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Preliminary stock assessment for Bigeye tuna *Thunnus obesus* in the Indian Ocean using JABBA

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Summary

In this study, Bayesian State-Space Surplus Production Model was constructed to assess the status of Bigeye tuna *Thunnus obesus* stock in the Indian Ocean from 1975 to 2018. This assessment was carried out in the open-source stock assessment environment, JABBA (Just Another Bayesian Biomass Assessment). In the sensitivity analysis, 8 scenarios including joint CPUE (1979-2018) in different regions were tested, and results indicated that model fitting and result, especially for stock status, did not show significant difference. Therefore, joint CPUE in all regions were used for the *Base case* model. B_{2018} was estimated to be 607,766 t, while B_{MSY} estimate was 476,817t. Catch in 2018 is 93,515t, while MSY was estimated to be 126,820 (105,576~157,865) t for median and 95% confidence interval. The results of JABBA Base case indicated that the stock of Bigeye tuna in the Indian Ocean is not overfished and does not subject to overfishing. The results of projection also revealed that there is little probability for the stock to violate the MSY-based target or limit reference points in the next 3 or 10 years, when the catches are relative to catches from 2018 (same, ± 10%, and ± 20%).

The join of CPUE from China longline fishery during 2012~2018 did not change the assessment results largely. This process of CPUE standardization from China Bigeye tuna fishery will be improved together with its application in the stock assessment in the future.

1 Introduction

In 2016, the 18th Working Party on Tropical Tuna of Indian Ocean Tuna Commission (IOTC WPTT18) conducted stock assessment for Bigeye tuna, with multiple models, including Stock Synthesis 3 (SS3), Age Structured Assessment Program (ASAP), A Stock-Production Model Incorporating Covariates (ASPIC), Biomass Dynamics Model (BDM), Statistical-Catch-At-Age model (SCAA), and Bayesian State-Space Production model (BSPM). These models yielded different estimates for Bigeye tuna's population dynamics, reference points and stock status.

Results from the base case indicated 83.7% probability that the stock of Bigeye tuna in the Indian Ocean was not overfished and is not subject to overfishing. Therefore, recent management advice for Bigeye tuna in the Indian Ocean is that, if catch remains below the estimated MSY levels estimated for the current mix of fisheries, then immediate management measures are not required.

Even not used as the base case model for development of management advice, three production models also contributed much as supporting evidence. In this study, Bayesian State-Space Production model were constructed in an open-source environment, JABBA (Just Another Bayesian Biomass Assessment) to make preliminary stock assessment for Bigeye tuna with the update catch and joint CPUE data.

2 Methods and Materials

Data used in this study includes nominal catch and joint standardized CPUE for Bigeye tuna in the Indian Ocean. As recommended from 2016 WPTT report for BET stock assessment, catch data used covers from 1975 to 2018, while joint CPUE was spatial estimated in five regions, include three in tropical and two in temperate regions (Figure 1). All catch and CPUE data were extracted from the IOTC stock assessment dataset repository of the 21st Meeting on of Working Party on Tropical Tuna (https://www.iotc.org/meetings/21st-working-party-tropical-tuna-wptt21). Wang *et al.* (2019) estimated standardized CPUE from 2012 to 2018, based on the observer dataset from China longline fishery for BET. This CPUE series was also tried in the stock assessment model (Figure 1). Based on different combinations of CPUE, 9 scenarios were carried out for BET stock assessment in this study (Table 1).

The stock assessment model was constructed in an open-source environment, JABBA (Just Another Bayesian Biomass Assessment, Winker *et al.* 2018). The Fox function was used, with informative prior for key parameters (K, r and B_{1975}/K) for BET based on the previous assessment settings and results in 2016 (Table 2). The process error and observation error were estimated simultaneously. The catchability, q was estimated separately for each CPUE, with uninformative wide uniform prior.

JABBA used in this study was the most recently updated version (v1.5 Beta) (www.github.com/henning-winker/JABBAbeta). Each model was running for 30,000 iterations, with a burn-in period of 5,000 for each of 3 chains and subsequently saving every 5th step to attain a joint posterior of 15,000 saved values.

The time series of biomass B and fishing rate F were estimated for BET population, and reference points (MSY, B_{MSY}, F_{MSY}, and B/B_{MSY} and F/F_{MSY}) were also computed to evaluate the stock status. The target and limit reference points for BET were defined by the 2018 CMM of IOTC, which are MSY-based target and B_{Lim} = 0.5 B_{MSY}; F_{Lim} = 1.3 F_{MSY}.

A retrospective analysis was constructed for the *Base case* by sequentially removing the most the recent year and refitting the model over a period of 5 years (*i.e* 2018 back to 2013). Projection also was estimated for the Base case for the future ten years (2019-2028). Catch in 2019 was assumed to be the average catch among 2016-2018, while catch of the next nine years were set to be relative to catches from 2018 (same, ± 10%, ± 20%).

3. Results and Discussions

Catch of BET in the Indian Ocean increased to the peak 162,481t in 1999, and then declined. CPUE index in different regions also exhibit conflicts, especially among tropical and temperate regions. However, all these 8 scenarios (S1-S8) with different combinations for CPUE indices performed reasonable and good model fitting, with RMSE ranging from 0.20 to 0.33 (Figure 2). Additionally, the stock status all yielded in the green quadrant, indicating the BET population has not been overfished or subject to overfishing (Figure 3).

The Base case model estimated the median and 95% confidence interval for initial depletion rate (B_{1975}/K), carrying capacity (K), and population growth rate r to be 1.25 (0.86, 1.90), 0.28 (0.17, 0.43) $\times 10^6$ t and 0.81 (0.53, 1.03), respectively (Table 3 and Figure 4). The catchability q for different CPUE index ranged from 1.20 to 1.52×10^{-6}.

The biomass estimated from the Base case showed a declined trend from 1975 and has become relative stable since 2000 (Figure 5), but still above the B_{MSY} level. B_{2018} was estimated to be 607,766 t, while B_{MSY} estimate was 476,817t. Catch in 2018 is 93,515t, while MSY was estimated to be 126,820 (105,576~157,865) t. F/F_{MSY}

increased from 1975 to about 2000 and showed a slight decrease in recent two decades, whose values were always estimated lower than 1 with a wide confidence interval (Figure 6).

The Base case Kobe plot indicated 90.5% probability that the stock of Bigeye tuna in the Indian Ocean fell into the green zone (Figure 7). The results of projection also revealed that there is little probability for the stock to violate the MSY-based target or limit reference points in the future 3 or 10 years, when the catches are relative to catches from 2018 (same, ± 10%, and ± 20%) (Figure 8 and Table 4).

Results of JABBA Base case indicated that the stock of Bigeye tuna in the Indian Ocean is not overfished and does not subject to overfishing in 2018 (Figure 7), even with a certain retrospective pattern (Figure 9). Therefore, the stock status is still healthy for Indian Ocean Bigeye tuna but with high uncertainty, which more update for the data and model structure to improve the stock assessment model, especially for the retrospective pattern.

The join of standardized CPUE from China longline fishery in short period (2012-2018) did not largely change the model fitting and assessment results (Figures 2 and 3). The estimates of model parameters, population dynamics and the stock status were mostly similar with the Base case S1(Figure 10). The process of CPUE standardization from China longline fishery for Bigeye tuna will be paid with more effort to improve with its application in the stock assessment in the future.

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Tables:

Table 1 Different scenarios for JABBA stock assessment of Bigeye tuna in the Indian Ocean

Scenarios	CPUE
S1	Joint CPUE from both Tropical and Temperate Regions
S2	Joint CPUE from all Tropical Regions
S3	Joint CPUE from all Temperate Regions
S4	Joint CPUE from Tropical Region 1(R1)
S5	Joint CPUE from Tropical Region 1(R2)
S6	Joint CPUE from Tropical Region 1(R5)
S7	Joint CPUE from Temperate Region 1(R3)
S8	Joint CPUE from Temperate Region 1(R4)
S9	Joint CPUE from both Tropical and Temperate Regions, and standardized CPUE from China Longline fishery

Table 2 Parameters' priors for JABBA stock assessment of Bigeye tuna in the Indian Ocean

Parameters	Description	Prior
K	carrying capacity	Lognormal (mean=3.5×10^6, CV=0.75)
B_{1975}/K	initial depletion level	Lognormal (mean=0.9, CV=0.25)
r	growth rate	Lognormal (mean=0.4, CV=0.31)
$sigma^2$	process variance	Inverse Gamma (shape=5, rate=0.01)
tau^2	Part of observe variance	Inverse Gamma (shape=0.001, rate=0.001)
	observe variance	tau^2+0.25
p	catchability	Uniform (lower=10^{-30}, upper=10^3)

Table 3. Parameters and reference points estimates (median) from base case S1 for JABBA stock assessment of Bigeye tuna in the Indian Ocean

	Median and 95% Confidence Interval
C_{2018} (10^6 t)	0.0935
mean$C_{2014\text{-}2018}$ (10^6 t)	0.0921
MSY (10^6 t)	0.13 (0.10, 0.16)
B_{MSY} (10^6 t)	0.46 (0.32, 0.70)
F_{MSY}	0.28 (0.17, 0.43)
B_{2018}/B_{MSY}	1.30 (0.87, 1.75)
F_{2018}/F_{MSY}	0.57 (0.35, 0.99)
B_{1975}/K	0.81 (0.53, 1.03)
B_{2018}/K	0.48 (0.32, 0.64)
K (10^6 t)	1.25 (0.86, 1.90)
r	0.28 (0.17, 0.43)
q.1 (10^{-6})	1.20 (0.75, 1.86)
q.2(10^{-6})	1.14 (0.71, 1.76)
q.3(10^{-6})	1.49 (0.92, 2.30)
q.4(10^{-6})	1.25 (0.77, 1.91)
q.5(10^{-6})	1.52 (0.94, 2.34)
B_{1975}/K	0.81 (0.53, 1.03)
sigma^2	0.0028 (0.0012, 0.0085)
tau^2.1	0.0042 (0.0005, 0.0373)
tau^2.2	0.0039 (0.0005, 0.0311)
tau^2.3	0.0042 (0.0005, 0.0350)
tau^2.4	0.0047 (0.0005, 0.0454)
tau^2.5	0.0043 (0.0005, 0.0375)

Table 4. Bigeye tuna: JABBA base case Scenario 1 Indian Ocean assessment Kobe II Strategy Matrix. Probability (percentage) of violating the MSY-based target (top) and limit (bottom) reference points for constant catch projections (relative to catches from 2018 (93,515t), ± 10%, ± 20%) projected for 3 and 10 years.

Reference point and projection timeframe	Alternative catch projections (relative to the catch level from 2018) and weighted probability (%) scenarios that violate reference point				
	80% (74,812t)	90% (84,163t)	100% (93,515t)	110% (102,866t)	120% (112,218t)
$\boldsymbol{B_{2021}<B_{MSY}}$	2.12	2.59	3.01	3.31	3.99
$\boldsymbol{F_{2021}>F_{MSY}}$	0.00	0.00	0.00	0.00	0.00
$\boldsymbol{B_{2028}<B_{MSY}}$	0.12	0.48	1.26	2.98	6.57
$\boldsymbol{F_{2028}>F_{MSY}}$	0.00	0.00	0.00	0.00	0.00
Reference point and projection timeframe	Alternative catch projections (relative to the catch level from 2015) and probability (%) of violating MSY-based limit reference points (B_{Lim} = 0.5 B_{MSY}; F_{Lim} = 1.3 F_{MSY})				
	80% (74,812t)	90% (84,163t)	100% (93,515t)	110% (102,866t)	120% (112,218t)
$\boldsymbol{B_{2021}<B_{Lim}}$	0.00	0.01	0.01	0.01	0.02
$\boldsymbol{F_{2021}>F_{Lim}}$	0.00	0.00	0.00	0.00	0.00
$\boldsymbol{B_{2028}<B_{Lim}}$	0.01	0.01	0.05	0.11	0.39
$\boldsymbol{F_{2028}>F_{Lim}}$	0.00	0.00	0.00	0.00	0.00

Figures

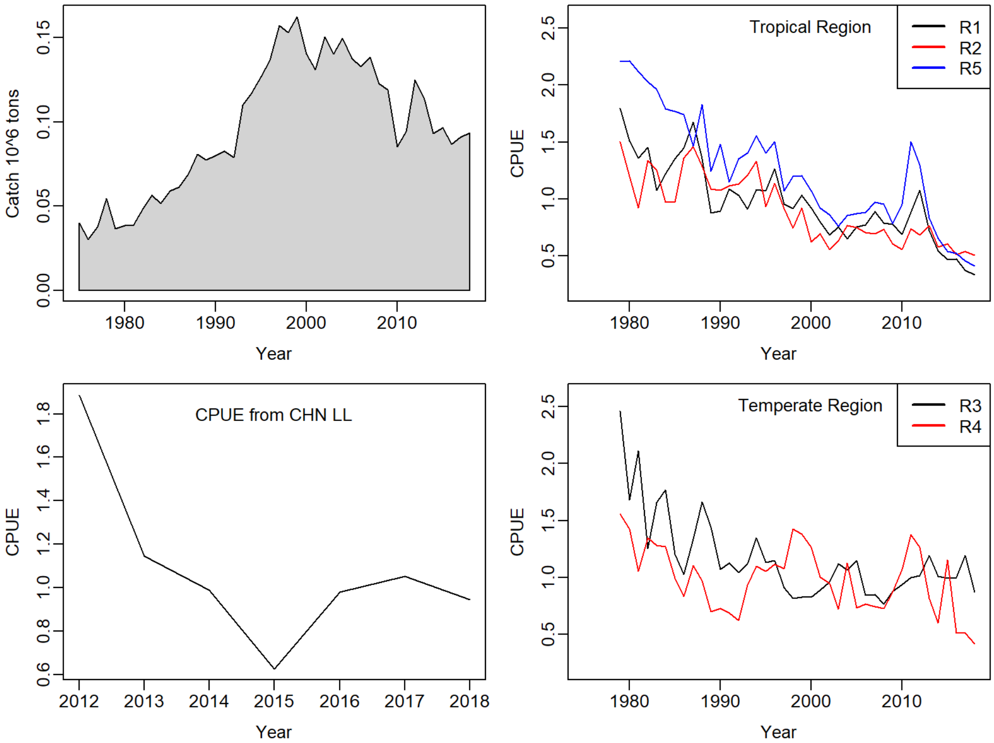

Figure 1. Catch and CPUE of Bigeye tuna in the Indian Ocean used in the JABBA-stock assessment

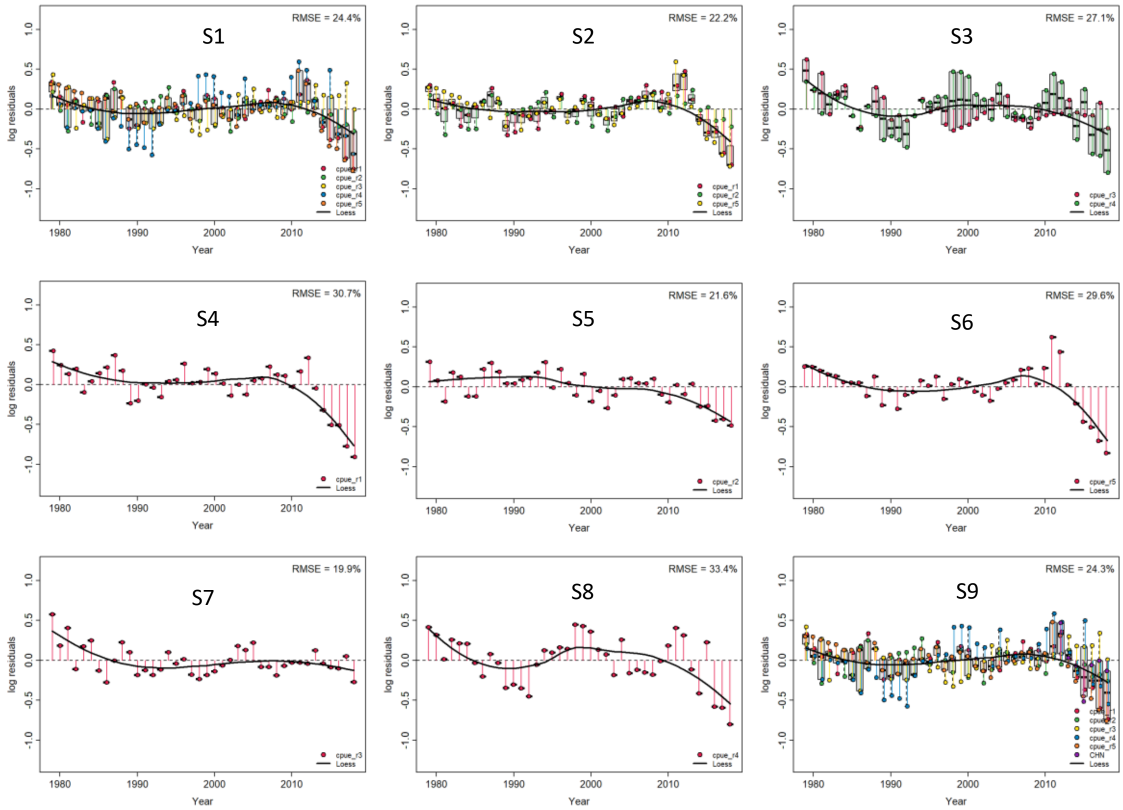

Figure 2. Residuals from different scenarios (S1-S9) for JABBA stock assessment of Bigeye tuna in the Indian Ocean

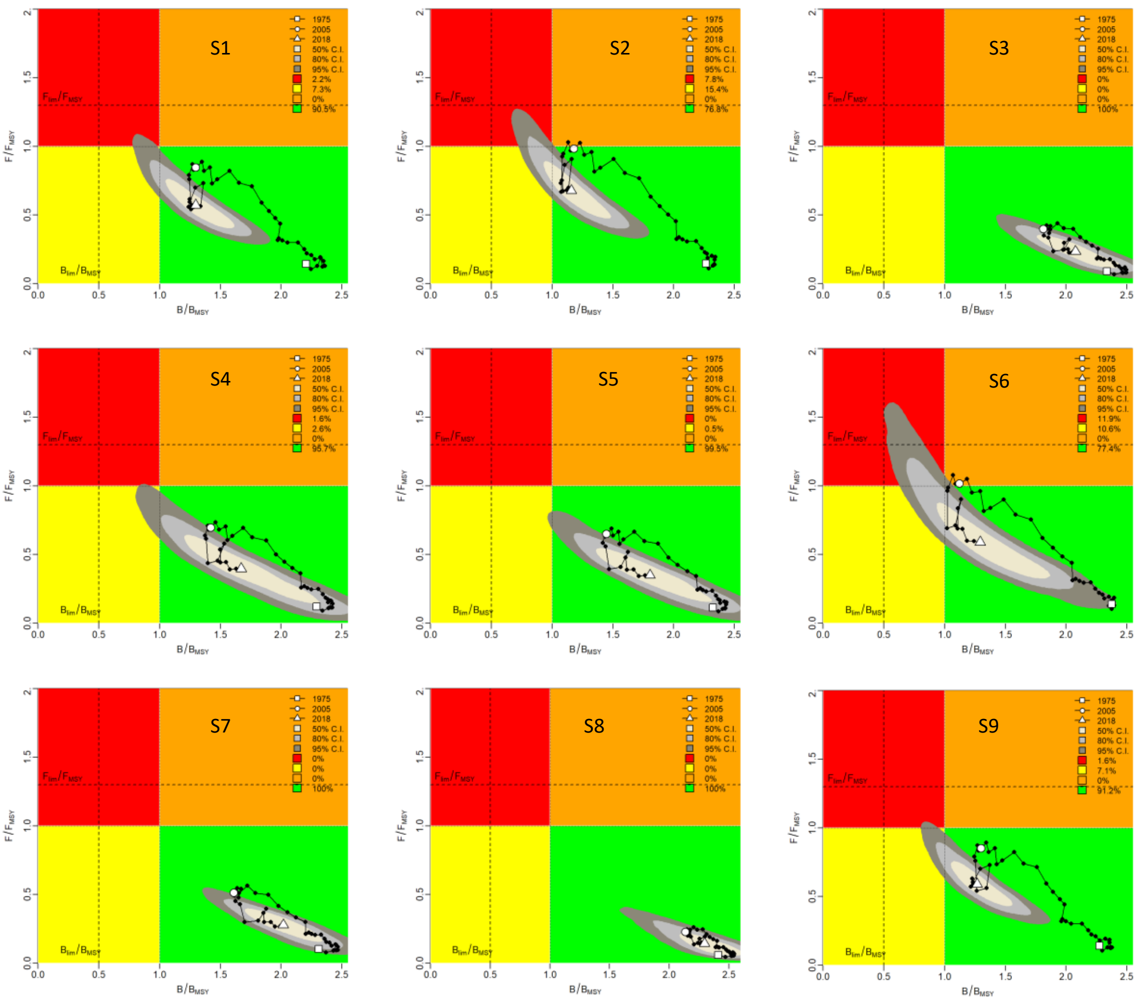

Figure 3. Kobe plots from different scenarios (S1-S9) for JABBA stock assessment of Bigeye tuna in the Indian Ocean

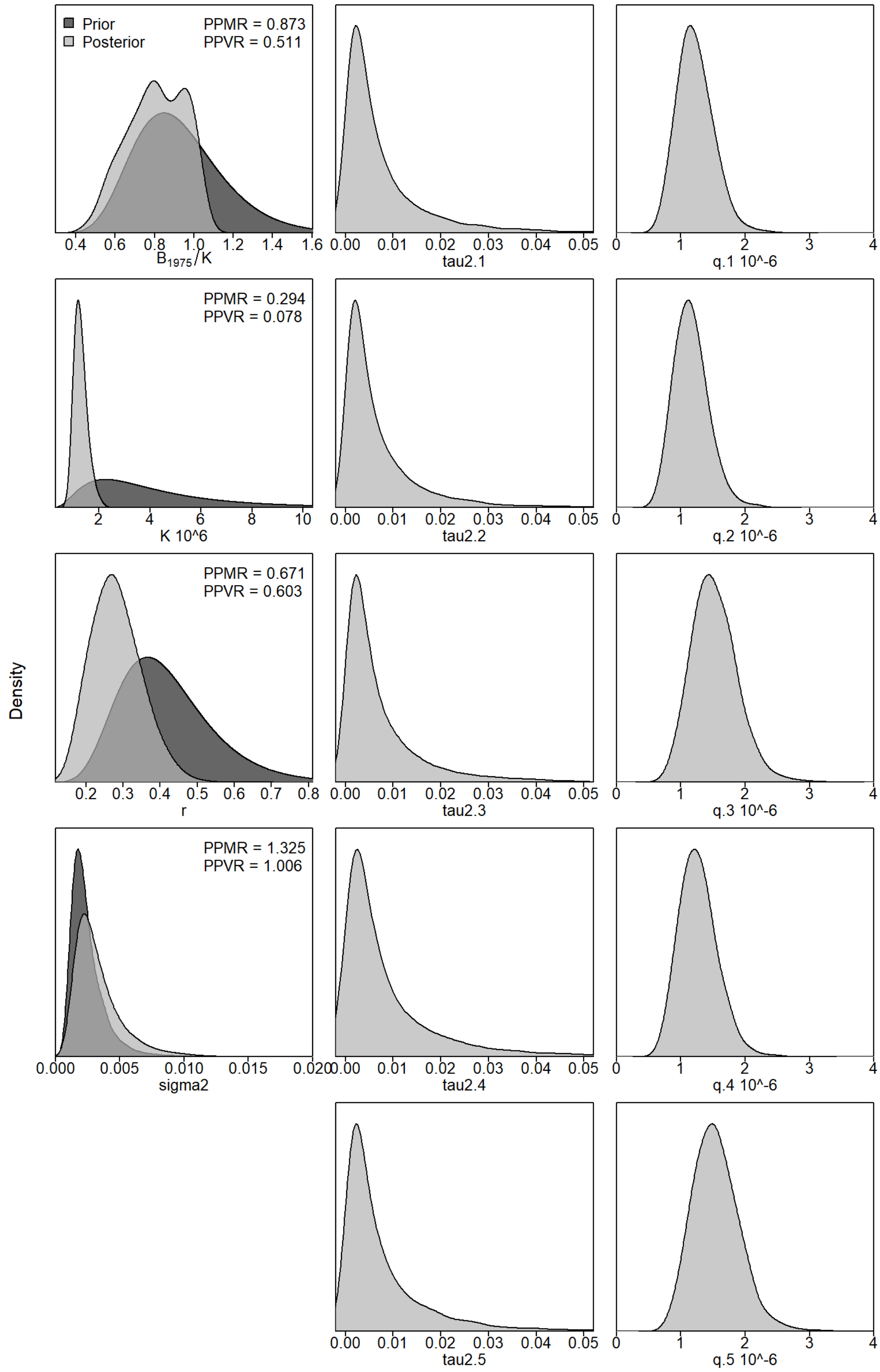

Figure 4. Priors and posteriors for parameters in JABBA base case S1 for stock assessment of Bigeye tuna in the Indian Ocean

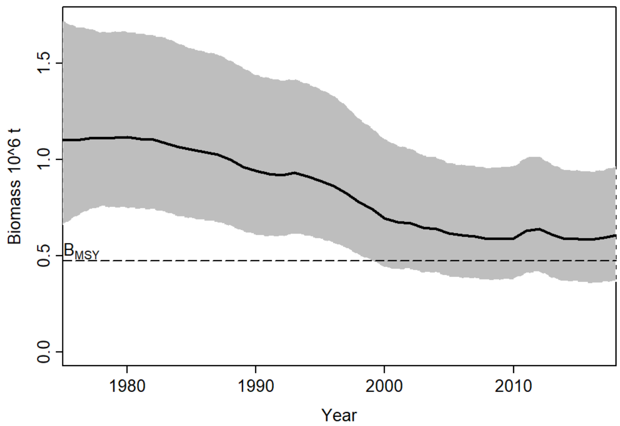

Figure 5. Biomass estimates from base case S1 for JABBA stock assessment of Bigeye tuna in the Indian Ocean

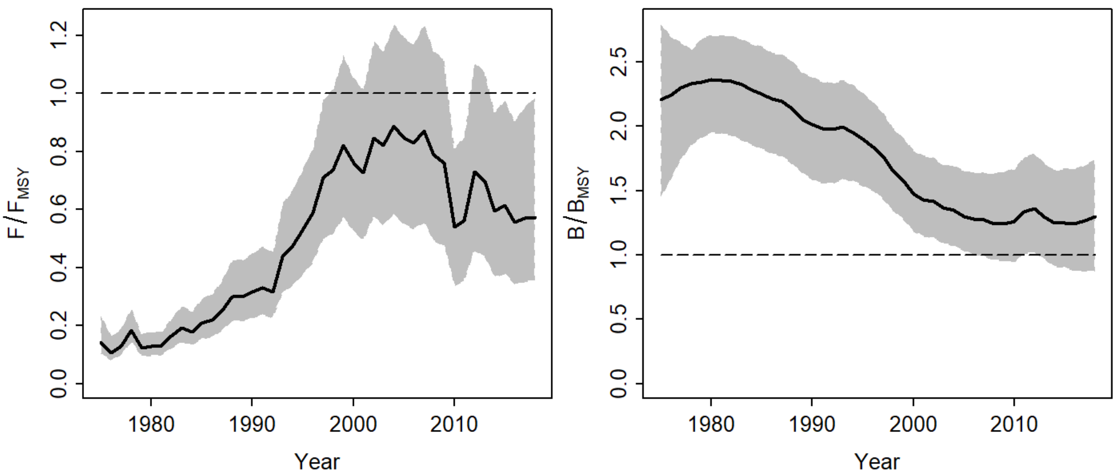

Figure 6. B/B_{MSY} and F/F_{MSY} estimates from base case S1 for JABBA stock assessment of Bigeye tuna in the Indian Ocean

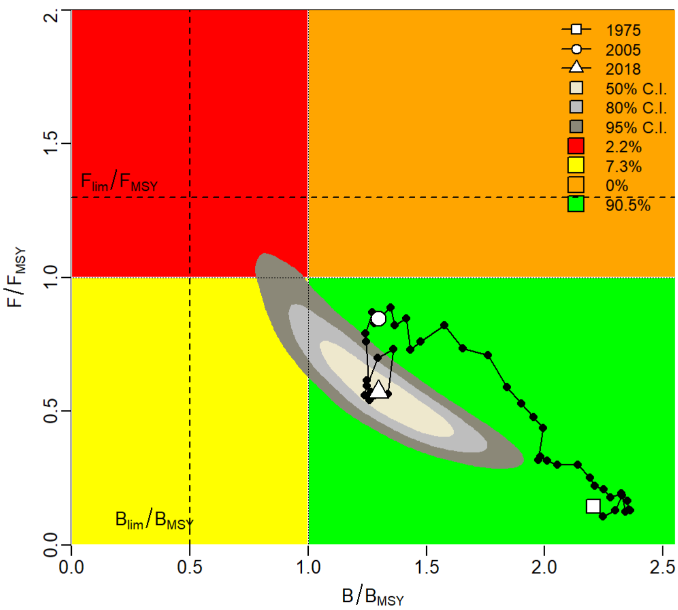

Figure 7. Kobe plots from base case S1 for JABBA stock assessment of Bigeye tuna in the Indian Ocean

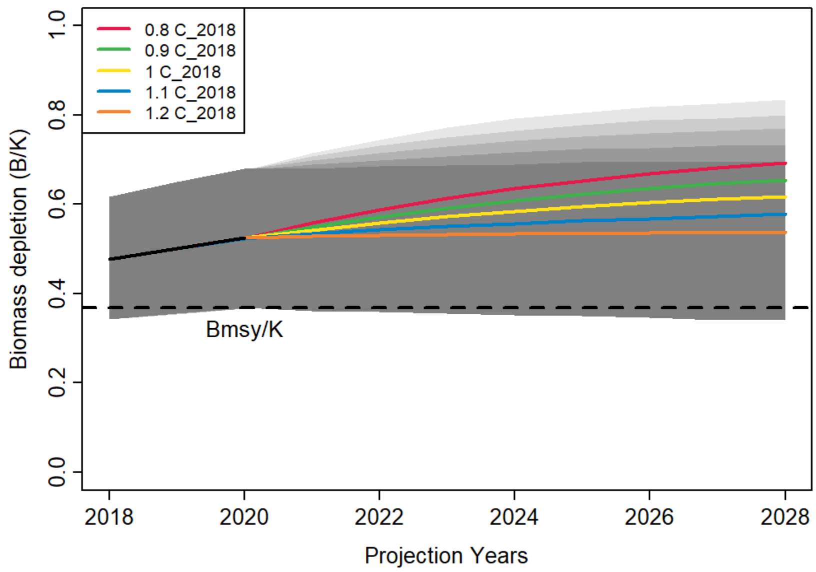

Figure 8. 10-year projections from base case S1 for JABBA stock assessment of Bigeye tuna in the Indian Ocean

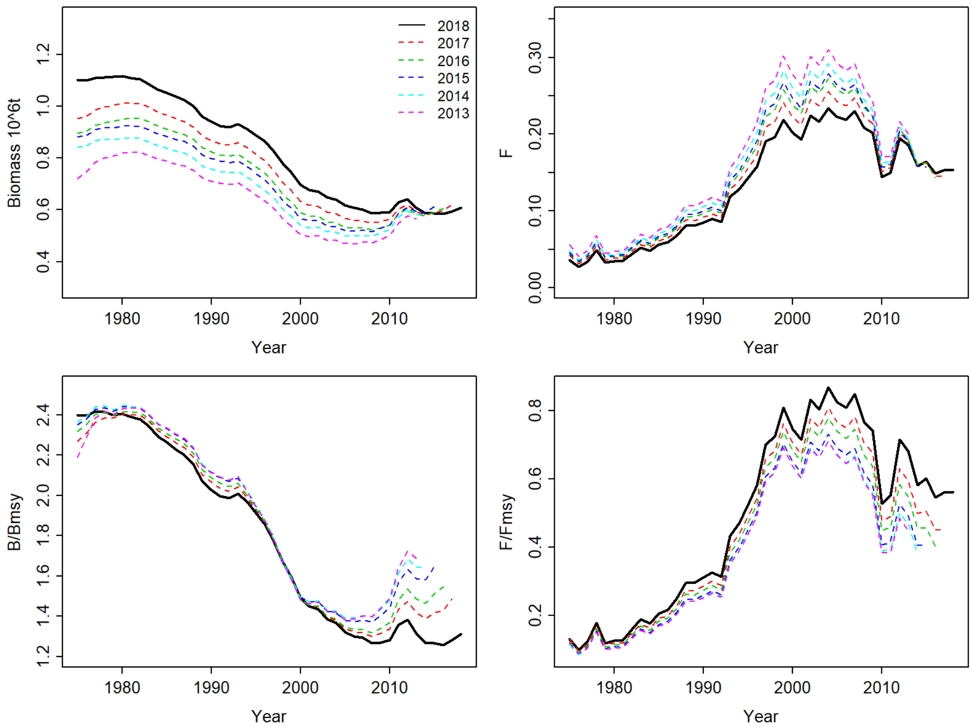

Figure 9. Successive estimates for B, F, B/B_{MSY} and F/F_{MSY} from a retrospective analysis of JABBA Base case S1 for Bigeye tuna stock assessment in the Indian Ocean

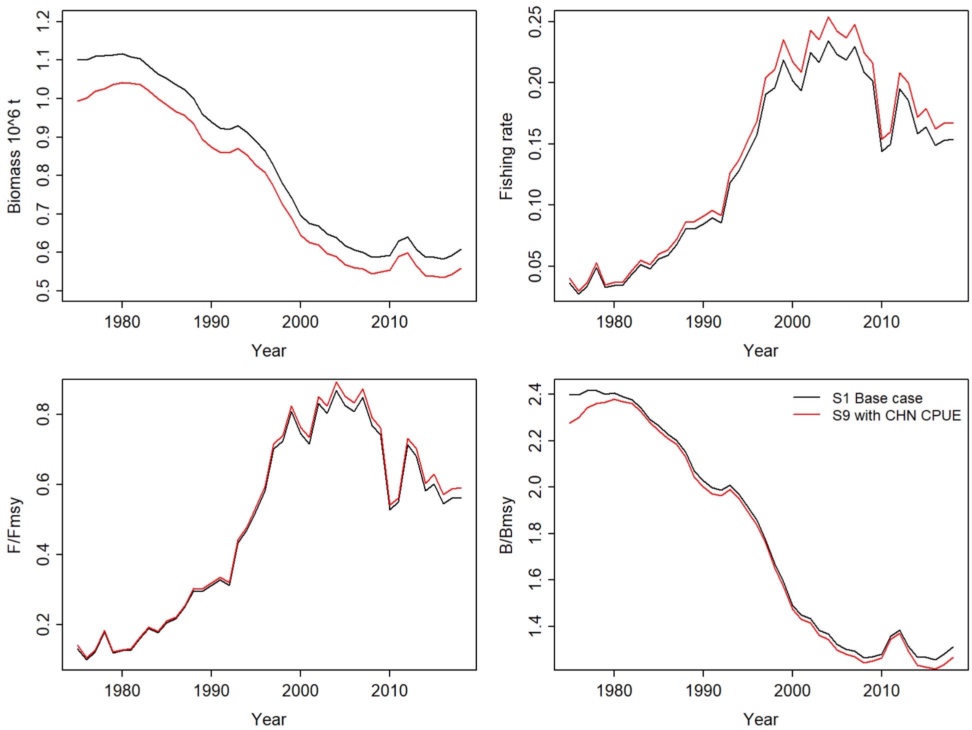

Figure 10. Estimates comparison for S1 Base case and S9 with China for Bigeye tuna stock assessment in the Indian Ocean