Preliminary stock assessment for Indian Ocean Yellowfin tuna (*Thunnus albacares*) using Bayesian surplus production model (JABBA)

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SUMMARY

In this assessment, Bayesian State-Space Surplus Production Model was constructed to assess the status of yellowfin tuna (Thunnus albacares) stock in the Indian Ocean from 1950 to 2023. This assessment was carried out in the open-source stock assessment environment, JABBA (Just Another Bayesian Biomass Assessment). Eighteen scenarios were tested using various surplus production models and CPUE scenarios. The results showed no significant differences in model fit or outcomes, particularly regarding the forecast of stock biomass. According to the fitting results, the CPUE selected by the base case model is the jointed of R1 and R2, and the jointed of R3 and R4 and FSC. B_{2023} *was estimated to be 2,512,635 t, while* B_{MSY} *estimate was 2,991,096t. Catch in 2023 is 400,951t, while MSY was estimated to be 516,484 (395,027~679,094) t for median and 95% confidence interval. The results of JABBA Base case indicated that the stock of yellowfin tuna in the Indian Ocean is overfished but does not subject to overfishing. Sensitivity analysis was conducted for r and K with different prior Settings, and the results showed that different scenarios had little difference in the assessment results of relative biomass* B/B_{MSY}*, but had big difference in relative fishing mortality* F/F_{MSY}*.*

KEYWORDS

Stock assessment; Yellowfin tuna; JABBA.

1. Introduction

Yellowfin tuna (*Thunnus albacares*) is a cosmopolitan species distributed mainly in the tropical and subtropical oceanic waters of the three major oceans, where it forms large schools, often associated with floating objects (*Chassot et al. 2015*). Longline catch data indicates that yellowfin tuna is distributed throughout the entire tropical Indian Ocean and is one of the main target species for tuna fisheries in the Indian Ocean. Yellowfin tuna have been exploited in the Indian Ocean for more than 700 years (*Adam, 2004*). The industrial fishery dates back to 1952 when longliners

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started operating in the eastern region followed by the western region in 1954 and by 1960s most areas of the Indian Ocean were being exploited (*Pecoraro et al. 2017*). In recent years catches have been evenly split between industrial and artisanal fisheries. Purse seiners (free and associated schools) and longline fisheries still account for around 40% of total catches, while catches from artisanal gears-namely handline, gillnet, and pole-and-line-have steadily increased since the 1980s.

The latest stock assessment for the yellowfin tuna was carried out by the Indian Ocean Tuna Commission (IOTC) in 2021. The 2021 stock assessment was carried out using Stock Synthesis III (SS3), a fully integrated model that is currently used to provide scientific advice for the three tropical tunas stocks in the Indian Ocean (*Fu et al. 2021*). The assessment based on the four-area spatial configuration from 2018 which included a standardized catch per unit effort (CPUE) series from the main longline fleets, EU purse seine indices, operating on free schools and floating objects, and an index from the Maldivian pole and line fishery. Various exploratory models were presented to address observational datasets issues, enhance model stability, and explore the effects of alternative model assumptions. The results indicated that the spawning biomass in 2020 was estimated to be 31% on average of the unfished (1950) levels. Spawning biomass estimates have been generally declining over time and particularly since 2011. Spawning biomass in 2020 was estimated to be 78% of the level that supports the maximum sustainable yield (SB_{2020}/SB_{MSY} = 0.78). Current fishing mortality is estimated to be 27% higher than F_{MSY} (F_{2020}/F_{MSY} =1.27). The probability of the stock being in the red Kobe quadrant in 2020 is estimated to be 67%. On the weight-of-evidence available since 2018, the yellowfin tuna stock is determined to remain overfished and subject to overfishing.

In recent years, the increase in catches has substantially increased the pressure on the Indian Ocean stock, resulting in fishing mortality exceeding the *MSY*-related levels. In order to ensure the sustainable use of this resource, scientific resource assessment is the key to formulate fishery management measures. Traditional fisheries stock assessment methods usually rely on catch and effort data (such as catch, catch rate, etc.), while the State-Space Model can show more flexibility and robustness in dealing with data uncertainty and process errors. The JABBA Model (Bayesian State-Space Surplus Production Model) is a commonly used assessment tool that can effectively combine different data sources and uncertainties to assess stock state. The JABBA model uses a Bayesian framework for parameter estimation and can combine prior information and observational data to not only generate estimates of the current stock state, but also quantify uncertainties.

The aim of this assessment was to use the JABBA model to assess the stock status of yellowfin tuna in the Indian Ocean and to construct multiple scenarios with different model settings and data sources to explore the sensitivity of the model parameters to the assessment results. In particular, we will combine different catch per unit effort (CPUE) and different surplus production model (Schaefer model, Fox model and Pella-Tomlinson model) to assess the stock state. Estimate maximum sustainable yield (*MSY*) and other biological reference points (e.g. B_{MSY}, F_{MSY}, etc.). By setting out different scenarios, this assessment not only helps us understand the impact of different CPUE data on the assessment results, but also reveals the differences in stock states under different surplus production model assumptions. This will provide fisheries managers with the scientific basis to develop more effective management measures to ensure the sustainability of yellowfin tuna stocks and the long-term stability of the fishery.

2.Materials and methods

2.1 Data sources

Fisheries data include catch and CPUE time series. The data were obtained from the IOTC for the period 1950-2023 (IOTC-2024-WPTT26 (AS)-DATA03-NC_Rev1). The CPUE time series data includes joint CPUE for yellowfin tuna by the Japanese, Korean and Taiwan,China longline fishery for 1975-2023 (Matsumoto et al. 2024) and EU purse seine free-swimming school CPUE for 1991-2022 (Kaplan et al. 2024). The joint longline CPUE has three types of annual data, which are divided into four regions (R1, R2, R3, and R4) and two regions (R1+R2 and R3+R4, or R1+R2+ R3 and R4). The CPUE time series description were showed in Table 1.

2.2 JABBA model

The stock assessment model uses the version v1.1 of JABBA (*Winker et al. 2018*), which can be found online at: https://github.com/jabbamodel/JABBA. The Fox, Schaefer and Pella-Tomlinson production functions was used, with informative prior for key parameters (K, r and B_{1950}/K) for yellowfin tuna (Table 2).

2.3 Model scenario setting

JABBA model can fit multiple CPUE indices at the same time. This assessment considers the influence of different CPUE indices and types of surplus production models on the model, and sets different model scenarios as shown in the Table 3.

2.4 Model diagnostic

Markov Chain Monte Carlo (MCMC) iterative trajectory diagram is used for the diagnosis of model parameter convergence. The convergence of parameter posterior distribution is determined by Geweke and Heidelberger-Welch diagnostic tests. When its statistical value is less than 1, it’s considered that the model is convergent, that is, the model results are more reliable. Log Residual Diagnostic Plots were used to compare the goodness of fit between CPUE observations and estimates in the model. Root Mean Squared Error (RMSE) and Deviation Information Criteria (DIC) were used to judge the goodness of fit between CPUE and different model scenarios. The smaller the RMSE and DIC values, the better the model fitting effect.

2.5 Retrospective analysis

A retrospective problem (RP) refers to a systematic deviation in the estimate of a resource variable (such as the biomass) for the same year as the time series of the evaluated data increases, that is, the phenomenon of persistent overestimation or underestimation. In order to check the systematic bias of the model, a retrospective analysis was performed. The model is re-fitted by deleting one year's worth of data one by one, for a total of 5 years, and the Mohn ρ statistic is calculated to compare the bias between the models. The calculation formula is:

$$\rho = \sum_{t} \frac{X_{(t1:t),t} - X_{(t1:t2),t}}{X_{(t1:t),t}}$$

Where, $t1$ and $t2$ represent the first and last year of the catch data. t is a year between $t1$ and $t2$. X represents an estimated variable, in this case the amount of biomass. When ρ value is 0, there is no RP, that is, there is no systematic bias estimation, when ρ value is positive, there is a positive RP, that is, the short time series of resources in the same year is greater than the long time series, otherwise, it is negative RP.

3. Results and analysis

3.1 Model fitting and diagnosis

The diagnostic analysis of the JABBA for the yellowfin tuna in the Indian Ocean showed reliable convergence and satisfactory model fitting (Figure1-3). MCMC diagnostics, including the Geweke and Heidelberger-Welch tests, confirmed that all model parameter posterior distributions were symmetric, with statistical values consistently below 1, indicating robust convergence. The RMSE and DIC values varied across model scenarios (Table 4), with scenario S15 (Pella-Tomlinson model with CPUE indices LL1+LL2, LL3+LL4, FSC) achieving the lowest RMSE (48.9) and DIC (-273.1), suggesting it provided the best model fit.

Additionally, the residual diagnostics indicated a strong alignment between observed and predicted CPUE values across model scenarios, enhancing confidence in the model's predictive performance. The small RMSE and DIC values across several scenarios underscore the model’s ability to integrate CPUE data accurately and provide a stable stock assessment under different model assumptions.

Retrospective analysis conducted by sequentially removing recent years of data revealed limited retrospective bias, with Mohn ρ values for biomass (B) and B/B_{MSY} centered around -0.193, indicating minor underestimation bias (Table 5). These results suggest that the JABBA model’s predictions are robust over time, supporting the model's capacity to consistently estimate biomass levels with minimal systematic bias (Figure 4).

However, the analysis highlighted a more notable impact on F/F_{MSY}, with Mohn ρ value at 0.343, suggesting some fluctuation in fishing mortality estimates due to observation error. This aligns with the broader tendency in fisheries assessments, where observation errors can lead to higher variability in F/F_{MSY} estimates than biomass-related parameters, impacting assessments of overfishing risk.

3.2 Stock status

The assessment applied three surplus production models (the Schaefer, Fox, and Pella-Tomlinson models) across various combinations of CPUE inputs (totaling 18 scenarios). The Pella-Tomlinson model, which underpins the base case scenario (S15), exhibited stability across various CPUE combinations, aligning closely with empirical observations and offering a balanced fit to the data. According to the fitting results, the CPUE selected by the base case model is the jointed of R1 and R2, and the jointed of R3 and R4. B_{2023} was estimated to be 2,512,635 t, while B_{MSY} estimate was 2,991,096t. Catch in 2023 is 400,951t, while MSY was estimated to be 516,484 (395,027~679,094) t for median and 95% confidence interval. The results of JABBA Base case indicated that the stock of yellowfin tuna in the Indian Ocean is overfished but does not subject to overfishing (Figure 5-7). The estimate parameters and reference points, kobe plots for the 18 scenarios are shown in Table 6 and Figure 8.

3.3 Projection

Set the catch for the initial forecast year to the average catch from 2021 to 2023, which is 412,000t. Establish different levels of total allowable catch (TAC) as a short-term management strategy, with increments of 20,000t, ranging from 0.8 to 1.2 times the average catch of 412,000t, to project resource dynamics over the next 10 years.

At lower catch levels (e.g., 330,000 to 390,000t), the biomass depletion rate remains relatively stable throughout the forecast period and consistently stays above the threshold line, suggesting that lower catches may support biomass recovery. In contrast, higher catch levels (e.g., 450,000 to 490,000t) lead to slower biomass recovery, increasing the risk of biomass depletion under high-catch scenarios. While the population demonstrates good resilience under varying fishing pressures, there remains some risk of overfishing due to current uncertainties in stock status (Figure 9).

3.4 Sensitivity analysis

Additional sensitivity analyses were provided based on the base case including different prior settings for r and K (Table 7). In the sensitivity analysis of the JABBA model, various assumptions for the distributions of r and K were examined to assess their effects on MSY, B_{MSY}, B/B_{MSY}, F_{MSY}, and F/F_{MSY}. Sensitivity analysis was conducted for r and K with different prior settings, and the results showed that different scenarios had little difference in the assessment results of relative biomass B/B_{MSY}, but had significant influence in relative fishing mortality F/F_{MSY} (Figure 10).

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Tables:

Table 1. The description of CPUE time series

CPUE code	Description	Period
LL1	Joint CPUE for R1	1975-2023
LL2	Joint CPUE for R2	1975-2023
LL3	Joint CPUE for R3	1975-2023
LL4	Joint CPUE for R4	1975-2023
LL1+LL2	Joint CPUE for R1 and R2	1975-2023
LL3+LL4	Joint CPUE for R3 and R4	1975-2023
LL1+LL2+LL3	Joint CPUE for R1, R2 and R3	1975-2023
FSC	EU purse seine free-swimming school CPUE	1991-2022

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

Parameters	Description	Prior
K	Carrying capacity	Lognormal (mean=7.5×10^6, CV=0.02)
B_{1950}/K	Initial depletion level	Lognormal (mean=0.9, CV=0.05)
r	Intrinsic growth rate	Lognormal (mean=0.32, CV=0.22)
sigma2	Process variance	Inverse Gamma (shape=8, rate=0.2)
tau2	Part of observe variance	Inverse Gamma (shape=0.001, rate=0.001)
q	Catchability	Uniform (lower=10^{-30}, upper=10^3)

Table 3. Scenarios setting of JABBA model for Indian Ocean Yellowfin tuna

Model scenarios	CPUE	Model type	fixed.obsE
S1	LL1、LL2、LL3、LL4、FSC	Schaefer	0.2
S2	LL1、LL2、LL3、LL4、FSC	Fox	0.2
S3	LL1、LL2、LL3、LL4、FSC	Pella	0.2
S4	LL1+LL2、LL3+LL4、FSC	Schaefer	0.2
S5	LL1+LL2、LL3+LL4、FSC	Fox	0.2
S6	LL1+LL2、LL3+LL4、FSC	Pella	0.2
S7	LL1+LL2+LL3、LL4、FSC	Schaefer	0.2
S8	LL1+LL2+LL3、LL4、FSC	Fox	0.2

S9	LL1+LL2+LL3、LL4、FSC	Pella	0.2
S10	LL1、LL2、LL3、LL4、FSC	Schaefer	0.3
S11	LL1、LL2、LL3、LL4、FSC	Fox	0.3
S12	LL1、LL2、LL3、LL4、FSC	Pella	0.3
S13	LL1+LL2、LL3+LL4、FSC	Schaefer	0.3
S14	LL1+LL2、LL3+LL4、FSC	Fox	0.3
S15	LL1+LL2、LL3+LL4、FSC	Pella	0.3
S16	LL1+LL2+LL3、LL4、FSC	Schaefer	0.3
S17	LL1+LL2+LL3、LL4、FSC	Fox	0.3
S18	LL1+LL2+LL3、LL4、FSC	Pella	0.3

Table 4. Goodness of fitting of S1−S18 scenarios in JABBA for Indian Ocean yellowfin tuna

Model scenarios	RMSE	DIC	Model scenarios	RMSE	DIC
S1	49.7	-190.3	S10	50	-192
S2	49.1	-199.8	S11	49.3	-200.6
S3	49.3	-198.2	S12	49.4	-200.3
S4	51.8	-263.1	S13	49.5	-270.9
S5	51.6	-263.7	S14	49	-271.4
S6	51.5	-261.8	**S15***	**48.9**	**-273.1**
S7	63.9	-303.3	S16	60.3	-285
S8	64.2	-302.6	S17	60.9	-283.4
S9	64.1	-302.8	S18	60.6	-284.4

Table 5. Retrospective patterns of base case in JABBA of Indian Ocean yellowfin tuna

	B	MSY	B_{MSY}	F_{MSY}	B/B_{MSY}	F/F_{MSY}
2022	-0.132	-0.023	-0.001	-0.023	-0.131	0.187
2021	-0.176	-0.051	-0.001	-0.049	-0.176	0.276
2020	-0.284	-0.095	-0.001	-0.094	-0.282	0.547
2019	-0.2	-0.089	-0.001	-0.088	-0.199	0.38
2018	-0.175	-0.083	-0.001	-0.083	-0.175	0.326
Mean	-0.193	-0.068	-0.001	-0.067	-0.193	0.343

Table 6. Parameters and reference points estimates for yellowfin tuna in the Indian Ocean

Model	***r***			***K***			***MSY***			B_{MSY}			F_{MSY}			$B_{2023}/B_{\mathrm{MSY}}$			$F_{2023}/F_{\mathrm{MSY}}$		
scenarios	**Mean**	**2.5%**	**97.5%**	**Mean**	**2.5%**	**97.5%**	**Mean**	**2.5%**	**97.5%**	**Mean**	**2.5%**	**97.5%**	**Mean**	**2.5%**	**97.5%**	**Mean**	**2.5%**	**97.5%**	**Mean**	**2.5%**	**97.5%**
S1	0.293	0.225	0.373	7517696	7231692	7812474	551249	421303	700544	3758848	3615846	3906237	0.147	0.112	0.187	0.398	0.277	0.566	1.835	1.19	2.814
S2	0.193	0.155	0.235	7483162	7196781	7778533	531008	427288	646363	2754277	2648871	2862993	0.193	0.155	0.235	0.512	0.353	0.734	1.482	0.966	2.273
S3	0.214	0.171	0.262	7488804	7205246	7785384	538787	431331	661634	2995385	2881967	3114012	0.18	0.144	0.221	0.48	0.333	0.683	1.557	1.02	2.383
S4	0.25	0.186	0.33	7492437	7202105	7786190	468720	347714	618625	3746218	3601052	3893095	0.125	0.093	0.165	0.731	0.447	1.093	1.183	0.681	2.114
S5	0.195	0.148	0.259	7476967	7189565	7773275	535563	406861	714138	2751997	2646215	2861057	0.195	0.148	0.259	1.053	0.65	1.58	0.716	0.397	1.337
S6	0.206	0.156	0.273	7479734	7195065	7778784	519623	393712	687640	2991757	2877895	3111372	0.174	0.131	0.23	0.956	0.578	1.434	0.816	0.457	1.503
S7	0.248	0.185	0.333	7485491	7196361	7788617	464675	347022	624892	3742746	3598181	3894308	0.124	0.092	0.167	1.015	0.716	1.395	0.854	0.518	1.404
S8	0.208	0.155	0.283	7476968	7187066	7779371	570799	424944	780599	2751998	2645295	2863301	0.207	0.155	0.283	1.442	1.019	1.971	0.486	0.289	0.839
S9	0.217	0.16	0.29	7482450	7193956	7787070	545211	401856	733081	2992844	2877451	3114686	0.182	0.134	0.244	1.311	0.919	1.809	0.562	0.335	0.968
S10	0.285	0.215	0.364	7511850	7226135	7811349	534828	405454	682711	3755925	3613067	3905675	0.142	0.108	0.182	0.42	0.278	0.624	1.795	1.111	2.883
S11	0.191	0.153	0.234	7482496	7200137	7779751	525677	423058	645008	2754032	2650106	2863441	0.191	0.153	0.234	0.529	0.349	0.801	1.445	0.894	2.331
S12	0.212	0.169	0.261	7487063	7199959	7785358	533328	425879	658159	2994689	2879852	3114001	0.178	0.142	0.22	0.496	0.327	0.739	1.523	0.954	2.453
S13	0.254	0.19	0.335	7492364	7204905	7796500	475421	355818	628030	3746182	3602453	3898250	0.127	0.095	0.167	0.661	0.399	1.047	1.288	0.717	2.335
S14	0.194	0.149	0.257	7478175	7196470	7771099	532500	407925	708213	2752442	2648757	2860256	0.194	0.148	0.257	0.934	0.559	1.481	0.811	0.429	1.533
S15	**0.205**	**0.157**	**0.27**	**7478081**	**7197540**	**7775711**	**516484**	**395028**	**679095**	**2991096**	**2878885**	**3110143**	**0.173**	**0.132**	**0.227**	**0.841**	**0.501**	**1.334**	**0.928**	**0.5**	**1.732**
S16	0.249	0.185	0.33	7489377	7199799	7785867	465784	345576	617877	3744688	3599899	3892933	0.124	0.092	0.165	0.829	0.519	1.253	1.044	0.594	1.91
S17	0.203	0.151	0.275	7475444	7186384	7769080	558065	413752	758924	2751437	2645044	2859513	0.203	0.151	0.275	1.225	0.778	1.822	0.588	0.32	1.118
S18	0.211	0.158	0.284	7478162	7192575	7775893	529407	396711	715197	2991129	2876899	3110216	0.177	0.133	0.239	1.089	0.701	1.639	0.699	0.383	1.267

Table 7. Sensitivity analysis of Indian Ocean Yellowfin tuna r and K distributions and base case (S15) Biological Reference Points

Model scenarios	r	K	MSY	B_{MSY}	B/B_{MSY}	F_{MSY}	F/F_{MSY}
S15	Ln (0.32,0.22)	Ln (7506000,0.02)	516484	2991096	0.841	0.173	0.928
S19	U (0.15,0.45)	Ln (7506000,0.02)	454416	2995449	0.793	0.152	1.121
S20	Ln (0.32,0.22)	U (6800000,8200000)	512968	2932488	0.841	0.175	0.935
S21	U (0.15,0.45)	U (6800000,8200000)	450699	2951588	0.799	0.153	1.125

Figures:

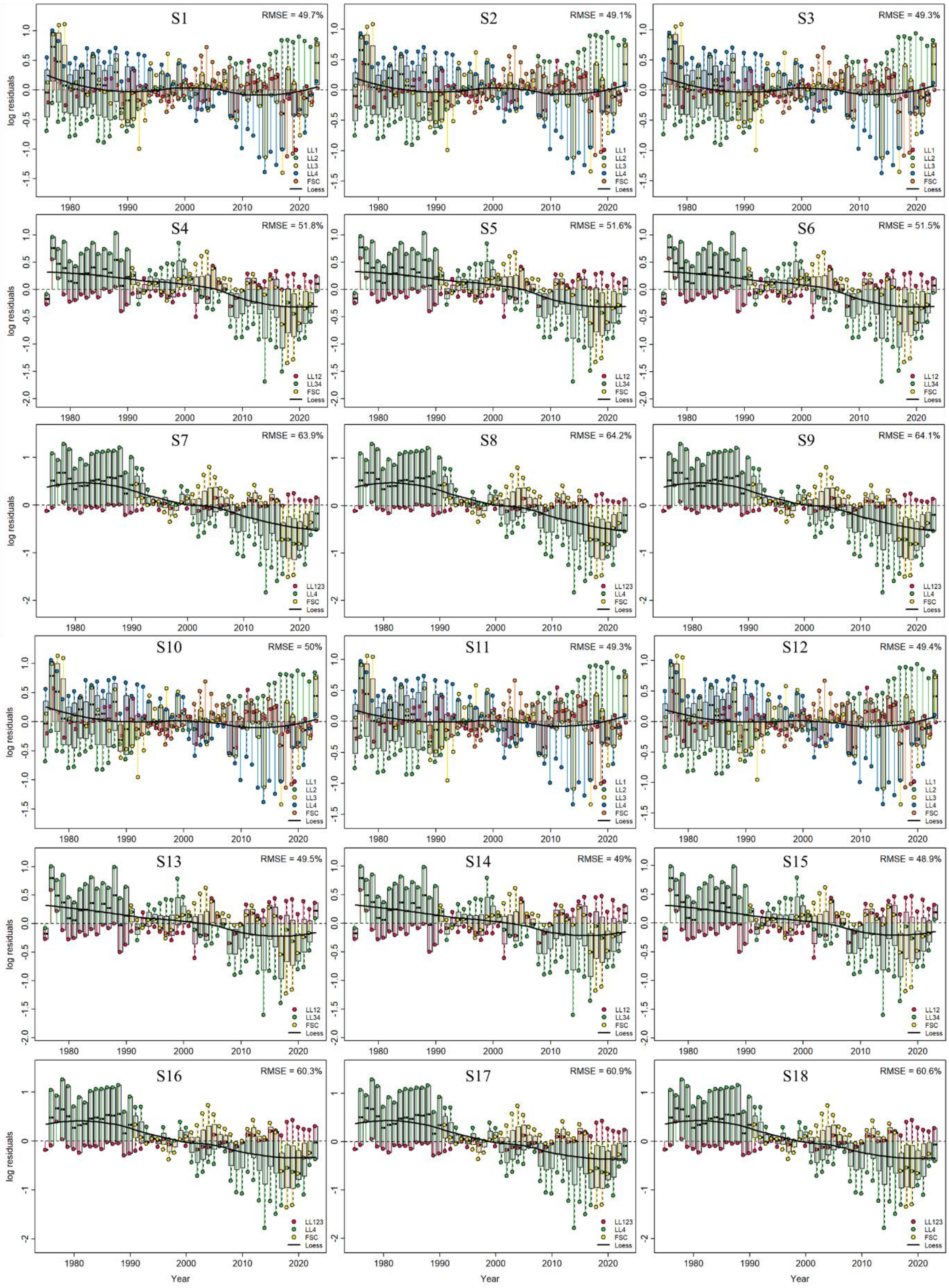

Figure 1. Residuals of standardized CPUEs of Indian Ocean yellowfin tuna S1−S18 scenarios of JABBA

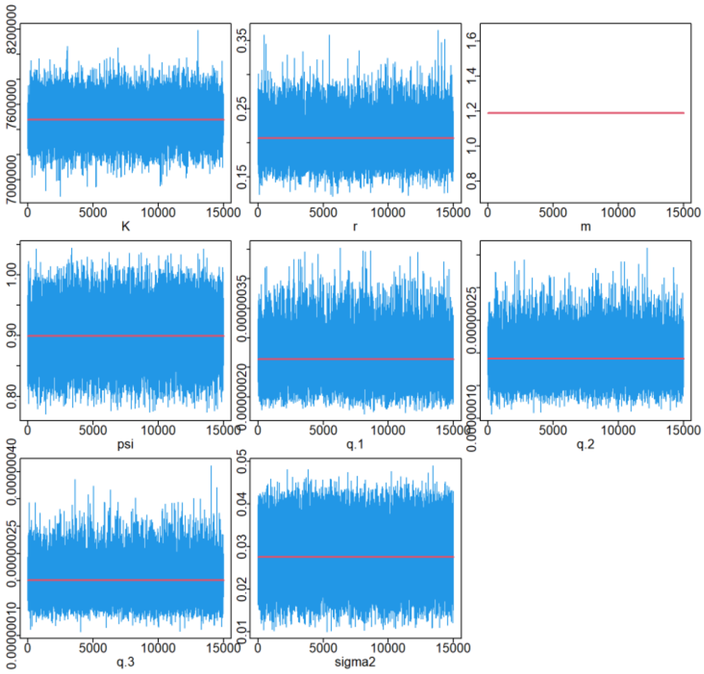

Figure 2. MCMC diagnosis of Indian Ocean yellowfin tuna JABBA base case

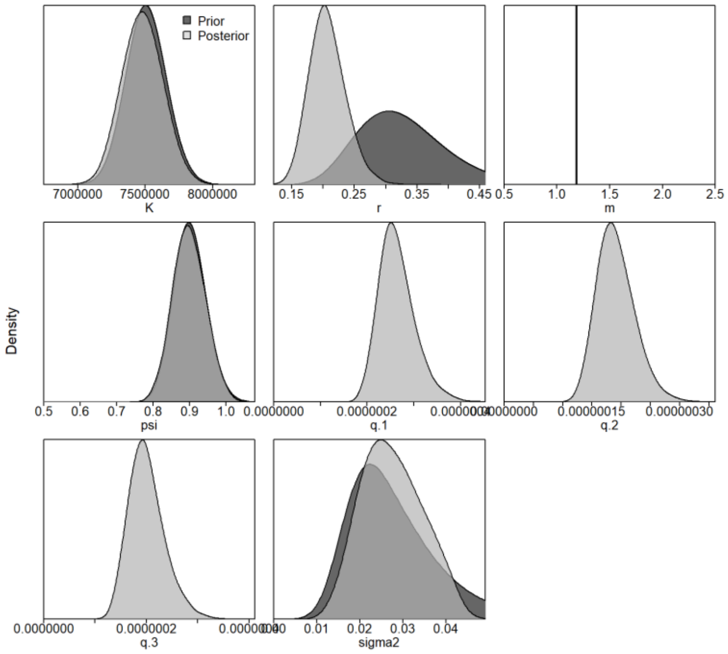

Figure 3. Priors (dark) and posteriors (light) of parameters of base model in JABBA for Indian Ocean yellowfin tuna

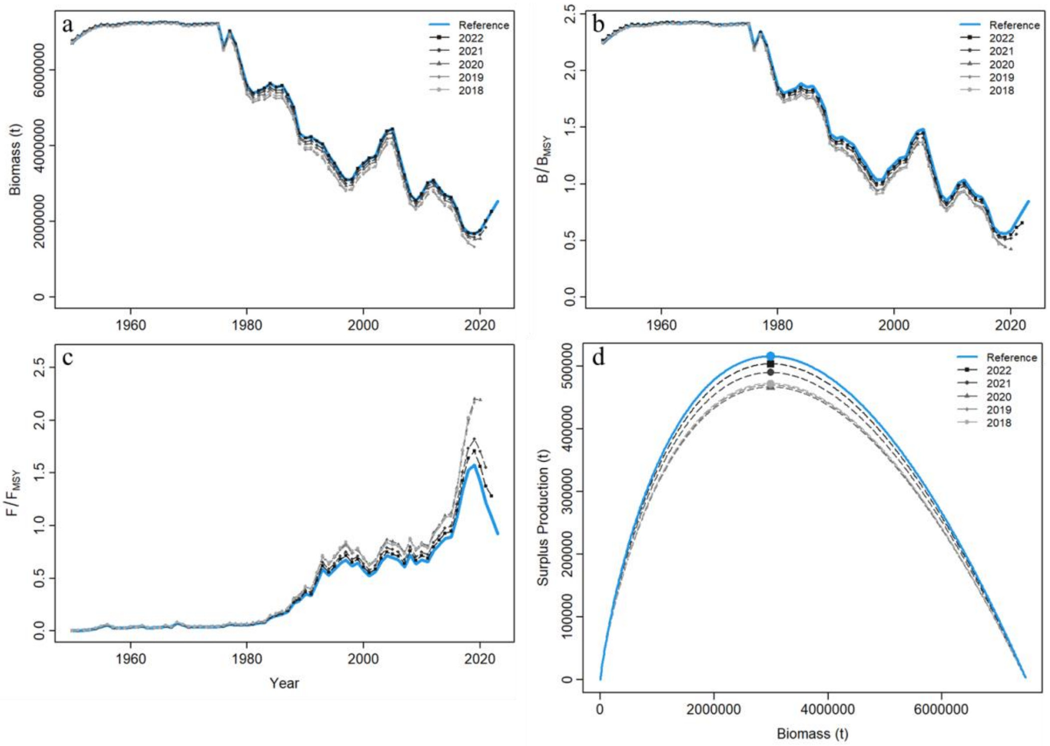

Figure 4. Retrospective analysis of B, B/B_{MSY}, F/F_{MSY} and surplus production of base case in JABBA of Indian Ocean yellowfin tuna

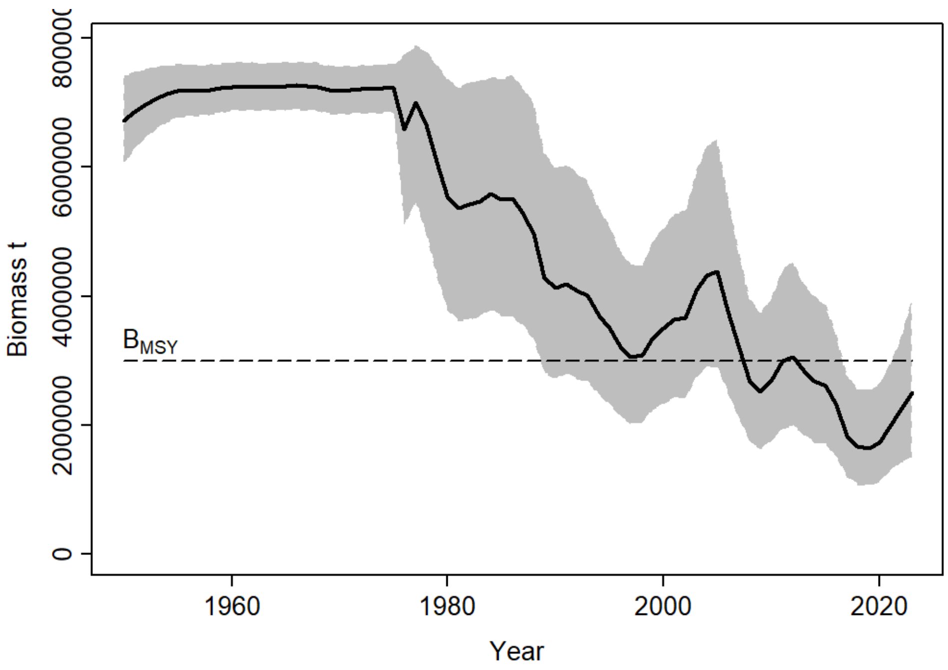

Figure 5. The biomass of Indian Ocean yellowfin tuna from 1950 to 2023 (base case)

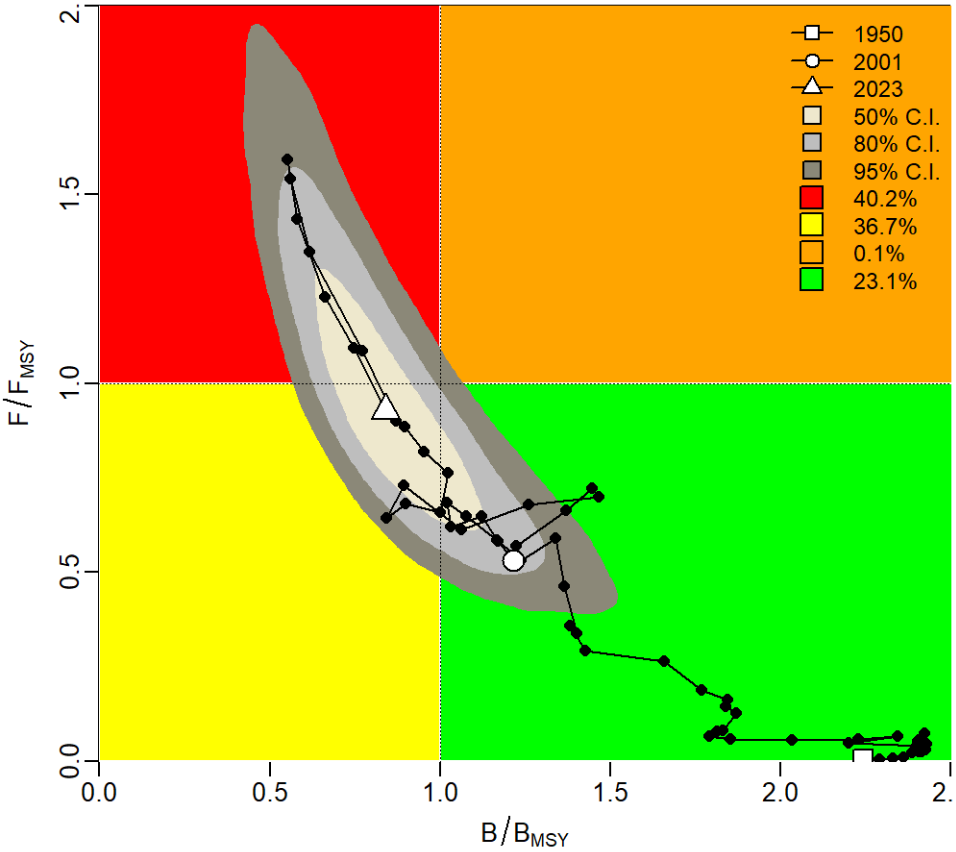

Figure 6. Kobe plot of the assessment of stock status for yellowfin tuna in the Indian Ocean

(base case)

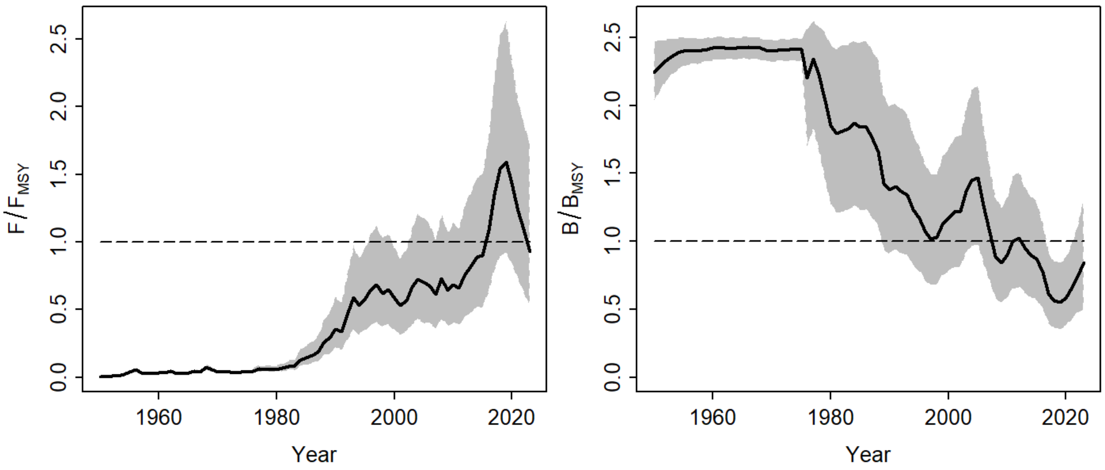

Figure 7. F/F_{MSY} and B/B_{MSY} of Indian Ocean yellowfin tuna of base case in JABBA

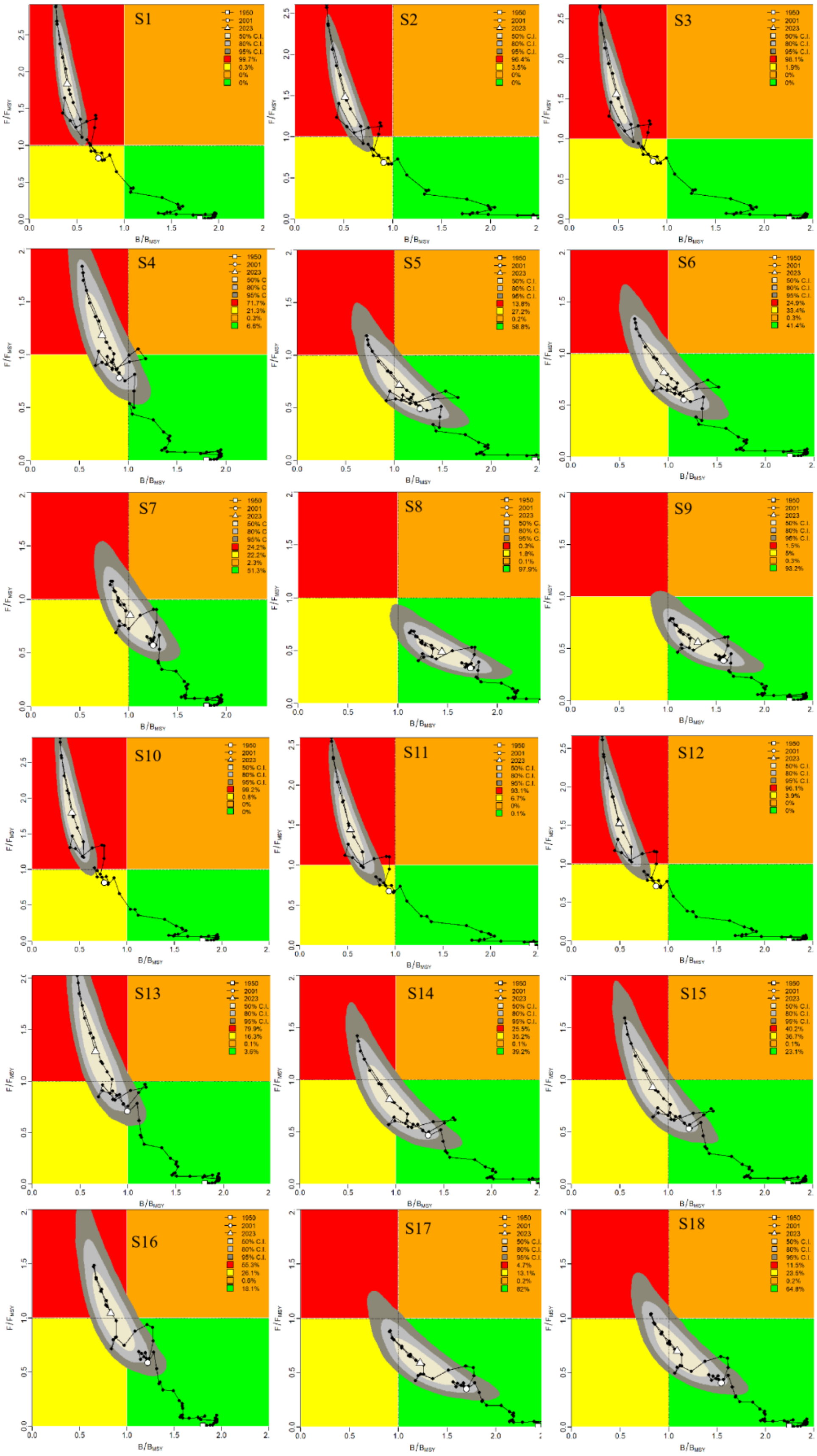

Figure 8. Kobe plots of the assessment of stock status for yellowfin tuna in the Indian Ocean (S1-S18)

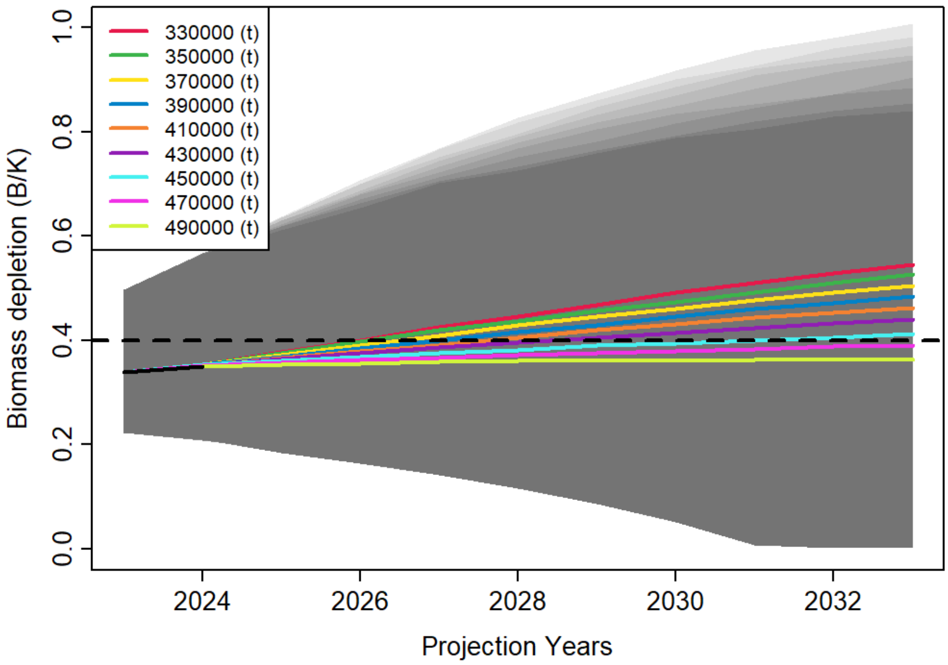

Figure 9. 10-year projections from base case S15 for JABBA stock assessment of YFT in the Indian Ocean

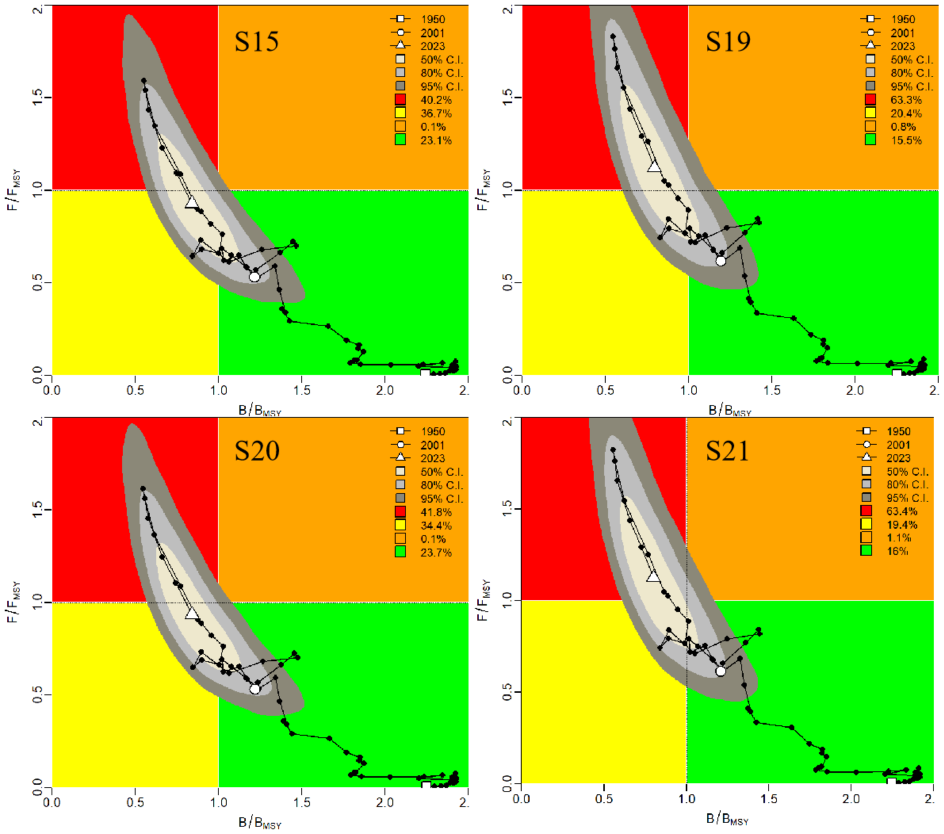

Figure 10. Kobe plots of the assessment of stock status for yellowfin tuna in the Indian Ocean (S15, S19-S21)