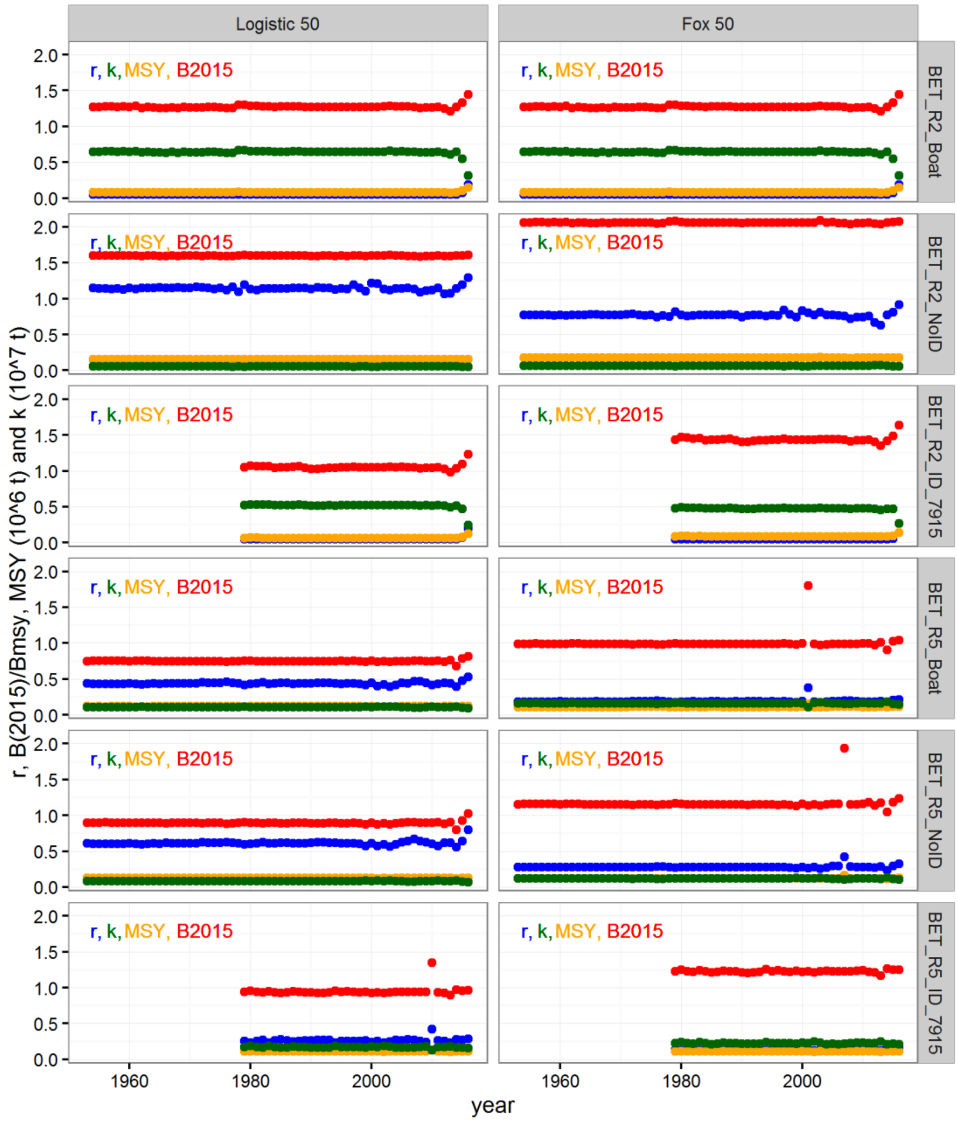


Figure 6. Jacknife analyses applied to the CPUE data series used.

The fits obtained were bootstrapped and probability distributions found for fishery indicators in 2015 and throughout the time series. In addition, differences between bootstrapped results and direct fits were checked, noting that fitted and bootstrapped median were very similar (Figure 7):

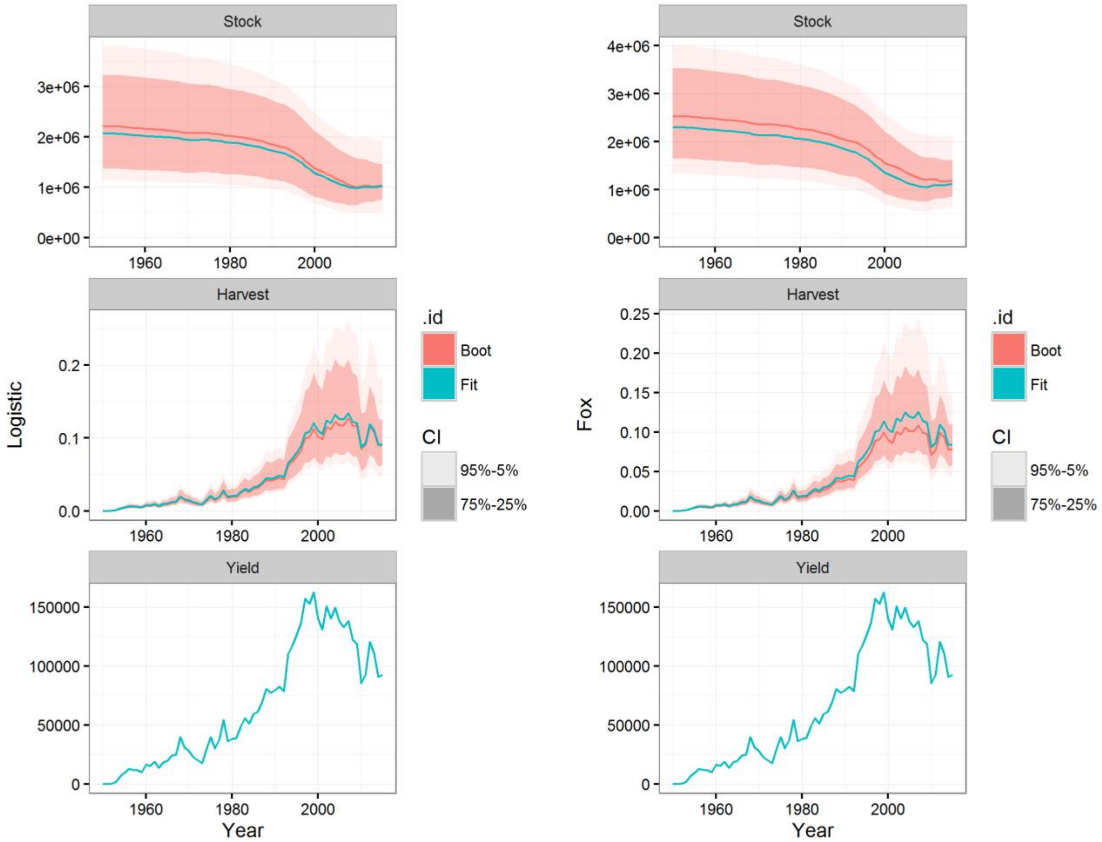


Figure 7. Bootstrapped and fitted results for the four main runs.

The median bootstrap trajectory and the 500 iterations for the stock status in 2015 were plotted in a Kobe diagram (Figure 8):

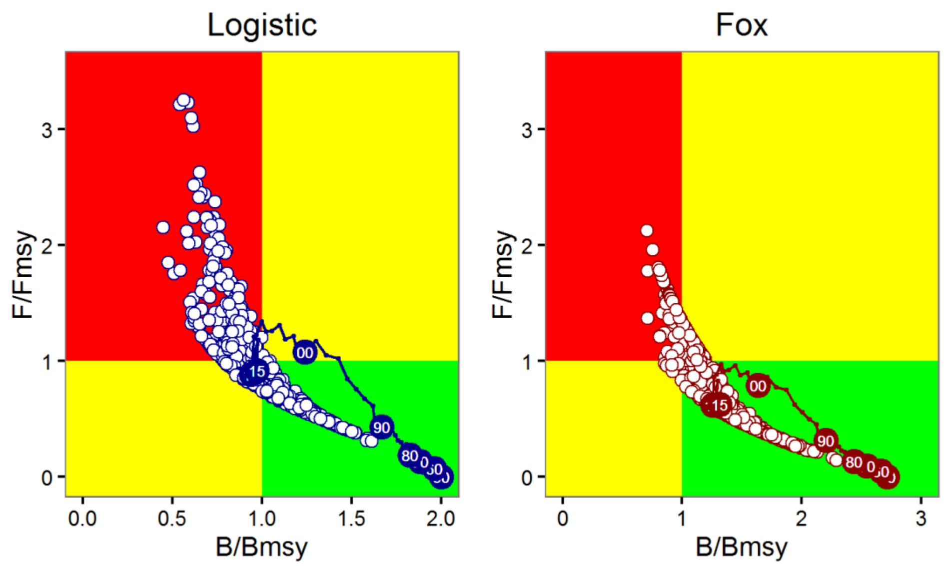


Figure 8. Relative biomass and Relative fishing mortality trajectories (median from bootstrap) and bootstrapped stock status for the two models run.

The probabilities from bootstrapped stock status are also displayed in a single Kobe diagram with densities for the estimated relative F and relative B in Figure 9. Note that current relative biomass is more precisely estimated with the logistic, but the fishing mortality with the Fox model:

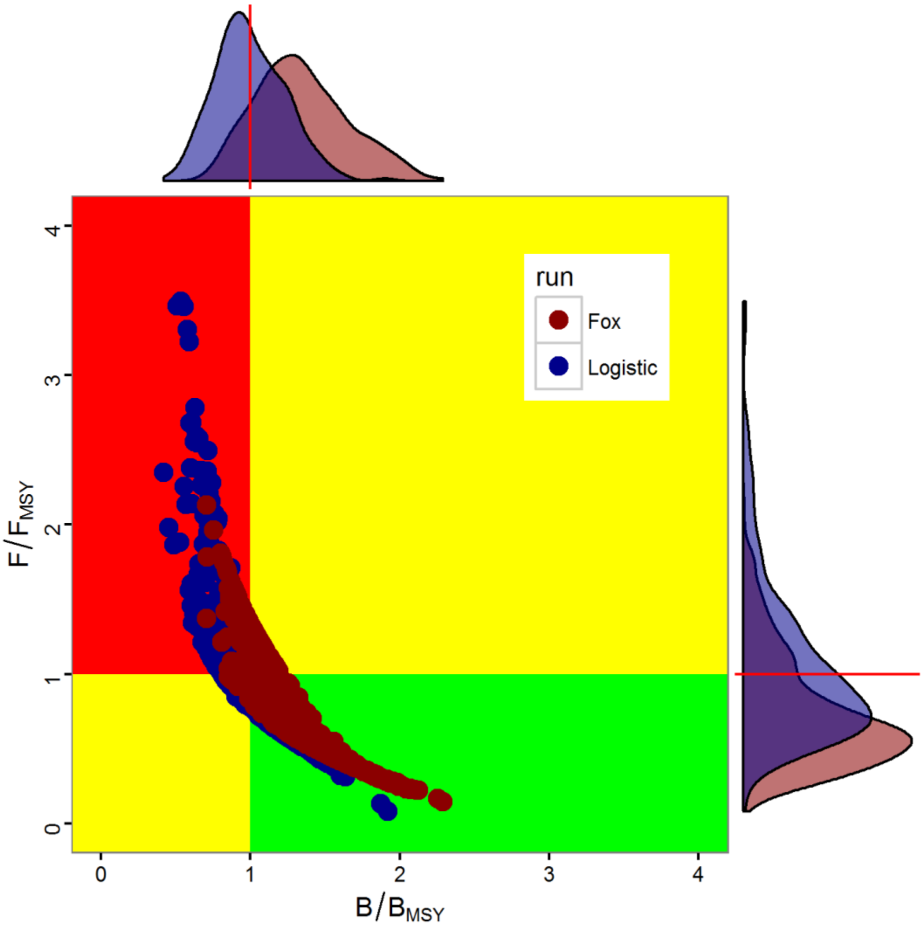
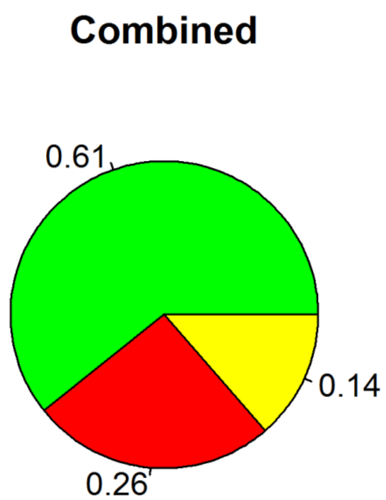


Figure 9. Relative stock status in 2015 with densities shown in the margins of the figure.

Overall current stock status and for each run is also shown with pie charts in Figure 10:



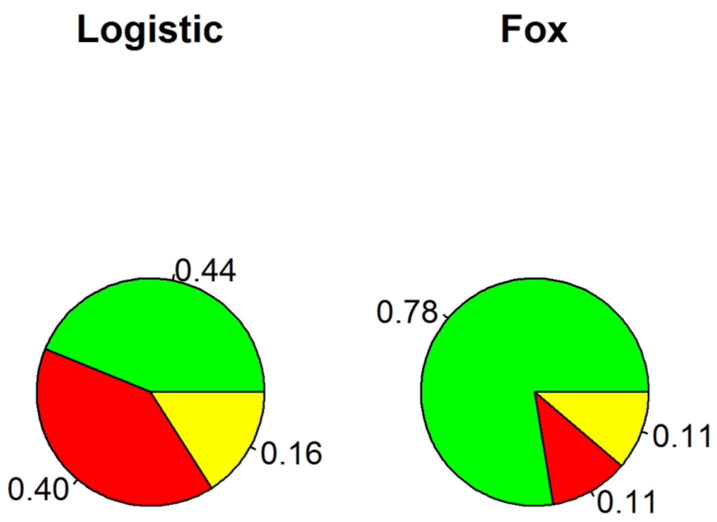


Figure 10. Pie charts with probabilities of the stock to be in 2015 in the different regions of the Kobe diagram.

The production functions and time series of yield vs stock biomass are presented in Figure 11. These show that catch has most of the time been above the surplus production of the stock for the corresponding stock abundance since the beginning of the fishery with the exception of the last few years, where it was nearby equilibrium values and below the estimated MSY for in the last three.

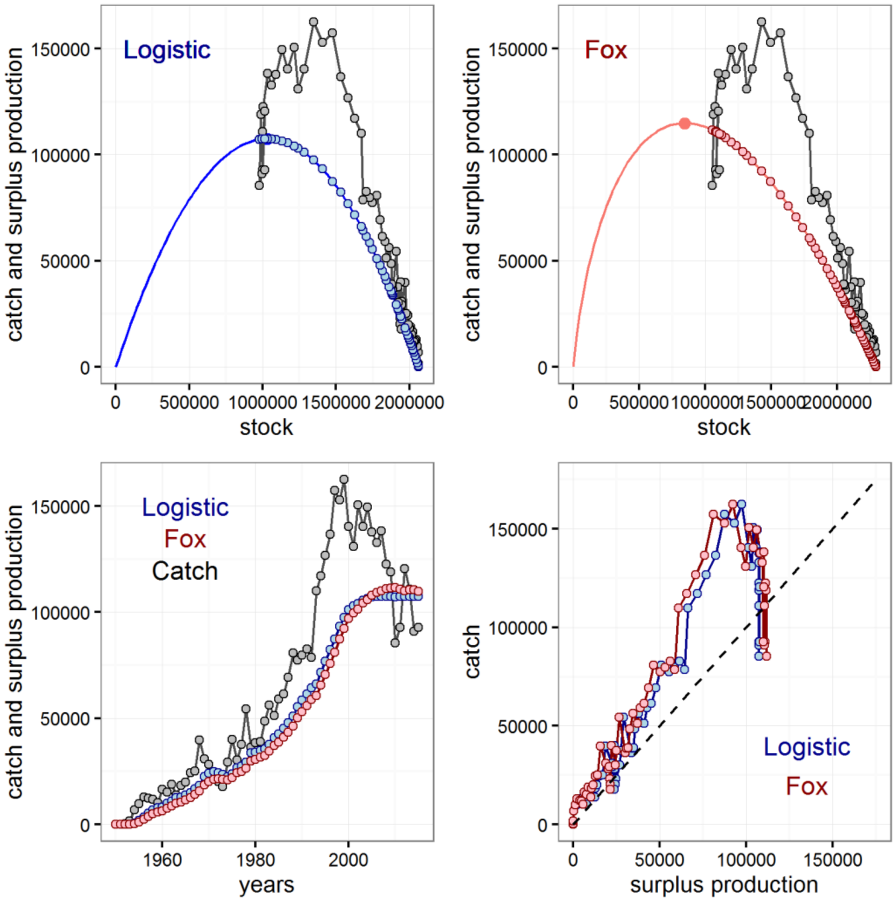


Figure 11. Production functions and time series of yield vs stock biomass.

Likelihood profiles are used to check that a solution has actually been found and to evaluate the information content of the data. It is not uncommon for indices to contain insufficient information to estimate the parameters of a stock assessment model. Indices may also be conflicting and fitting therefore involves weighting averages of contradictory trends. The profiles of the fits obtained in the four runs are shown in Figure 12:

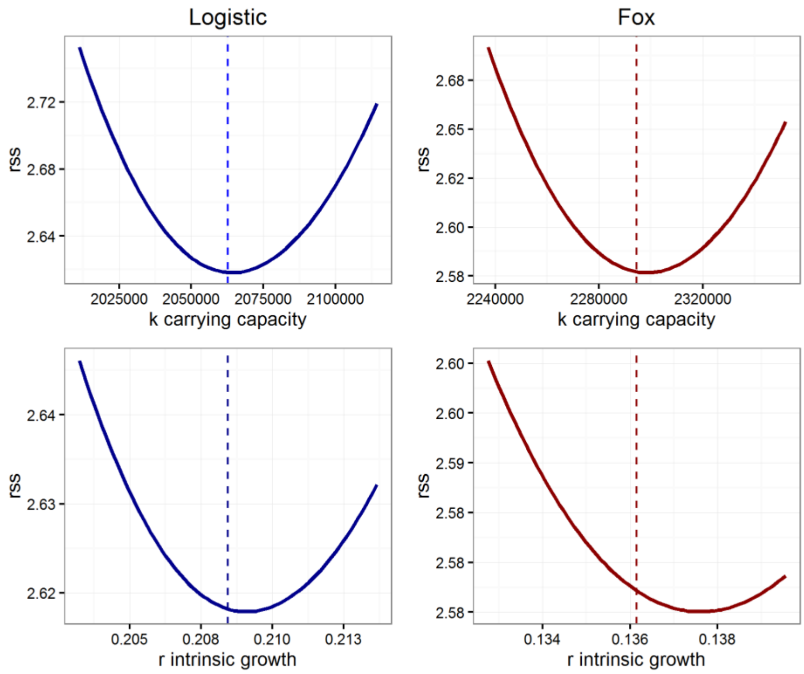


Figure 12. Likelihood profiles for r and K.

The *residual sum of squares (rss)* shown in Figure 12 corresponds to the *summed rss* for all indices in each run. From Figure 12 it is noted that the two models find a solution very close to the value of minimum error, i.e. both models are precise in their fits. In figure 13, we also check for the correlation between *r* and *K* from the bootstrapped results.

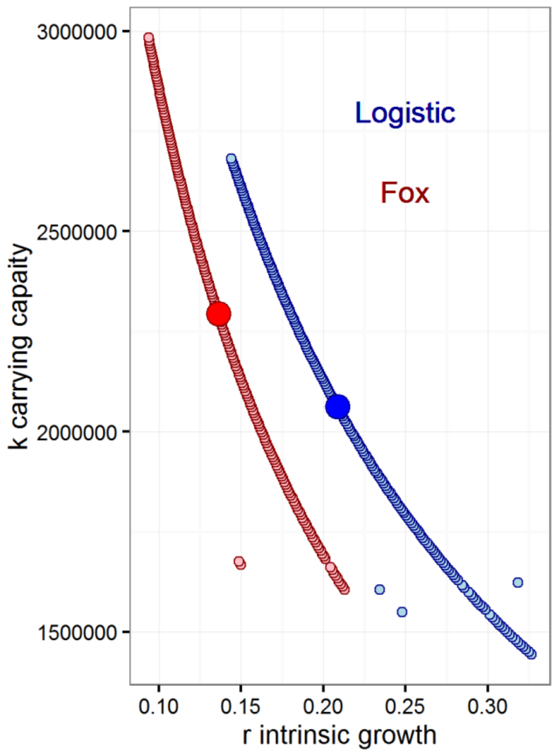


Figure 13. Correlation between the bootstrapped r and *K* for the two models.

Another diagnostic shown here is the retrospective analysis of the median trajectory of the bootstraps. We have fitted and bootstrapped the results obtained by fitting one year less from the available data and the results are shown in Figure 14:

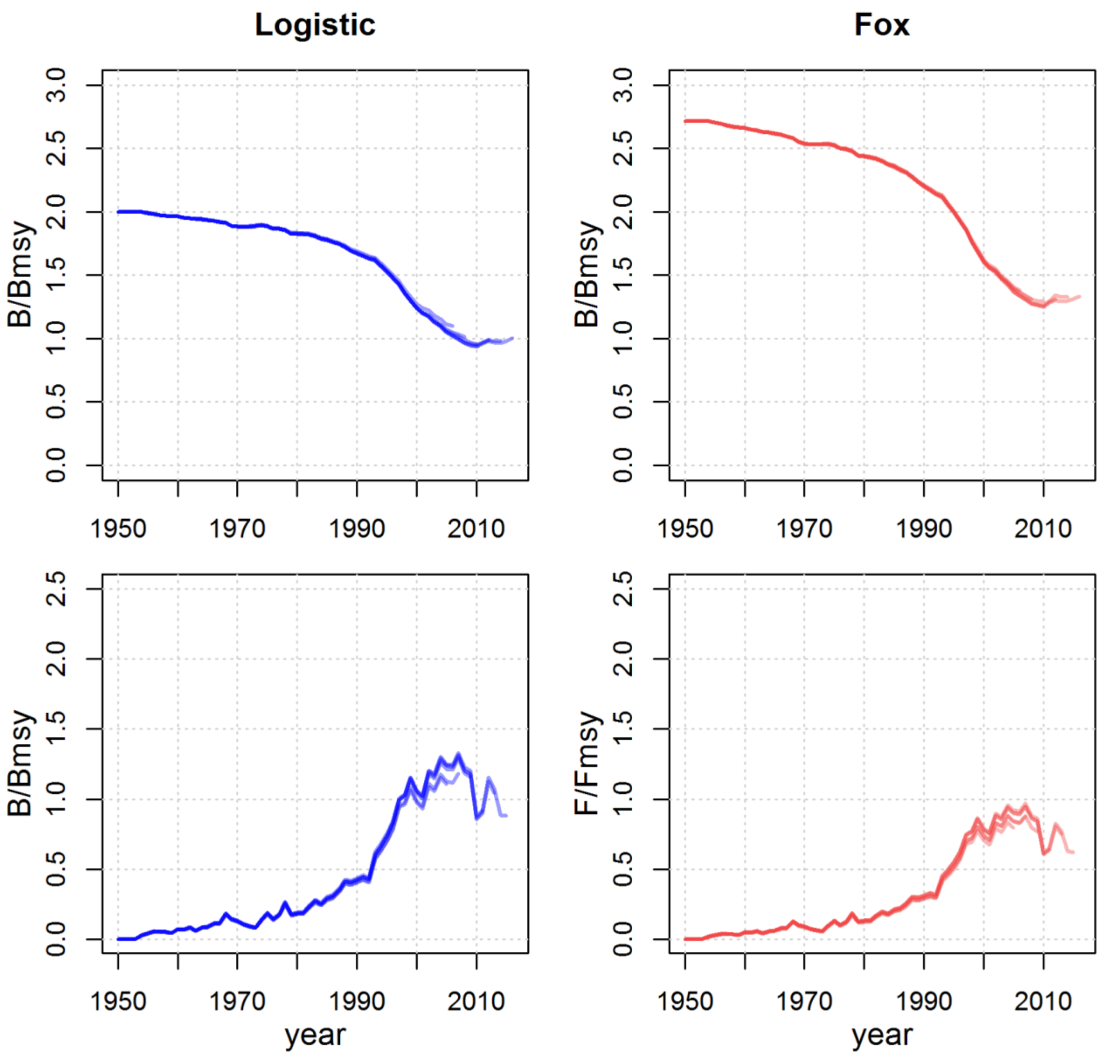


Figure 14. Retrospective analyses of bootstrapped results for the four runs.

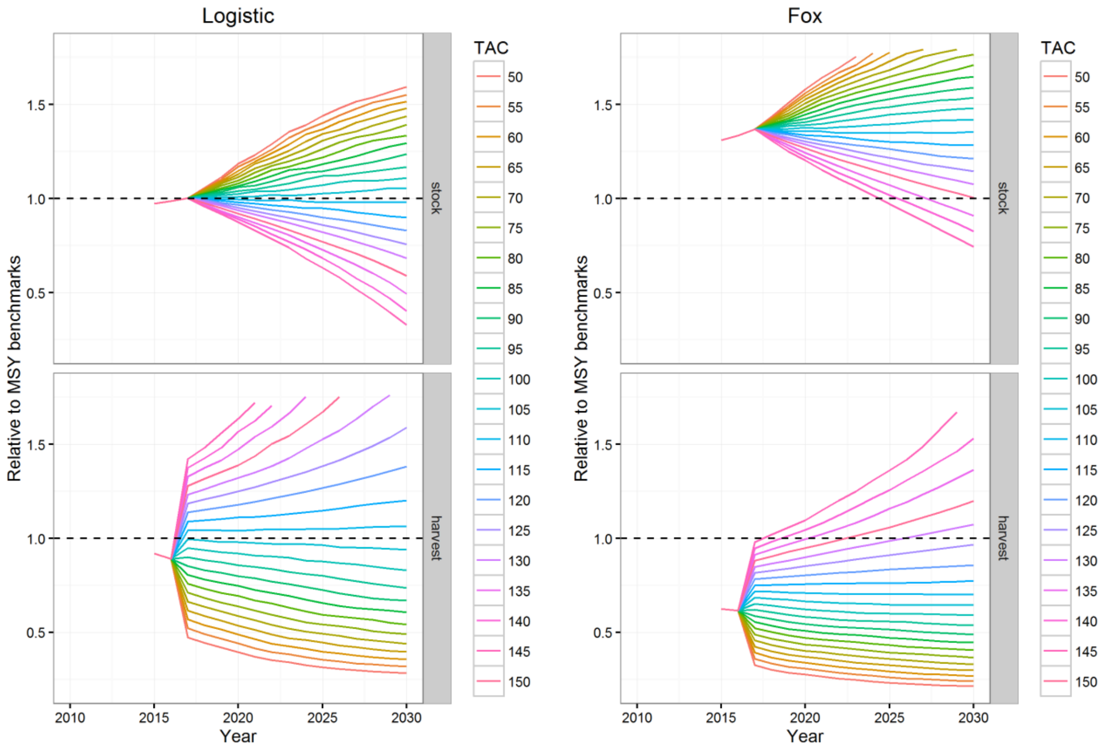
According to Figure 14, there is not a strong retrospective pattern and the trajectories estimated with all the series are very similar in all the four runs.

The values shown to describe the status of IOTC stocks is shown in Table 2, including catch in 2015, average catch 2011-2015, MSY, F_{MSY}, B_{MSY}, F_{2015}/F_{MSY}, B_{2015}/B_{MSY}, B_{2015}/B_0. Note that MSY estimates in all runs are (15-20%) lower than the MSY average estimated in 2013 which was 132 (IOTC, 2015).

variable	mean	median	10% CI	90% CI	model
MSY	110137.40	112421.49	71627.67	140678.11	Combined
Bmsy	1058111.51	1005694.93	554143.79	1674395.86	Combined
Fmsy	0.13	0.12	0.05	0.24	Combined
Catch15	92736.00	92736.00	92736.00	92736.00	Combined
Catch1115	101515.40	101515.40	101515.40	101515.40	Combined
Fcur	0.88	0.76	0.42	1.48	Combined
Bcur	1.17	1.14	0.80	1.61	Combined
BcurK	0.50	0.48	0.35	0.65	Combined
MSY	105975.83	110451.77	70599.61	129384.51	Logistic
Bmsy	1162211.51	1103063.06	609884.64	1798428.04	Logistic
Fmsy	0.12	0.10	0.04	0.21	Logistic
Catch15	92736.00	92736.00	92736.00	92736.00	Logistic
Catch1115	101515.40	101515.40	101515.40	101515.40	Logistic
Fcur	1.05	0.92	0.55	1.75	Logistic
Bcur	1.01	0.97	0.71	1.31	Logistic
BcurK	0.51	0.49	0.35	0.67	Logistic
MSY	114298.97	115519.33	72494.04	152514.17	Fox
Bmsy	954011.51	930227.69	521401.04	1405163.99	Fox
Fmsy	0.15	0.13	0.05	0.26	Fox
Catch15	92736.00	92736.00	92736.00	92736.00	Fox
Catch1115	101515.40	101515.40	101515.40	101515.40	Fox
Fcur	0.72	0.62	0.34	1.26	Fox
Bcur	1.36	1.31	0.95	1.79	Fox
BcurK	0.50	0.49	0.35	0.67	Fox

Table 2. Bootstrapped Reference Points and other indicators.

The bootstrapped stock status and parameters were projected into the future (2030) for a range of alternative catch limits ranging from 270,001 to 380,001 tons. The median relative biomass and relative fishing mortalities for the four runs are shown in Figure 15.



The resulting probability of $B>B_{MSY}$ averaged across the two model runs is shown over a K2SM (Table 3). The K2SM for the catch projections for each scenario are shown in the Appendix.

catch	2017	2018	2019	2020	2021	2022	2023	2024	2025	2026	2027	2028	2029	2030	2031
50001	0.68	0.73	0.77	0.80	0.82	0.83	0.85	0.86	0.87	0.88	0.89	0.90	0.90	0.91	0.92
55001	0.68	0.72	0.76	0.79	0.81	0.82	0.83	0.84	0.86	0.86	0.87	0.88	0.88	0.89	0.90
60001	0.68	0.72	0.76	0.78	0.80	0.81	0.82	0.83	0.84	0.85	0.86	0.86	0.87	0.88	0.88
65001	0.68	0.71	0.75	0.77	0.79	0.80	0.81	0.82	0.83	0.83	0.84	0.84	0.85	0.85	0.86
70001	0.68	0.71	0.74	0.76	0.77	0.78	0.79	0.80	0.81	0.82	0.82	0.82	0.83	0.83	0.83
75001	0.68	0.70	0.73	0.75	0.76	0.77	0.78	0.78	0.79	0.80	0.80	0.81	0.81	0.81	0.81
80001	0.68	0.70	0.72	0.74	0.75	0.76	0.76	0.77	0.77	0.78	0.78	0.78	0.79	0.78	0.79
85001	0.68	0.69	0.71	0.72	0.73	0.74	0.74	0.75	0.75	0.75	0.75	0.76	0.76	0.76	0.76
90001	0.68	0.69	0.70	0.71	0.71	0.72	0.72	0.73	0.73	0.73	0.73	0.73	0.73	0.73	0.73
95001	0.68	0.69	0.69	0.69	0.70	0.70	0.70	0.70	0.70	0.70	0.70	0.70	0.70	0.70	0.70
100001	0.68	0.68	0.69	0.68	0.67	0.68	0.68	0.68	0.68	0.68	0.68	0.67	0.68	0.68	0.67
105001	0.68	0.68	0.67	0.67	0.66	0.66	0.65	0.65	0.65	0.65	0.64	0.64	0.64	0.64	0.64
110001	0.68	0.68	0.66	0.65	0.65	0.64	0.64	0.63	0.62	0.62	0.62	0.62	0.61	0.61	0.60
115001	0.68	0.67	0.66	0.65	0.63	0.63	0.61	0.60	0.60	0.59	0.58	0.58	0.57	0.56	0.56
120001	0.68	0.67	0.65	0.63	0.62	0.60	0.59	0.58	0.57	0.56	0.55	0.54	0.54	0.53	0.52
125001	0.68	0.66	0.64	0.62	0.60	0.58	0.56	0.55	0.53	0.52	0.51	0.49	0.49	0.47	0.46
130001	0.68	0.65	0.63	0.60	0.58	0.55	0.53	0.51	0.50	0.48	0.47	0.45	0.43	0.42	0.41
135001	0.68	0.65	0.62	0.59	0.56	0.53	0.51	0.48	0.46	0.44	0.42	0.39	0.38	0.36	0.35
140001	0.68	0.65	0.61	0.57	0.53	0.51	0.48	0.44	0.42	0.39	0.37	0.34	0.32	0.30	0.28
145001	0.68	0.64	0.60	0.55	0.51	0.48	0.43	0.40	0.38	0.34	0.32	0.29	0.27	0.25	0.23
150001	0.68	0.64	0.58	0.54	0.49	0.44	0.40	0.36	0.32	0.30	0.27	0.25	0.23	0.21	0.20

Table 3. Kobe 2 Strategy Matrix, the indicated values are probabilities of the stock being above BMSY for each year.

In addition, projections were made with a series of Harvest Control Rules (HCR). The HCR tested are linear and defined by F_{lim}, B_{lim}, F_{tar} and B_{thresh}. K2SM for each HCR and their estimated catch are shown in Tables 4 and 5, averaged across the two model runs. The K2SM and Catch projections obtained with the HCRs in the two model runs are shown in the Appendix.

Ftar	Btrig	Blim	2017	2018	2019	2020	2021	2022	2023	2024	2025	2026	2027	2028	2029	2030	2031
0.75	0.3	0.1	0.68	0.71	0.74	0.77	0.79	0.81	0.82	0.84	0.85	0.87	0.88	0.89	0.91	0.92	0.93
0.8	0.3	0.1	0.68	0.70	0.73	0.76	0.77	0.79	0.81	0.82	0.83	0.85	0.86	0.87	0.89	0.89	0.91
0.85	0.3	0.1	0.68	0.70	0.72	0.74	0.76	0.77	0.79	0.81	0.82	0.83	0.84	0.85	0.86	0.87	0.88
0.9	0.3	0.1	0.68	0.69	0.70	0.72	0.74	0.75	0.76	0.78	0.79	0.80	0.81	0.82	0.83	0.84	0.84
0.95	0.3	0.1	0.68	0.69	0.69	0.70	0.71	0.72	0.73	0.74	0.75	0.76	0.77	0.78	0.78	0.80	0.81
1	0.3	0.1	0.68	0.68	0.68	0.68	0.68	0.68	0.68	0.68	0.68	0.68	0.68	0.68	0.68	0.68	0.68
0.75	0.4	0.1	0.68	0.71	0.75	0.78	0.81	0.83	0.84	0.86	0.88	0.89	0.90	0.91	0.92	0.93	0.94
0.8	0.4	0.1	0.68	0.71	0.73	0.76	0.79	0.81	0.83	0.85	0.86	0.87	0.89	0.90	0.90	0.91	0.92
0.85	0.4	0.1	0.68	0.70	0.73	0.75	0.77	0.79	0.82	0.83	0.85	0.86	0.87	0.88	0.89	0.89	0.90
0.9	0.4	0.1	0.68	0.70	0.72	0.73	0.75	0.77	0.79	0.81	0.82	0.84	0.85	0.86	0.87	0.87	0.87
0.95	0.4	0.1	0.68	0.69	0.70	0.72	0.72	0.74	0.75	0.77	0.78	0.80	0.81	0.82	0.83	0.85	0.85
1	0.4	0.1	0.68	0.68	0.69	0.70	0.70	0.71	0.71	0.72	0.72	0.73	0.73	0.74	0.74	0.74	0.75
0.75	0.5	0.1	0.68	0.72	0.77	0.80	0.83	0.85	0.87	0.89	0.91	0.92	0.93	0.94	0.95	0.95	0.95
0.8	0.5	0.1	0.68	0.72	0.76	0.80	0.82	0.84	0.86	0.88	0.90	0.91	0.92	0.93	0.94	0.94	0.95
0.85	0.5	0.1	0.68	0.71	0.75	0.79	0.81	0.83	0.86	0.86	0.89	0.90	0.91	0.92	0.93	0.93	0.94
0.9	0.5	0.1	0.68	0.71	0.74	0.77	0.80	0.82	0.84	0.86	0.87	0.88	0.89	0.90	0.91	0.92	0.93
0.95	0.5	0.1	0.68	0.71	0.73	0.76	0.78	0.81	0.83	0.84	0.85	0.87	0.88	0.88	0.89	0.89	0.90
1	0.5	0.1	0.68	0.70	0.72	0.74	0.76	0.78	0.80	0.81	0.82	0.83	0.83	0.84	0.84	0.85	0.85
0.75	0.3	0.2	0.68	0.71	0.74	0.77	0.79	0.81	0.82	0.84	0.86	0.87	0.88	0.89	0.91	0.92	0.93
0.8	0.3	0.2	0.68	0.70	0.73	0.76	0.77	0.79	0.81	0.82	0.83	0.85	0.86	0.87	0.89	0.90	0.91
0.85	0.3	0.2	0.68	0.70	0.72	0.74	0.76	0.78	0.79	0.81	0.82	0.83	0.84	0.85	0.86	0.87	0.88
0.9	0.3	0.2	0.68	0.69	0.70	0.72	0.74	0.75	0.76	0.78	0.79	0.81	0.81	0.82	0.83	0.84	0.84
0.95	0.3	0.2	0.68	0.69	0.69	0.70	0.71	0.72	0.73	0.74	0.75	0.76	0.77	0.78	0.78	0.80	0.81
1	0.3	0.2	0.68	0.68	0.68	0.68	0.68	0.68	0.68	0.68	0.68	0.68	0.68	0.68	0.68	0.68	0.68
0.75	0.4	0.2	0.68	0.71	0.75	0.78	0.81	0.84	0.85	0.87	0.89	0.90	0.90	0.91	0.92	0.93	0.94
0.8	0.4	0.2	0.68	0.71	0.73	0.77	0.80	0.82	0.85	0.86	0.87	0.88	0.89	0.90	0.91	0.91	0.92
0.85	0.4	0.2	0.68	0.71	0.73	0.75	0.78	0.81	0.83	0.85	0.86	0.87	0.87	0.89	0.89	0.90	0.90
0.9	0.4	0.2	0.68	0.70	0.72	0.73	0.76	0.78	0.81	0.83	0.84	0.86	0.86	0.87	0.87	0.87	0.88
0.95	0.4	0.2	0.68	0.69	0.71	0.72	0.73	0.74	0.77	0.79	0.81	0.83	0.83	0.84	0.85	0.85	0.86
1	0.4	0.2	0.68	0.69	0.70	0.70	0.71	0.72	0.73	0.73	0.74	0.75	0.75	0.75	0.75	0.75	0.75
0.75	0.5	0.2	0.68	0.73	0.77	0.81	0.84	0.86	0.89	0.90	0.92	0.93	0.94	0.95	0.95	0.95	0.96
0.8	0.5	0.2	0.68	0.72	0.77	0.80	0.83	0.86	0.88	0.90	0.91	0.92	0.93	0.94	0.95	0.95	0.95
0.85	0.5	0.2	0.68	0.72	0.76	0.80	0.82	0.85	0.87	0.89	0.90	0.91	0.92	0.93	0.94	0.94	0.95
0.9	0.5	0.2	0.68	0.71	0.75	0.79	0.81	0.84	0.86	0.88	0.89	0.90	0.91	0.92	0.93	0.93	0.94
0.95	0.5	0.2	0.68	0.71	0.74	0.78	0.80	0.83	0.85	0.86	0.87	0.88	0.89	0.90	0.91	0.91	0.92
1	0.5	0.2	0.68	0.71	0.73	0.77	0.79	0.81	0.82	0.84	0.84	0.85	0.86	0.86	0.86	0.86	0.87

Table 4. K2SM for the HCRs defined by Ftar, Btrig and Blim. The numbers indicate the probability of B>Bmsy.

Ftar	Btrig	Blim	2017	2018	2019	2020	2021	2022	2023	2024	2025	2026	2027	2028	2029	2030	2031
0.75	0.3	0.1	106	103	101	101	100	100	100	100	101	101	101	101	101	101	102
0.8	0.3	0.1	113	109	107	105	105	104	104	104	104	104	104	104	104	104	104
0.85	0.3	0.1	120	114	112	110	109	108	107	107	107	107	107	106	106	106	106
0.9	0.3	0.1	127	120	116	114	112	111	111	110	109	109	109	109	108	108	108
0.95	0.3	0.1	134	126	121	118	116	114	113	112	112	111	111	110	110	110	110
1	0.3	0.1	141	131	126	122	119	117	116	115	114	113	112	112	112	111	111
0.75	0.4	0.1	104	101	100	100	99	99	100	100	100	101	101	101	101	102	102
0.8	0.4	0.1	111	107	105	104	104	103	104	104	104	104	104	104	104	104	104
0.85	0.4	0.1	118	113	110	109	108	107	107	107	106	107	107	106	107	107	107
0.9	0.4	0.1	125	118	115	113	111	110	110	110	109	109	109	109	109	109	108
0.95	0.4	0.1	132	124	119	117	115	113	113	112	111	111	111	110	110	110	110
1	0.4	0.1	139	129	124	120	118	116	115	114	113	112	112	111	110	110	110
0.75	0.5	0.1	99	96	95	97	96	96	99	99	99	100	100	100	100	101	101
0.8	0.5	0.1	105	102	100	101	100	100	102	102	102	102	102	102	102	103	103
0.85	0.5	0.1	112	107	105	105	104	103	104	104	104	103	103	104	104	104	104
0.9	0.5	0.1	119	112	109	109	107	106	106	106	105	105	105	105	106	106	106
0.95	0.5	0.1	125	118	114	113	111	109	107	107	107	106	106	106	107	107	107
1	0.5	0.1	132	123	118	116	114	112	108	108	108	106	107	107	108	108	108
0.75	0.3	0.2	106	103	101	101	100	100	100	101	101	101	101	101	101	101	102
0.8	0.3	0.2	113	108	107	105	105	104	104	104	104	104	104	104	104	104	104
0.85	0.3	0.2	120	114	112	110	109	108	107	107	107	107	107	106	106	106	106
0.9	0.3	0.2	127	120	116	114	112	111	111	110	109	109	109	109	109	108	108
0.95	0.3	0.2	134	125	121	118	116	114	113	112	112	111	111	110	110	110	110
1	0.3	0.2	141	131	125	122	119	117	116	115	114	113	112	112	112	111	111
0.75	0.4	0.2	103	100	99	99	99	99	100	100	100	101	101	101	102	102	102
0.8	0.4	0.2	110	106	104	104	103	103	104	104	104	104	104	104	104	104	105
0.85	0.4	0.2	117	112	109	108	107	106	107	107	106	107	107	107	107	107	107
0.9	0.4	0.2	124	117	114	112	111	109	110	110	109	109	109	109	109	109	109
0.95	0.4	0.2	131	123	118	116	114	112	113	112	111	111	111	111	110	110	110
1	0.4	0.2	138	128	123	120	117	115	115	114	113	112	112	111	110	110	110
0.75	0.5	0.2	97	94	93	95	95	95	99	99	99	100	100	100	100	101	101
0.8	0.5	0.2	103	99	98	100	99	98	102	101	101	101	102	102	102	102	103
0.85	0.5	0.2	109	105	102	104	103	102	103	103	103	103	103	103	104	104	104
0.9	0.5	0.2	116	110	107	107	106	105	105	105	105	104	104	104	106	106	106
0.95	0.5	0.2	122	115	111	111	109	108	106	106	106	105	105	105	107	107	107
1	0.5	0.2	129	120	115	114	112	110	107	106	106	105	106	106	109	108	108

Table 5. Estimated catch for the HCRs defined by Ftar, Btrig and Blim in thousands of tons.

Discussion

The stock status of Indian Ocean bigeye estimated using the information available in 2016 and biomass dynamic models from the library *mpb* (Kell, 2016) is estimated to be in the green zone of the Kobe plot (not overfished and not undergoing overexploitation with a 61% of probability. However, the probability of being overfished and undergoing overexploitation is 26%. In 2013, the stock was estimated to be at 40% if the unfished levels and here, we estimate that current biomass is estimated to be at 50% of the unfished levels and 17% above the estimated B_{MSY}. Therefore, the state of the stock status has improved in the last three years. A possible reason for this is that catch has remained below the estimated MSY since 2013.

The estimates shown in this document are obtained by averaging over two model runs. We include a series of diagnostics that suggest that both model runs are plausible as model assumptions are not violated. For example, residuals from the fits (Figure 4) are evenly distributed across the time series in both models. The fits to the both the logistic and Fox models appear to be consistent with model assumptions. i.e. residuals are *normally* distributed. Both model runs show good retrospective fits, i.e. the estimated trajectories with shortened series of data are within the trajectories of the complete series'. The jackknife analyses yield comparable results across the abundance indices. For some indices estimates vary slightly by dropping the latest years of information. However, further analyses of the jackknife shown here may be necessary if a single index is to be chosen as abundance index for the stock assessment. With regards to the likelihood, both models show good profiles.

The management advice derived from the stock status (see Table 2) and the catch projections (Figure 15 and Table 3) indicate that catches are sustainable at current and higher levels. With catches as high as 130 thousand tons (40% more than in 2015) the stock would be above its B_{MSY} with more than 50% probability in 2020. However, with catches of 120 th tons, the stock would be at $B>B_{MSY}$ with more than 50% of probability in 2030. If current catch level of 92,736 tons is maintained, the probability of the stock being above B_{MSY} would be as high as 70% in 2030.

In 2016, the IOTC agreed implementing a Harvest Control Rule for the management of skipjack, one of the three stocks considered as tropical tunas in IOTC. It also encouraged continuing the assessment of HCRs through Management Strategy Evaluation. Here, using forward projections, we estimated the ability of a series of Harvest Control Rules to achieve conservation management objectives and evaluated their impact on the overall catch of bigeye tuna. As seen in Tables 4 and 5, all the HCRs would imply fixing catch limits at levels higher than the recent catch. All HCRs would allow the stock being above 50% of BMSY from now until 2030.

The scripts used to produce all the results shown in this paper will be available at request to all the participants to the 18th session of the WPTT. Furthermore, suggestion to the modelling choices, information used and results display will be accepted and added during the WPTT.

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Appendix

1) Reference Points and parameters

Model	MSY	Fmsy	Bmsy	r	k	p	B0
Log combined	**107489.345**	**0.10422116**	**1031358.21**	**0.20844231**	**2062716.42**	**1**	**1**
Fox combined	**114870.505**	**0.13601553**	**844539.64**	**0.13615154**	**2294549.96**	**0.001**	**1**
Log_BET_R1_Boat	80660.3562	0.02500004	3226408.76	0.05000008	6452817.53	1	1
Log_BET_R1_NovessID	152500.996	0.57219166	266520.827	1.14438333	533041.655	1	1
Log_BET_R1_VessID_79-15	65177.8709	0.02500003	2607111.61	0.05000006	5214223.21	1	1
Log_BET_R2_Boat	118060.059	0.21847416	540384.532	0.43694833	1080769.06	1	1
Log_BET_R2_NovessID	125494.957	0.30573244	410473.152	0.61146487	820946.304	1	1
Log_BET_R2_VessID_79-15	110507.915	0.12872214	858499.702	0.25744427	1716999.4	1	1
Log_BET_R1	100994.841	0.04758697	2122321.46	0.09517393	4244642.92	1	1
Log_BET_R2	118321.796	0.21023645	562803.439	0.4204729	1125606.88	1	1
Log_BET_R1&2_Boat	102398.739	0.0996318	1027771.65	0.1992636	2055543.29	1	1
Log_BET_R1&2_NovessID	122852.945	0.19229986	638861.326	0.38459972	1277722.65	1	1
Log_BET_R1&2_VessID_79-15	94186.4749	0.06329506	1488054.21	0.12659011	2976108.42	1	1
Fox_BET_R1_Boat	112340.618	0.04995008	2249057.72	0.05000003	6110518.74	0.001	1
Fox_BET_R1_NovessID	174891.997	0.76978142	227196.957	0.7705512	617276.851	0.001	1
Fox_BET_R1_VessID_79-15	87796.148	0.04995008	1757677.84	0.05000003	4775477	0.001	1
Fox_BET_R2_Boat	110163.021	0.18542991	594095.212	0.18561534	1614111.5	0.001	1
Fox_BET_R2_NovessID	120956.724	0.27882211	433813.246	0.27910093	1178637.59	0.001	1
Fox_BET_R2_VessID_79-15	110684.3	0.13417415	824930.156	0.13430832	2241272.48	0.001	1
Fox_BET_R1	116550.361	0.06722499	1733735.74	0.06729221	4710428.13	0.001	1
Fox_BET_R2	170590.786	0.37340779	456848.496	0.37378119	1241222.61	0.001	1
Fox_BET_R1&2_Boat	105543.314	0.12026644	877579.109	0.12038671	2384315.68	0.001	1
Fox_BET_R1&2_NovessID	131897.201	0.26779142	492537.074	0.26805921	1338185.76	0.001	1
Fox_BET_R1&2_VessID_79-15	98648.3507	0.07752817	1272419.38	0.0776057	3457066.68	0.001	1

2) Catch projections

catch Log50	2017	2018	2019	2020	2021	2022	2023	2024	2025	2026	2027	2028	2029	2030	2031
50001	0.50	0.58	0.64	0.68	0.71	0.73	0.76	0.78	0.79	0.81	0.82	0.84	0.84	0.86	0.86
55001	0.50	0.57	0.63	0.67	0.70	0.72	0.74	0.75	0.78	0.79	0.80	0.81	0.82	0.83	0.84
60001	0.50	0.56	0.62	0.65	0.69	0.71	0.72	0.74	0.75	0.77	0.78	0.79	0.80	0.81	0.81
65001	0.50	0.55	0.61	0.64	0.67	0.69	0.71	0.72	0.74	0.74	0.75	0.76	0.77	0.78	0.79
70001	0.50	0.54	0.60	0.62	0.65	0.68	0.69	0.70	0.72	0.73	0.74	0.74	0.74	0.75	0.76
75001	0.50	0.54	0.58	0.62	0.64	0.66	0.67	0.68	0.69	0.70	0.71	0.72	0.73	0.73	0.73
80001	0.50	0.53	0.57	0.60	0.62	0.63	0.65	0.66	0.67	0.68	0.69	0.69	0.70	0.70	0.71
85001	0.50	0.53	0.56	0.58	0.60	0.61	0.63	0.64	0.64	0.65	0.66	0.67	0.67	0.68	0.68
90001	0.50	0.53	0.54	0.57	0.58	0.59	0.61	0.61	0.62	0.62	0.63	0.64	0.64	0.65	0.65
95001	0.50	0.52	0.53	0.54	0.56	0.57	0.58	0.58	0.59	0.59	0.60	0.60	0.60	0.61	0.62
100001	0.50	0.51	0.53	0.52	0.53	0.54	0.55	0.55	0.55	0.56	0.56	0.57	0.58	0.58	0.58
105001	0.50	0.51	0.51	0.51	0.51	0.52	0.52	0.52	0.52	0.53	0.52	0.53	0.53	0.53	0.53
110001	0.50	0.50	0.50	0.49	0.50	0.50	0.49	0.49	0.49	0.49	0.49	0.49	0.49	0.49	0.49
115001	0.50	0.50	0.49	0.49	0.48	0.47	0.47	0.46	0.46	0.46	0.45	0.45	0.45	0.44	0.44
120001	0.50	0.49	0.47	0.46	0.46	0.45	0.44	0.43	0.43	0.42	0.41	0.41	0.40	0.40	0.40
125001	0.50	0.48	0.46	0.45	0.44	0.42	0.41	0.40	0.38	0.37	0.36	0.34	0.34	0.33	0.32
130001	0.50	0.47	0.45	0.43	0.41	0.39	0.37	0.35	0.34	0.33	0.31	0.30	0.29	0.28	0.27
135001	0.50	0.47	0.44	0.41	0.39	0.37	0.34	0.31	0.30	0.28	0.26	0.24	0.23	0.22	0.21
140001	0.50	0.46	0.42	0.39	0.37	0.33	0.31	0.27	0.25	0.23	0.22	0.21	0.19	0.17	0.16
145001	0.50	0.45	0.41	0.38	0.33	0.30	0.26	0.24	0.22	0.20	0.18	0.16	0.14	0.12	0.12
150001	0.50	0.45	0.40	0.36	0.31	0.26	0.23	0.20	0.18	0.16	0.13	0.12	0.11	0.09	0.08

catch Fox50	2017	2018	2019	2020	2021	2022	2023	2024	2025	2026	2027	2028	2029	2030	2031
50001	0.86	0.89	0.90	0.91	0.92	0.93	0.94	0.94	0.95	0.95	0.95	0.96	0.96	0.97	0.97
55001	0.86	0.88	0.90	0.90	0.92	0.92	0.93	0.93	0.94	0.94	0.95	0.95	0.95	0.95	0.95
60001	0.86	0.88	0.90	0.90	0.90	0.91	0.92	0.92	0.93	0.93	0.93	0.93	0.94	0.94	0.94
65001	0.86	0.87	0.89	0.90	0.90	0.90	0.91	0.92	0.92	0.92	0.92	0.92	0.92	0.92	0.92
70001	0.86	0.87	0.88	0.89	0.89	0.89	0.89	0.90	0.90	0.90	0.90	0.91	0.91	0.91	0.91
75001	0.86	0.87	0.87	0.88	0.88	0.88	0.88	0.88	0.88	0.89	0.89	0.89	0.89	0.89	0.89
80001	0.86	0.86	0.87	0.87	0.87	0.88	0.88	0.88	0.88	0.87	0.87	0.87	0.87	0.86	0.86
85001	0.86	0.86	0.86	0.87	0.87	0.86	0.86	0.86	0.86	0.85	0.85	0.84	0.84	0.84	0.84
90001	0.86	0.85	0.86	0.86	0.85	0.85	0.84	0.84	0.84	0.83	0.82	0.82	0.82	0.82	0.81
95001	0.86	0.85	0.85	0.85	0.84	0.83	0.83	0.82	0.81	0.81	0.81	0.80	0.80	0.80	0.79
100001	0.86	0.85	0.84	0.83	0.82	0.82	0.80	0.80	0.80	0.79	0.79	0.78	0.78	0.77	0.77
105001	0.86	0.85	0.84	0.82	0.81	0.80	0.79	0.78	0.78	0.77	0.76	0.76	0.76	0.75	0.75
110001	0.86	0.85	0.83	0.81	0.80	0.79	0.78	0.76	0.75	0.74	0.74	0.74	0.73	0.72	0.71
115001	0.86	0.84	0.82	0.81	0.79	0.78	0.76	0.74	0.74	0.73	0.71	0.70	0.69	0.68	0.68
120001	0.86	0.84	0.82	0.80	0.78	0.76	0.73	0.72	0.71	0.69	0.69	0.67	0.67	0.66	0.65
125001	0.86	0.84	0.81	0.78	0.76	0.74	0.71	0.70	0.68	0.67	0.66	0.65	0.63	0.62	0.60
130001	0.86	0.84	0.80	0.77	0.74	0.72	0.69	0.68	0.66	0.64	0.62	0.59	0.57	0.55	0.54
135001	0.86	0.84	0.80	0.76	0.73	0.69	0.67	0.65	0.62	0.59	0.57	0.54	0.52	0.50	0.48
140001	0.86	0.83	0.79	0.75	0.70	0.68	0.65	0.60	0.58	0.55	0.52	0.48	0.45	0.43	0.40
145001	0.86	0.83	0.78	0.72	0.69	0.65	0.60	0.57	0.54	0.48	0.46	0.42	0.40	0.37	0.35
150001	0.86	0.82	0.77	0.72	0.67	0.62	0.58	0.52	0.47	0.44	0.40	0.37	0.35	0.33	0.31

3) HCR projections

a. K2SM

Logistic

Ftar	Btrig	Blim	2017	2018	2019	2020	2021	2022	2023	2024	2025	2026	2027	2028	2029	2030	2031
0.75	0.3	0.1	0.50	0.54	0.59	0.63	0.66	0.69	0.71	0.73	0.76	0.78	0.79	0.81	0.84	0.85	0.86
0.8	0.3	0.1	0.50	0.53	0.56	0.61	0.64	0.67	0.69	0.71	0.73	0.75	0.77	0.78	0.80	0.81	0.84
0.85	0.3	0.1	0.50	0.53	0.55	0.59	0.62	0.64	0.66	0.69	0.71	0.72	0.73	0.75	0.76	0.78	0.80
0.9	0.3	0.1	0.50	0.52	0.54	0.55	0.58	0.60	0.62	0.65	0.66	0.69	0.70	0.71	0.72	0.73	0.74
0.95	0.3	0.1	0.50	0.51	0.52	0.53	0.54	0.55	0.57	0.59	0.60	0.62	0.63	0.64	0.66	0.67	0.69
1	0.3	0.1	0.50	0.50	0.50	0.50	0.50	0.50	0.50	0.50	0.50	0.50	0.50	0.50	0.50	0.50	0.50
0.75	0.4	0.1	0.50	0.54	0.59	0.63	0.68	0.70	0.72	0.74	0.77	0.79	0.80	0.82	0.84	0.85	0.87
0.8	0.4	0.1	0.50	0.53	0.56	0.61	0.65	0.68	0.71	0.73	0.74	0.76	0.78	0.79	0.81	0.82	0.84
0.85	0.4	0.1	0.50	0.53	0.55	0.59	0.62	0.65	0.68	0.71	0.72	0.74	0.74	0.76	0.78	0.79	0.81
0.9	0.4	0.1	0.50	0.52	0.54	0.55	0.58	0.61	0.63	0.67	0.68	0.71	0.72	0.73	0.74	0.74	0.75
0.95	0.4	0.1	0.50	0.51	0.52	0.53	0.54	0.55	0.57	0.59	0.61	0.63	0.65	0.67	0.68	0.69	0.71
1	0.4	0.1	0.50	0.50	0.50	0.50	0.50	0.50	0.50	0.50	0.50	0.50	0.50	0.50	0.50	0.50	0.50
0.75	0.5	0.1	0.50	0.55	0.62	0.67	0.71	0.74	0.77	0.79	0.82	0.84	0.86	0.88	0.89	0.90	0.90
0.8	0.5	0.1	0.50	0.54	0.61	0.66	0.70	0.73	0.75	0.78	0.80	0.82	0.84	0.86	0.88	0.89	0.89
0.85	0.5	0.1	0.50	0.53	0.58	0.64	0.67	0.71	0.74	0.75	0.78	0.80	0.82	0.83	0.85	0.87	0.88
0.9	0.5	0.1	0.50	0.53	0.57	0.62	0.65	0.69	0.72	0.73	0.75	0.77	0.79	0.80	0.82	0.84	0.85
0.95	0.5	0.1	0.50	0.52	0.55	0.60	0.63	0.66	0.69	0.70	0.72	0.74	0.75	0.76	0.78	0.78	0.80
1	0.5	0.1	0.50	0.51	0.53	0.56	0.59	0.62	0.64	0.64	0.66	0.67	0.67	0.68	0.69	0.69	0.70
0.75	0.3	0.2	0.50	0.54	0.59	0.63	0.66	0.69	0.71	0.73	0.76	0.78	0.79	0.81	0.84	0.85	0.86
0.8	0.3	0.2	0.50	0.53	0.56	0.61	0.64	0.67	0.69	0.71	0.73	0.75	0.77	0.78	0.80	0.82	0.84
0.85	0.3	0.2	0.50	0.53	0.55	0.59	0.62	0.64	0.66	0.69	0.71	0.72	0.73	0.76	0.77	0.78	0.80
0.9	0.3	0.2	0.50	0.52	0.54	0.55	0.58	0.60	0.62	0.65	0.66	0.69	0.70	0.71	0.73	0.74	0.75
0.95	0.3	0.2	0.50	0.51	0.52	0.53	0.54	0.55	0.57	0.59	0.60	0.62	0.63	0.64	0.66	0.67	0.69
1	0.3	0.2	0.50	0.50	0.50	0.50	0.50	0.50	0.50	0.50	0.50	0.50	0.50	0.50	0.50	0.50	0.50
0.75	0.4	0.2	0.50	0.54	0.59	0.64	0.68	0.72	0.73	0.75	0.77	0.80	0.81	0.82	0.84	0.86	0.88
0.8	0.4	0.2	0.50	0.53	0.56	0.61	0.66	0.69	0.72	0.73	0.74	0.76	0.79	0.80	0.81	0.82	0.85
0.85	0.4	0.2	0.50	0.53	0.55	0.59	0.63	0.66	0.69	0.72	0.73	0.74	0.75	0.77	0.78	0.79	0.81
0.9	0.4	0.2	0.50	0.52	0.54	0.55	0.58	0.61	0.65	0.68	0.70	0.71	0.72	0.73	0.74	0.75	0.76
0.95	0.4	0.2	0.50	0.51	0.52	0.53	0.54	0.55	0.58	0.61	0.64	0.66	0.67	0.68	0.69	0.70	0.72
1	0.4	0.2	0.50	0.50	0.50	0.50	0.50	0.51	0.51	0.51	0.51	0.51	0.51	0.51	0.51	0.51	0.51
0.75	0.5	0.2	0.50	0.55	0.63	0.68	0.72	0.75	0.79	0.81	0.84	0.87	0.88	0.89	0.90	0.90	0.92
0.8	0.5	0.2	0.50	0.54	0.62	0.67	0.71	0.74	0.77	0.80	0.82	0.85	0.87	0.88	0.89	0.89	0.90
0.85	0.5	0.2	0.50	0.54	0.60	0.65	0.69	0.73	0.75	0.77	0.80	0.82	0.84	0.86	0.88	0.89	0.89
0.9	0.5	0.2	0.50	0.53	0.59	0.64	0.67	0.70	0.74	0.76	0.77	0.79	0.82	0.84	0.85	0.87	0.88
0.95	0.5	0.2	0.50	0.53	0.57	0.62	0.65	0.68	0.71	0.73	0.75	0.77	0.78	0.79	0.81	0.83	0.84
1	0.5	0.2	0.50	0.52	0.55	0.60	0.63	0.64	0.67	0.68	0.69	0.71	0.72	0.72	0.72	0.73	0.73

Fox

Ftar	Btrig	Blim	2017	2018	2019	2020	2021	2022	2023	2024	2025	2026	2027	2028	2029	2030	2031
0.75	0.3	0.1	0.86	0.88	0.89	0.90	0.91	0.93	0.94	0.95	0.95	0.96	0.97	0.97	0.98	0.98	0.99
0.8	0.3	0.1	0.86	0.87	0.89	0.90	0.91	0.92	0.93	0.93	0.94	0.95	0.95	0.96	0.97	0.97	0.98
0.85	0.3	0.1	0.86	0.86	0.88	0.89	0.90	0.91	0.91	0.92	0.93	0.93	0.94	0.95	0.95	0.95	0.96
0.9	0.3	0.1	0.86	0.86	0.87	0.88	0.89	0.90	0.90	0.91	0.92	0.92	0.92	0.93	0.93	0.94	0.94
0.95	0.3	0.1	0.86	0.86	0.86	0.87	0.87	0.88	0.89	0.89	0.90	0.90	0.90	0.91	0.91	0.92	0.92
1	0.3	0.1	0.86	0.86	0.86	0.86	0.86	0.86	0.86	0.86	0.86	0.86	0.86	0.86	0.86	0.86	0.86
0.75	0.4	0.1	0.86	0.89	0.90	0.92	0.93	0.95	0.96	0.97	0.98	0.99	1.00	1.00	1.00	1.00	1.00
0.8	0.4	0.1	0.86	0.88	0.90	0.91	0.93	0.94	0.95	0.97	0.97	0.99	1.00	1.00	1.00	1.00	1.00
0.85	0.4	0.1	0.86	0.88	0.90	0.90	0.93	0.93	0.95	0.96	0.97	0.98	0.99	1.00	1.00	1.00	1.00
0.9	0.4	0.1	0.86	0.87	0.90	0.90	0.92	0.93	0.94	0.95	0.96	0.97	0.98	0.99	1.00	1.00	1.00
0.95	0.4	0.1	0.86	0.87	0.89	0.90	0.91	0.92	0.93	0.94	0.95	0.96	0.97	0.98	0.99	1.00	1.00
1	0.4	0.1	0.86	0.86	0.88	0.90	0.90	0.91	0.92	0.93	0.94	0.95	0.95	0.97	0.98	0.98	0.99
0.75	0.5	0.1	0.86	0.89	0.91	0.93	0.95	0.97	0.97	0.99	1.00	1.00	1.00	1.00	1.00	1.00	1.00
0.8	0.5	0.1	0.86	0.89	0.91	0.93	0.95	0.96	0.97	0.98	1.00	1.00	1.00	1.00	1.00	1.00	1.00
0.85	0.5	0.1	0.86	0.89	0.91	0.93	0.95	0.96	0.97	0.98	0.99	1.00	1.00	1.00	1.00	1.00	1.00
0.9	0.5	0.1	0.86	0.89	0.91	0.92	0.94	0.95	0.97	0.98	0.99	1.00	1.00	1.00	1.00	1.00	1.00
0.95	0.5	0.1	0.86	0.89	0.90	0.92	0.94	0.95	0.97	0.97	0.98	1.00	1.00	1.00	1.00	1.00	1.00
1	0.5	0.1	0.86	0.89	0.90	0.92	0.93	0.95	0.96	0.97	0.98	0.99	1.00	1.00	1.00	1.00	1.00
0.75	0.3	0.2	0.86	0.88	0.89	0.90	0.91	0.93	0.94	0.95	0.95	0.96	0.97	0.98	0.98	0.98	1.00
0.8	0.3	0.2	0.86	0.87	0.89	0.90	0.91	0.92	0.93	0.93	0.94	0.95	0.95	0.96	0.97	0.98	0.98
0.85	0.3	0.2	0.86	0.86	0.88	0.89	0.90	0.91	0.92	0.92	0.93	0.93	0.94	0.95	0.95	0.95	0.96
0.9	0.3	0.2	0.86	0.86	0.87	0.88	0.89	0.90	0.91	0.91	0.92	0.92	0.92	0.93	0.93	0.94	0.94
0.95	0.3	0.2	0.86	0.86	0.86	0.87	0.87	0.88	0.89	0.90	0.90	0.90	0.91	0.91	0.91	0.92	0.92
1	0.3	0.2	0.86	0.86	0.86	0.86	0.86	0.86	0.86	0.86	0.86	0.86	0.86	0.86	0.86	0.86	0.86
0.75	0.4	0.2	0.86	0.89	0.90	0.93	0.94	0.96	0.97	0.99	1.00	1.00	1.00	1.00	1.00	1.00	1.00
0.8	0.4	0.2	0.86	0.89	0.90	0.93	0.94	0.95	0.97	0.98	1.00	1.00	1.00	1.00	1.00	1.00	1.00
0.85	0.4	0.2	0.86	0.89	0.90	0.92	0.93	0.95	0.97	0.98	0.99	1.00	1.00	1.00	1.00	1.00	1.00
0.9	0.4	0.2	0.86	0.88	0.90	0.92	0.93	0.95	0.96	0.98	0.99	1.00	1.00	1.00	1.00	1.00	1.00
0.95	0.4	0.2	0.86	0.88	0.90	0.91	0.92	0.94	0.95	0.97	0.98	1.00	1.00	1.00	1.00	1.00	1.00
1	0.4	0.2	0.86	0.87	0.89	0.91	0.92	0.93	0.95	0.96	0.98	0.99	1.00	1.00	1.00	1.00	1.00
0.75	0.5	0.2	0.86	0.90	0.92	0.94	0.96	0.97	0.99	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00
0.8	0.5	0.2	0.86	0.90	0.92	0.94	0.95	0.97	0.99	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00
0.85	0.5	0.2	0.86	0.90	0.92	0.94	0.95	0.97	0.98	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00
0.9	0.5	0.2	0.86	0.90	0.92	0.94	0.95	0.97	0.98	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00
0.95	0.5	0.2	0.86	0.89	0.91	0.93	0.95	0.97	0.98	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00
1	0.5	0.2	0.86	0.89	0.91	0.93	0.95	0.97	0.98	0.99	1.00	1.00	1.00	1.00	1.00	1.00	1.00

b. Catch

Logistic

Ftar	Btrig	Blim	2017	2018	2019	2020	2021	2022	2023	2024	2025	2026	2027	2028	2029	2030	2031
0.75	0.3	0.1	86	85	86	87	88	89	90	90	91	92	92	93	93	93	94
0.8	0.3	0.1	92	90	91	91	92	92	93	94	94	95	95	96	96	96	97
0.85	0.3	0.1	97	95	95	95	96	96	96	97	97	98	98	98	98	99	99
0.9	0.3	0.1	103	100	100	99	99	99	100	100	100	100	100	100	101	101	101
0.95	0.3	0.1	109	105	104	103	103	102	102	102	102	102	102	102	103	103	103
1	0.3	0.1	115	110	108	106	106	105	105	105	104	104	104	104	104	104	104
0.75	0.4	0.1	85	84	85	86	87	88	89	90	91	92	92	93	93	94	94
0.8	0.4	0.1	90	89	90	90	91	92	93	94	94	95	95	96	96	96	97
0.85	0.4	0.1	96	94	94	94	95	95	96	97	97	98	98	98	99	99	99
0.9	0.4	0.1	102	99	98	98	98	98	99	99	100	100	100	101	101	101	101
0.95	0.4	0.1	107	103	102	102	102	101	102	102	102	103	103	103	103	103	103
1	0.4	0.1	113	108	106	105	105	104	105	104	104	104	104	104	104	104	104
0.75	0.5	0.1	80	80	81	84	85	85	89	90	90	92	92	93	93	94	94
0.8	0.5	0.1	86	85	85	88	88	89	92	93	93	95	95	96	96	97	97
0.85	0.5	0.1	91	89	89	92	92	92	96	96	96	98	98	98	99	99	99
0.9	0.5	0.1	97	94	93	95	95	95	99	99	99	100	100	100	101	101	101
0.95	0.5	0.1	102	98	97	99	98	98	102	101	101	103	102	102	103	103	103
1	0.5	0.1	107	103	101	102	101	101	104	103	103	104	104	104	105	105	104
0.75	0.3	0.2	86	85	86	87	88	88	90	90	91	92	92	93	93	93	94
0.8	0.3	0.2	92	90	91	91	92	92	93	94	94	95	95	96	96	96	97
0.85	0.3	0.2	97	95	95	95	95	96	97	97	97	98	98	98	99	99	99
0.9	0.3	0.2	103	100	99	99	99	99	100	100	100	100	100	101	101	101	101
0.95	0.3	0.2	109	105	104	103	102	102	102	102	102	102	102	102	103	103	103
1	0.3	0.2	114	109	108	106	105	105	105	105	104	104	104	104	104	104	104
0.75	0.4	0.2	84	84	84	86	87	87	90	90	91	92	92	93	93	94	94
0.8	0.4	0.2	90	88	89	90	90	91	93	94	94	95	95	96	96	97	97
0.85	0.4	0.2	95	93	93	94	94	94	96	97	97	98	98	98	99	99	99
0.9	0.4	0.2	101	98	97	98	98	98	99	100	100	100	101	101	101	101	101
0.95	0.4	0.2	107	103	102	101	101	101	102	102	102	103	103	103	103	103	103
1	0.4	0.2	112	107	105	105	104	103	105	104	104	105	105	104	105	105	104
0.75	0.5	0.2	79	78	79	83	83	84	89	89	90	92	92	93	94	94	94
0.8	0.5	0.2	84	83	83	87	87	88	93	93	93	95	95	96	97	97	97
0.85	0.5	0.2	89	87	87	90	91	91	96	96	96	98	98	98	99	100	100
0.9	0.5	0.2	94	92	91	94	94	94	99	99	99	101	101	101	102	102	102
0.95	0.5	0.2	100	96	95	97	97	97	102	101	101	103	103	103	104	104	104
1	0.5	0.2	105	100	99	101	100	99	104	103	103	105	105	104	105	105	105

Fox

Ftar	Btrig	Blim	2017	2018	2019	2020	2021	2022	2023	2024	2025	2026	2027	2028	2029	2030	2031
0.75	0.3	0.1	125	120	117	114	113	112	111	111	110	110	110	110	109	109	109
0.8	0.3	0.1	134	127	122	120	118	116	115	114	113	113	113	112	112	112	112
0.85	0.3	0.1	142	133	128	124	122	120	118	117	116	116	115	115	114	114	114
0.9	0.3	0.1	150	140	133	129	126	123	122	120	119	118	117	117	116	116	116
0.95	0.3	0.1	159	146	138	133	129	126	124	123	121	120	119	118	118	117	117
1	0.3	0.1	167	152	143	137	133	129	127	125	123	122	121	120	119	118	118
0.75	0.4	0.1	124	118	115	113	112	111	111	110	110	110	110	110	110	110	110
0.8	0.4	0.1	132	125	121	118	116	115	115	114	113	113	113	112	112	112	112
0.85	0.4	0.1	140	131	126	123	120	118	118	117	116	116	115	115	115	114	114
0.9	0.4	0.1	148	138	131	127	124	122	121	120	118	118	117	117	116	116	116
0.95	0.4	0.1	156	144	137	132	128	125	124	122	120	120	119	118	117	117	117
1	0.4	0.1	165	150	141	135	131	128	126	124	122	120	119	118	117	116	116
0.75	0.5	0.1	117	112	109	110	108	107	109	108	108	108	108	107	107	107	107
0.8	0.5	0.1	125	119	115	114	112	111	111	110	110	108	108	108	108	108	108
0.85	0.5	0.1	133	125	120	119	116	114	112	112	111	109	109	109	109	109	109
0.9	0.5	0.1	141	131	125	123	120	118	113	112	112	109	109	109	110	110	110
0.95	0.5	0.1	148	137	130	126	123	120	113	113	113	109	109	110	111	111	111
1	0.5	0.1	156	143	135	130	126	123	112	113	113	109	109	110	112	111	111
0.75	0.3	0.2	125	120	117	114	113	112	111	111	110	110	110	110	109	109	109
0.8	0.3	0.2	134	127	122	119	117	116	115	114	114	113	113	112	112	112	112
0.85	0.3	0.2	142	133	128	124	122	120	118	117	116	116	115	115	114	114	114
0.9	0.3	0.2	150	140	133	129	126	123	122	120	119	118	117	117	116	116	116
0.95	0.3	0.2	159	146	138	133	129	126	124	123	121	120	119	118	118	117	117
1	0.3	0.2	167	152	143	137	133	129	127	125	123	122	121	120	119	119	118
0.75	0.4	0.2	123	117	114	113	111	110	111	110	110	110	110	110	110	110	110
0.8	0.4	0.2	131	124	120	118	116	114	115	114	113	113	113	113	113	112	112
0.85	0.4	0.2	139	130	125	122	120	118	118	117	116	116	115	115	115	115	114
0.9	0.4	0.2	147	137	130	127	123	121	121	120	118	118	118	117	117	116	116
0.95	0.4	0.2	155	143	135	131	127	124	124	122	120	120	119	118	117	117	117
1	0.4	0.2	164	149	140	135	130	127	126	124	122	119	119	118	116	116	116
0.75	0.5	0.2	114	110	107	108	107	106	109	108	107	107	107	107	107	107	107
0.8	0.5	0.2	122	116	112	113	111	109	111	110	109	108	108	108	108	108	108
0.85	0.5	0.2	130	122	117	117	114	113	111	111	110	107	108	108	109	109	109
0.9	0.5	0.2	137	128	122	121	118	116	111	111	111	107	108	108	110	109	109
0.95	0.5	0.2	145	134	127	124	121	118	110	110	110	107	107	108	111	110	110
1	0.5	0.2	153	139	131	128	124	121	109	109	110	106	107	107	112	111	111