Stock assessment of black marlin (*Makaira indica*) in the Indian Ocean using the JABBA

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ABSTRACT

In this study, the stock assessment for black marlin in the Indian Ocean was used to conduct using Just Another Bayesian Biomass Assessment (JABBA) based on the model specifications from scenario S2 of Parker (2021), which was adopted by WPB as a reference case, with updated catches and standardized CPUE indices. Five scenarios were created based on model specifications that incorporated three different *r* priors and associated input values of B_{MSY}/K, and two different three different process error variance. The results from most scenarios indicated that the current status of black marlin in the Indian Ocean is not overfished but may be subjected to overfishing.

1. INTRODUCTION

In 2021, the stock assessment of balck marlin in the Indian Ocean was conducted using only the Bayesian Surplus Production Model (JABBA) (IOTC, 2021). Six scenarios were selected in that assessment, which incorporated three different CPUE time-series combinations, three different priors for intrinsic population growth rate *r* and associated input values of B_{MSY}/K, and two different values for process error. The results of JABBA indicated that MSY-based reference points were not exceeded for the Indian Ocean population as a whole ($F_{2019}/F_{MSY} < 1$; $SB_{2019}/SB_{MSY} > 1$). However, due to the catch levels appeared to be inconsistent with the observed increase in CPUE, the stock assessment was highly uncertain. Therefore, the black marlin stock was classified as “Not assessed/Uncertain” and should be treated with extreme caution (IOTC, 2021; 2022b).

Here we provide an updated stock assessment of black marlin in the Indian Ocean using JABBA by incorporating the updated catches and standardized CPUE series from various fleets. The model specifications followed scenario S2 of Parker (2021), which was adopted by WPB as a reference case.

2. MATERIALS AND METHODS

2.1 Assessment model

The stock assessment analysis was conducted by fitting the catch data and standardized CPUE series to JABBA (version 2.3.0), which is available as 'R package' that can be installed from github.com/jabbamodel/JABBA. A full JABBA model description, including formulation and state-space implementation, prior specification options and diagnostic tools is available in Winker et al. (2018a).

2.2 Data used

The catch data from 1950 to 2022 were provided by IOTC secretariat and the aggregated total catch of all fleets was used in the assessment (Fig. 1).

The standardized CPUE series were available from Taiwanese (TWN by 2 areas, 2005-2022; Xu et al., 2024), and Japanese (JPN, 1994-2022; Matsumoto et al., 2024) and Indonesian (IND, 2006-2022; Setyadji et al., 2024) longline fleets. In this study, the CPUE data were used based on the Reference Model of Parker (2021): TWN_NW (2005-2022), TWN_NE (2005-2022), JPN (1994-2022) and IND (2006-2022).

2.3 Model specifications

As suggested by the previous IOTC WPB, the time period of the assessment started in 1950 when the stock would have been very close to unfished biomass (IOTC, 2021).

Based on the study of Parker (2021), Pella-Tomlinson production function was used for the assessment analysis. Five model specifications based on three different *r* priors and associated input values of B_{MSY}/K, and three different process error variances were considered in this study. The input priors were objectively derived from the simulations in an Age Structured Equilibrium Model ASEM (Winker et al., 2018b; Winker et al., 2018c), which allowed approximating the parameterizations based on range of stock recruitment steepness values for the stock recruitment relationship (h = 0.4, h = 0.5 and h = 0.6), while admitting reasonable uncertainty about the natural mortality M. The *r* prior associated with B_{MSY}/K = 0.37 (h = 0.5) was set as the reference scenario, as in the 2021 assessment. In addition, a scenario with a higher *r* prior that corresponds to a higher steepness value of h = 0.6 and a scenario with a lower *r* prior based on h = 0.4, were also run (Table 1).

The unfished equilibrium biomass (K) was set an informative lognormal prior with a mean 50,000 metric tons and CV of 300%. The initial depletion ($\varphi = B_{1950}/K$) was set a lognormal prior with mean = 1 and CV of 10%. Initial trials indicated that estimating the process error (sigma) resulted in large variance estimates that would result implausible large variations in annual stock biomass. Therefore, in addition to the reference scenario where the process error was fixed at 0.07 (see Ono et al., 2012 for details), two scenarios were considered: one where the process error was fixed at 0.2, and another where it was estimated using an inverse-gamma distribution with mean = 0.07 and CV = 0.01 (Table 1). The following five scenario specifications were run in this study:

- S1 (Ref.): for B_{MSY}/K = 0.37 (h = 0.5), *r* prior *LN* ~ (log (0.19), 0.3), process error = 0.07
- S2 (Low): for B_{MSY}/K = 0.41 (h = 0.4), *r* prior *LN* ~ (log (0.16), 0.3), process error = 0.07
- S3 (High): for B_{MSY}/K = 0.34 (h = 0.6), *r* prior *LN* ~ (log (0.21), 0.3), process error = 0.07
- S4 (Proc.): for B_{MSY}/K = 0.37 (h = 0.5), *r* prior *LN* ~ (log (0.19), 0.3), process error = 0.2
- S5 (Est. Proc.): for B_{MSY}/K = 0.37 (h = 0.5), *r* prior *LN* ~ (log (0.19), 0.3), process error variance prior *igamma* ~ (0.07, 0.01)
- S6: Same priors with S1 (BMSY/K = 0.37 (h = 0.5), r prior LN ~ (log (0.19), 0.3), process error = 0.07) but exclude Indonesian CPUE.
- Same priors with S1 (BMSY/K = 0.37 (h = 0.5), r prior LN ~ (log (0.19), 0.3), process error = 0.07 and include Japanese CPUE from 1979 to 1993

To further evaluate the robustness of important stock status quantities (biomass, surplus production, B/B_{MSY} and F/F_{MSY}) for use in projections, we conducted a retrospective analysis (Mohn, 1999) for the reference scenario (S1) by sequentially removing the most the recent year (retrospective 'peel') and refitting the model over a period of ten years (i.e. 2022 back to 2017).

3. RESULTS AND DISCUSSIONS

Based on the examination of marginal posterior and prior distributions, the relatively narrow posterior distribution and the small prior to posterior variance ratio (PPVR) suggest that the data are to some extent informative for *K*. The extensive prior/posterior overlap, as well as both PPMR and PPVR values close to 1, indicate that the posterior for initial depletion (φ) was largely informed by the prior (Fig3. 2 and 3).

The model appeared to fit CPUE data well, and run tests conducted on the log-residuals indicated no evidence to reject the hypothesis of randomly distributed residual patterns except for CPUE of JPN (S1) and JPN in the early period (Figs. 4 and 5). CPUE model fits were generally comparable among all scenarios (Fig. 6), which was also supported by the similarity in the goodness-of-fits as judged by the narrow range RMSE values (RMSE = 29.9% - 32.9%).

The retrospective analysis for reference scenario (S1) showed highly consistent stock status estimates back to 2017 (Fig. 7). The estimated Mohn's rho for B (ρ = 0.07) and B/B_{MSY} (ρ = 0.03) fell well within the acceptable range of -0.15 and 0.20 (Carvalho et al., 2017; Hurtado-Ferro et al., 2015) and confirm the absence of an undesirable retrospective pattern.

Based on the hindcasting cross-validation of reference scenario (S1), results for the TWN_NW and IND indices suggest that the model has good prediction skill as judged by the MASE scores of 0.86 and 0.79, respectively, which indicates that future projections are consistent with reality of model-based scientific advice (Fig. 10).

The estimated biomass and fishing mortality for all scenarios were shown in Fig. 9. The biomass trajectory showed a decline from the mid-1990s to the mid-2000s, followed by a moderate recovery, and then a subsequent decrease by the mid-2010s, but it remained above B/B_{MSY} = 1. In contrast, fishing mortality increased steadily after 1990 and reached a peak in 2022, with a brief period of stability between 2004 and 2010. The highest fishing levels in 2022 likely exceeded F/F_{MSY} = 1 in scenarios with low production (S2), increased process error (S4) and estimated process error (S5). The scenario with higher process error (S4) and with JPN CPUE in the early period (S7) are considerably more pessimistic than those from other scenarios.

The MSY estimates ranged between 12,108 (S4) and 18,143 (S3) tons for all five scenarios (Table 2) and the corresponding range of B_{MSY} estimates was between 54,143 tons (S4) and 101,517 tons (S2). The range of median F/F_{MSY} estimates were between 0.77 (S3) and 1.83 (S4) and the reference scenario (S1) F_{MSY} estimate was 0.21. The range of median estimates for B/B_{MSY} was 1.2 - 1.84 and the range for B/K median estimates was 0.44 - 0.62 (Table 2).

Figs. 10 and 11 show the Kobe plot for scenarios S1-S5. The Kobe plots for scenarios S1 and S3 were similar, with the highest probability of terminal (2022) point being in the "green" quadrant. In contrast, the terminal point for scenarios S2, S4, and S5 showed the highest probability of being in the "orange" quadrant. A risk of being overfished and overfishing may occur only in a scenario with higher process error (S4) based on the confidence surfaces. Notably, an implausible trajectory is evident in all Kobe plots which suggest that black marlin B/B_{MSY} increases with an associated increase in F/F_{MSY} for the period 2010-2016. The results of JABBA reference scenario (S1) indicated that the current status of black marlin in the Indian Ocean is not overfished but may be subjected to overfishing.

Projections with future catch at constant levels from 40% to 160% indicated that the stock status of black marlin in the Indian Ocean may be not overfished and not subject to overfishing when fishing exploitation can be maintained at current catch level (Fig. 12).

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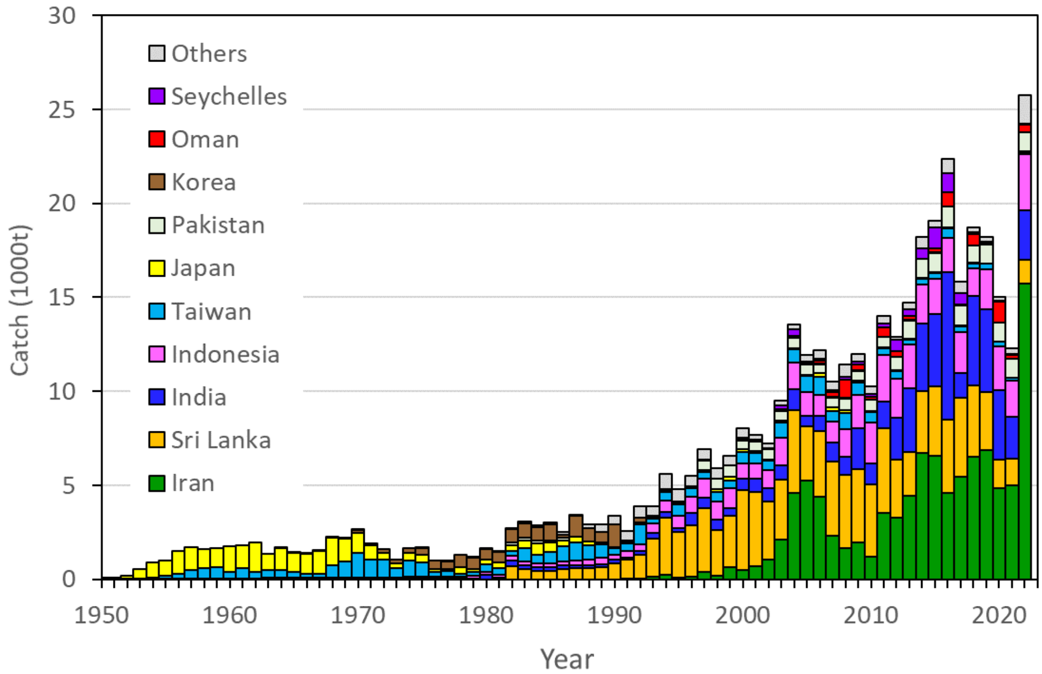


Fig. 1. Annual catches by fleets black marlin in the Indian Ocean during 1950–2022.

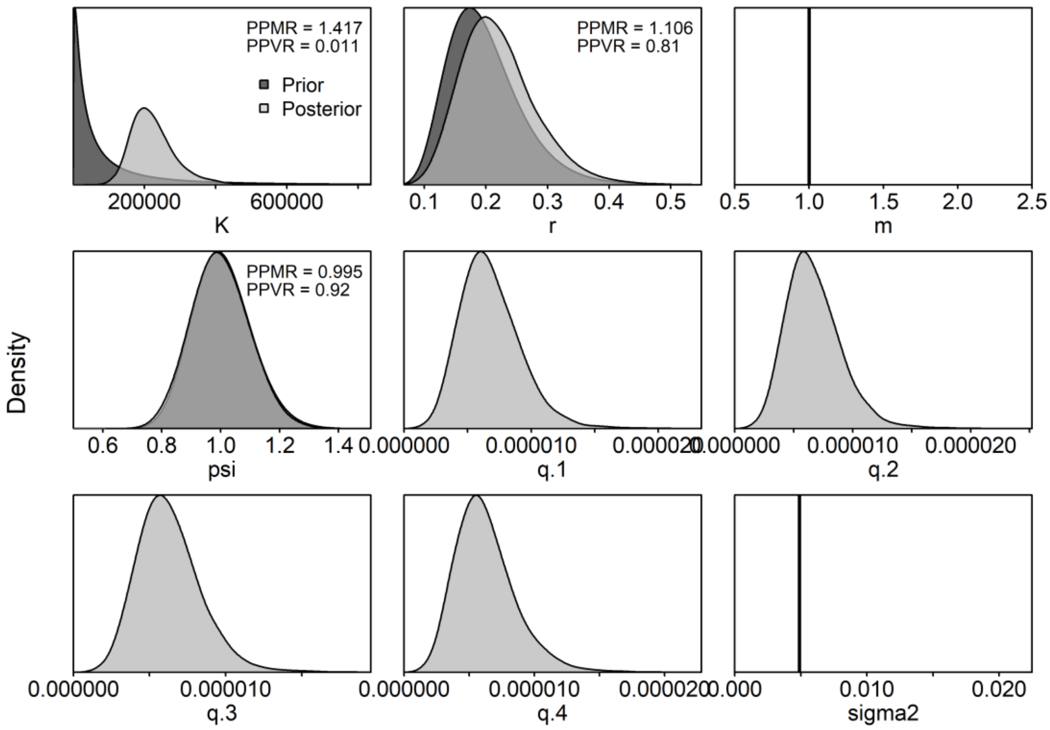


Fig. 2. Prior and posterior distributions for reference scenario (S1) for black marlin in the Indian Ocean. PPRM: Posterior to Prior Ratio of Means; PPRV: Posterior to Prior Ratio of Variances.

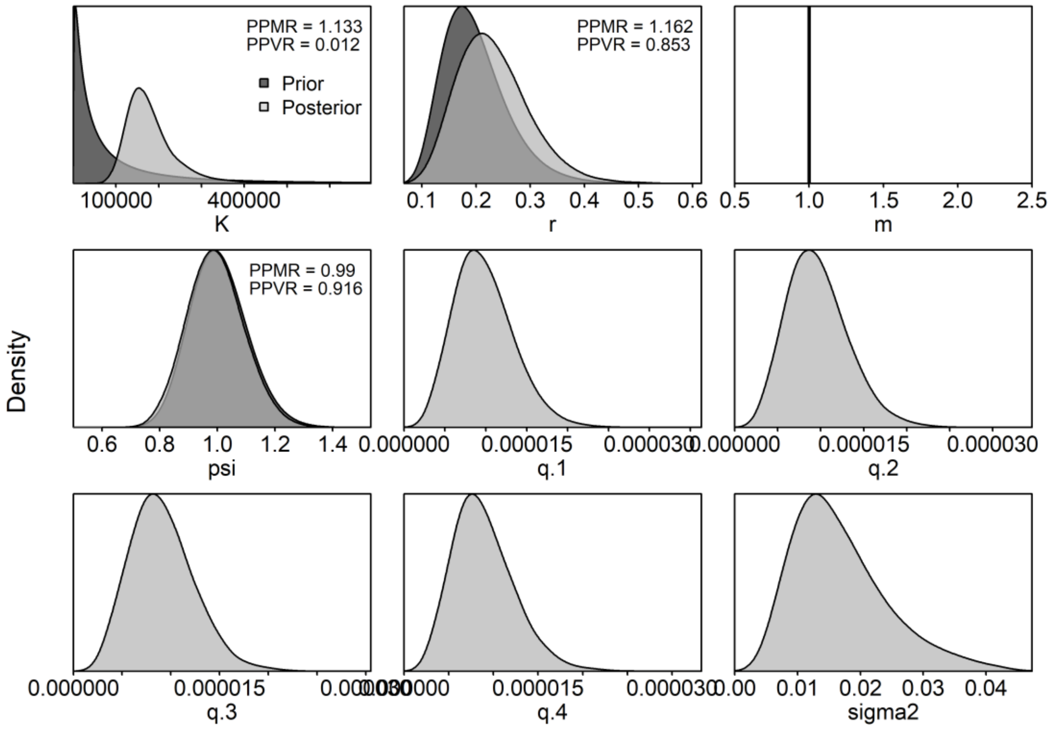
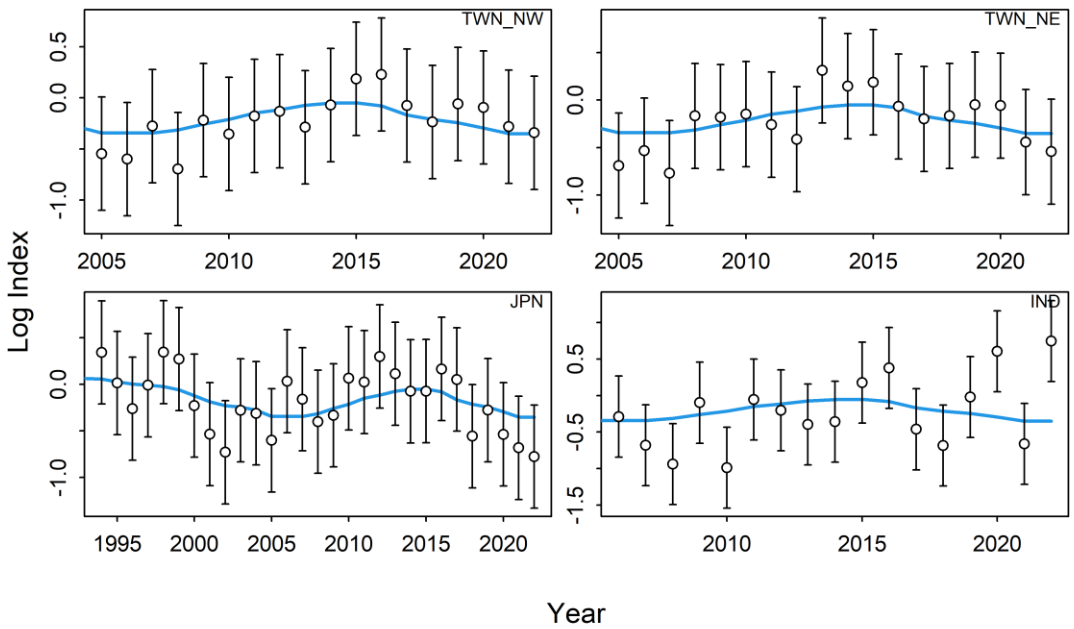


Fig. 3. Prior and posterior distributions for reference scenario (S5) for black marlin in the Indian Ocean. PPRM: Posterior to Prior Ratio of Means; PPRV: Posterior to Prior Ratio of Variances.

S1



S6

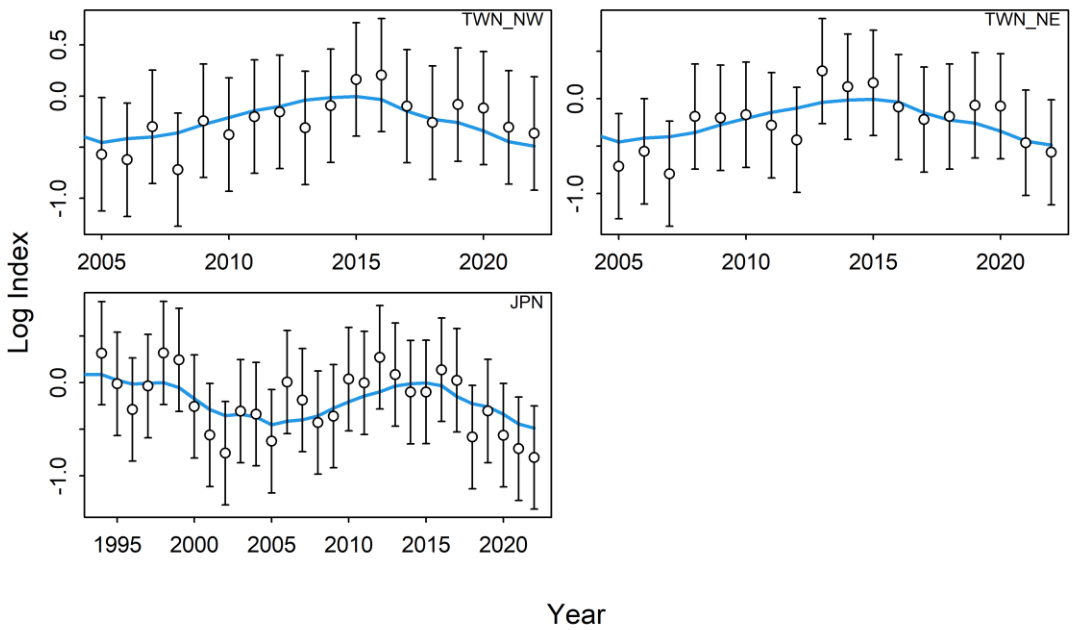


Fig. 4. Time-series of observed (circle) with 95% confidence intervals (error bars) and predicted (solid line) CPUE of JABBA reference scenario (S1) for black marlin in the Indian Ocean.

S7

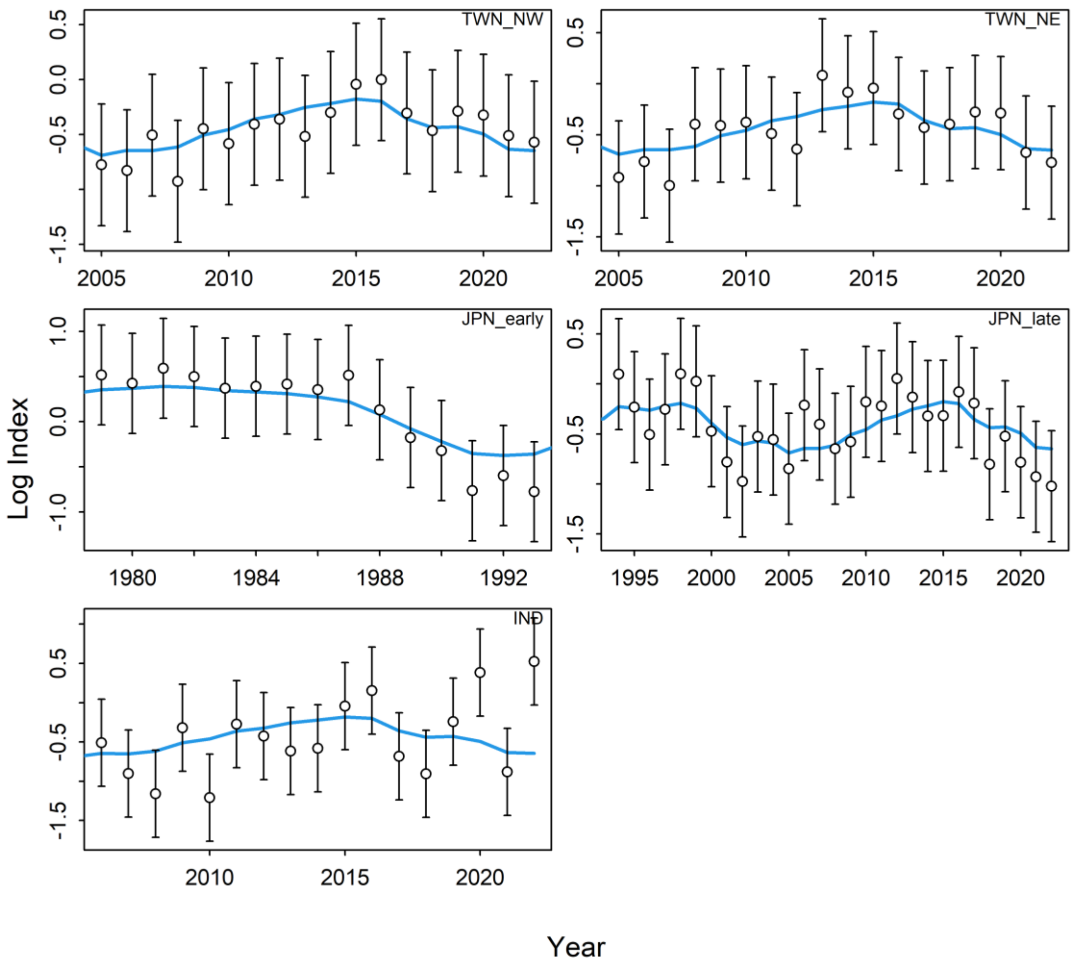


Fig. 4. (Continued).

S1

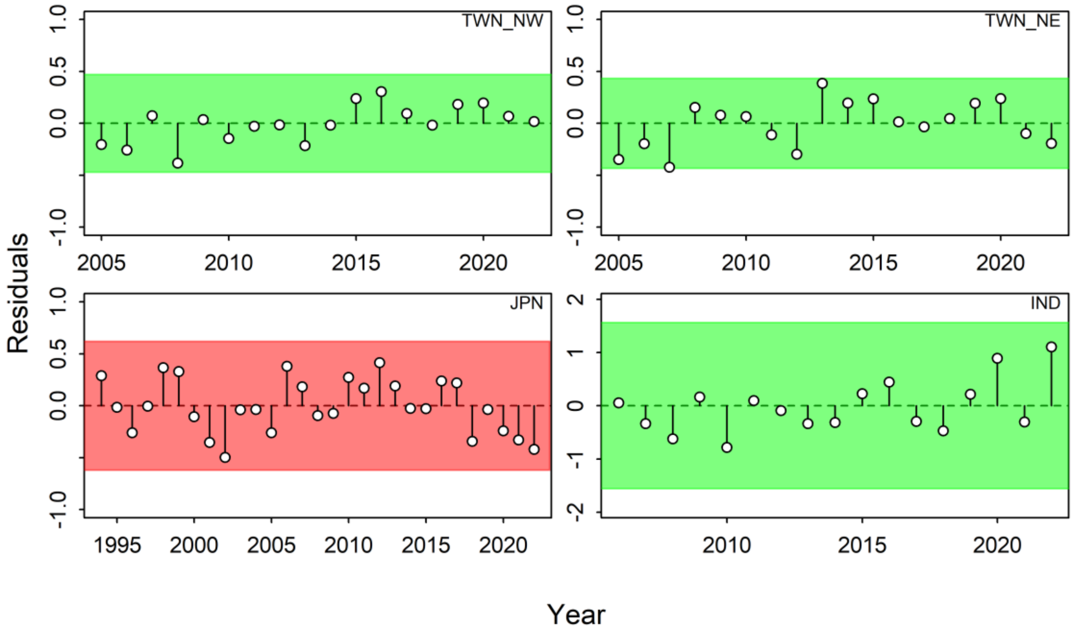
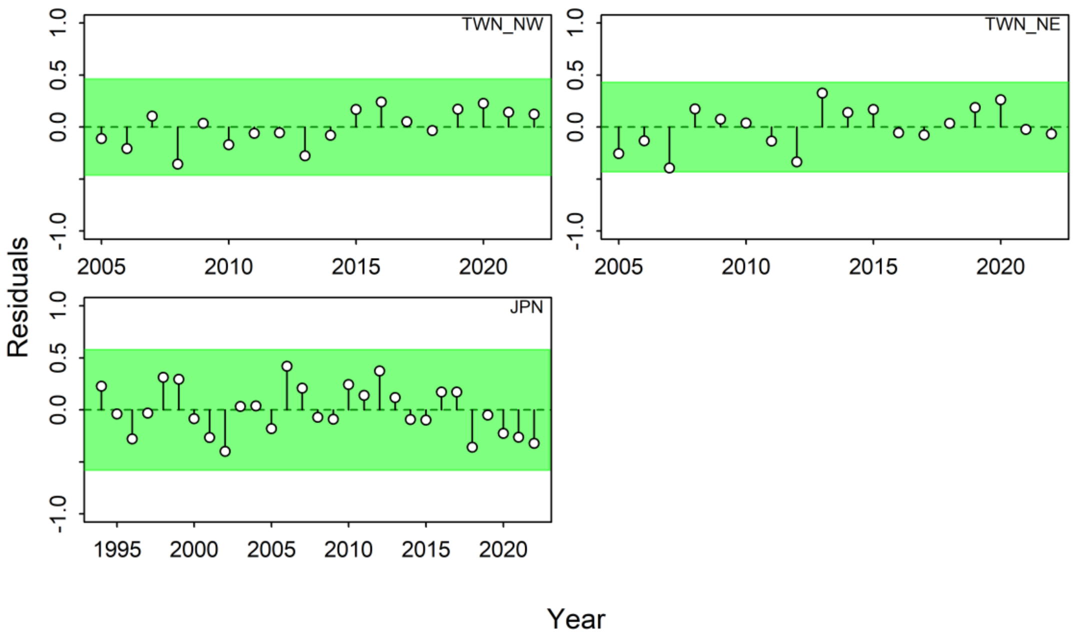


Fig. 4. Runs tests of JABBA reference scenario (S1) for the randomness of the time series of CPUE residuals by fleet for black marlin in the Indian Ocean. Green panels indicate no evidence of lack of randomness of time series residuals (p>0.05) while red panels indicate the opposite. The inner shaded area shows three standard errors from the overall mean and red circles identify a specific year with residuals greater than this threshold value (3x sigma rule).

S6



S7

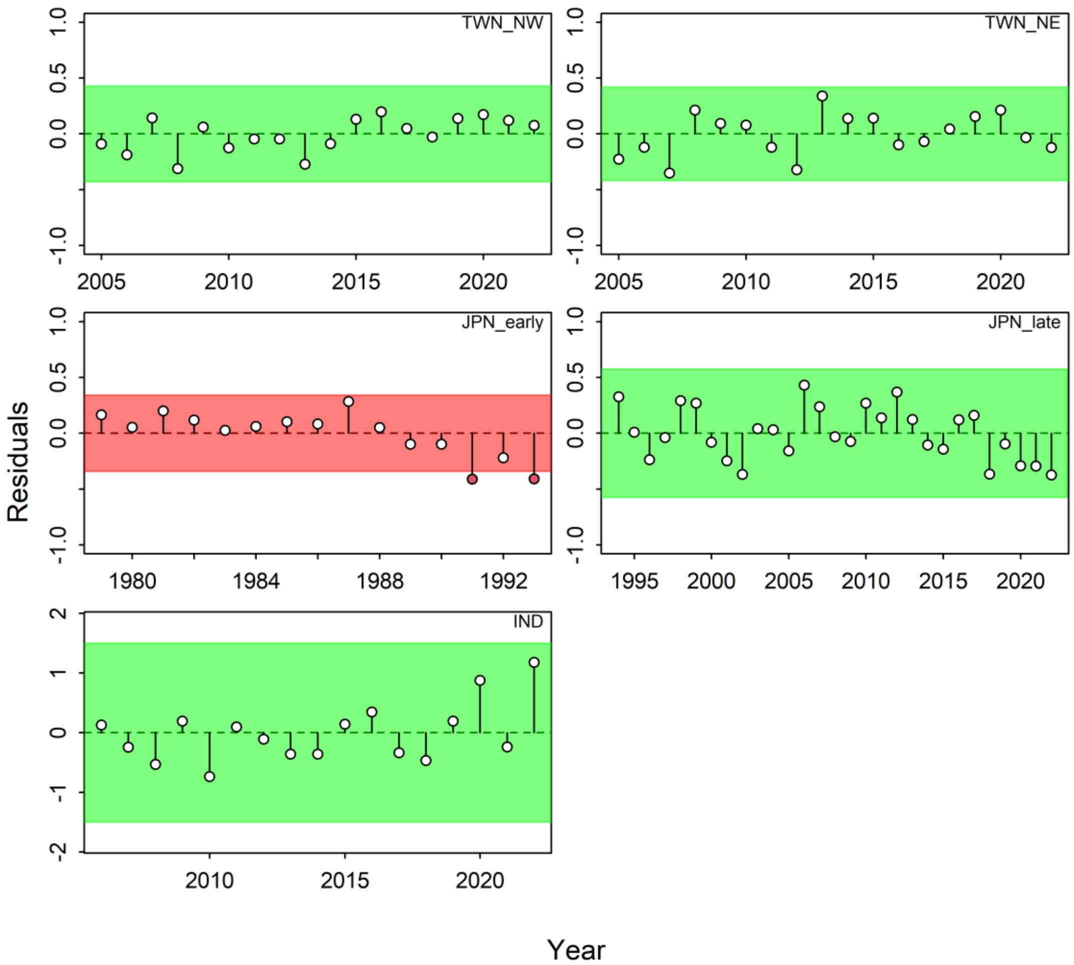


Fig. 5. (Continued).

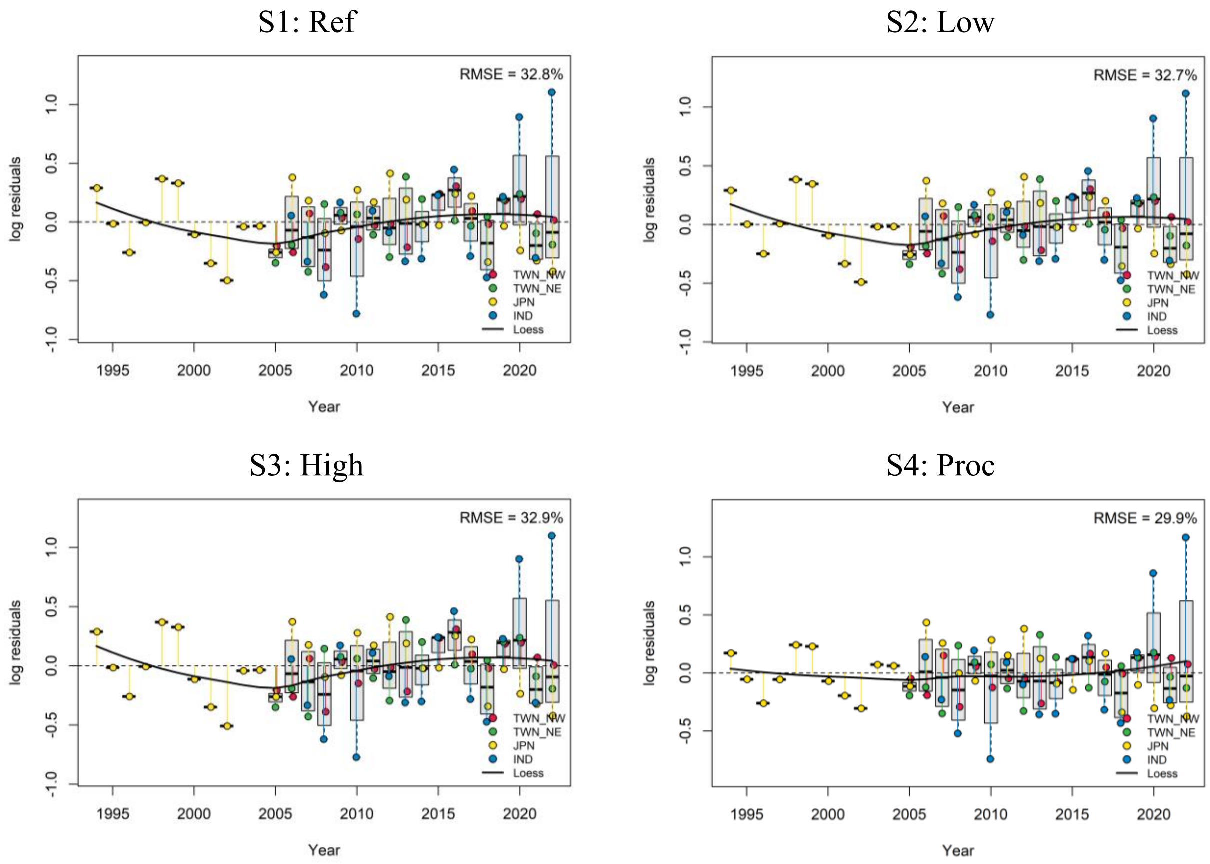
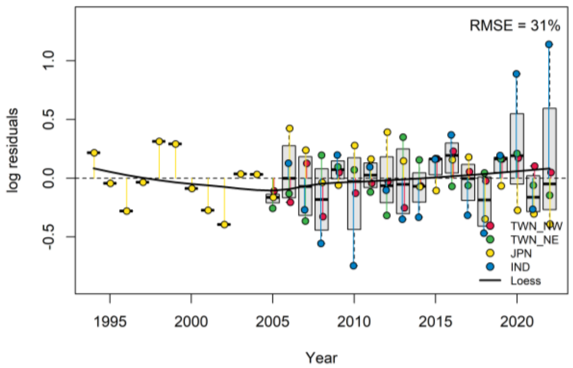
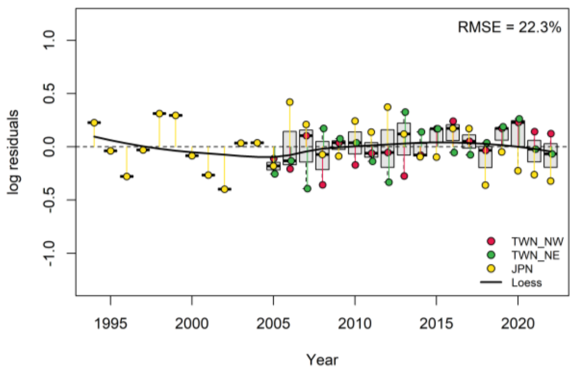


Fig. 6. Residual diagnostic plots of JABBA for all scenarios for CPUE indices for black marlin in the Indian Ocean. Boxplots indicating the median and quantiles of all residuals available for any given year, and solid black lines indicate a loess smoother through all residuals.

S5: Proc.est



S6



S7

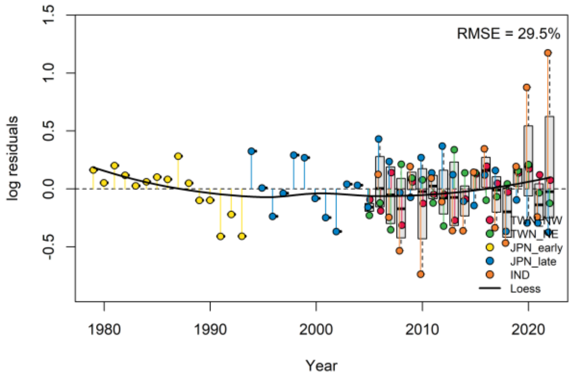


Fig. 6. (Continued).

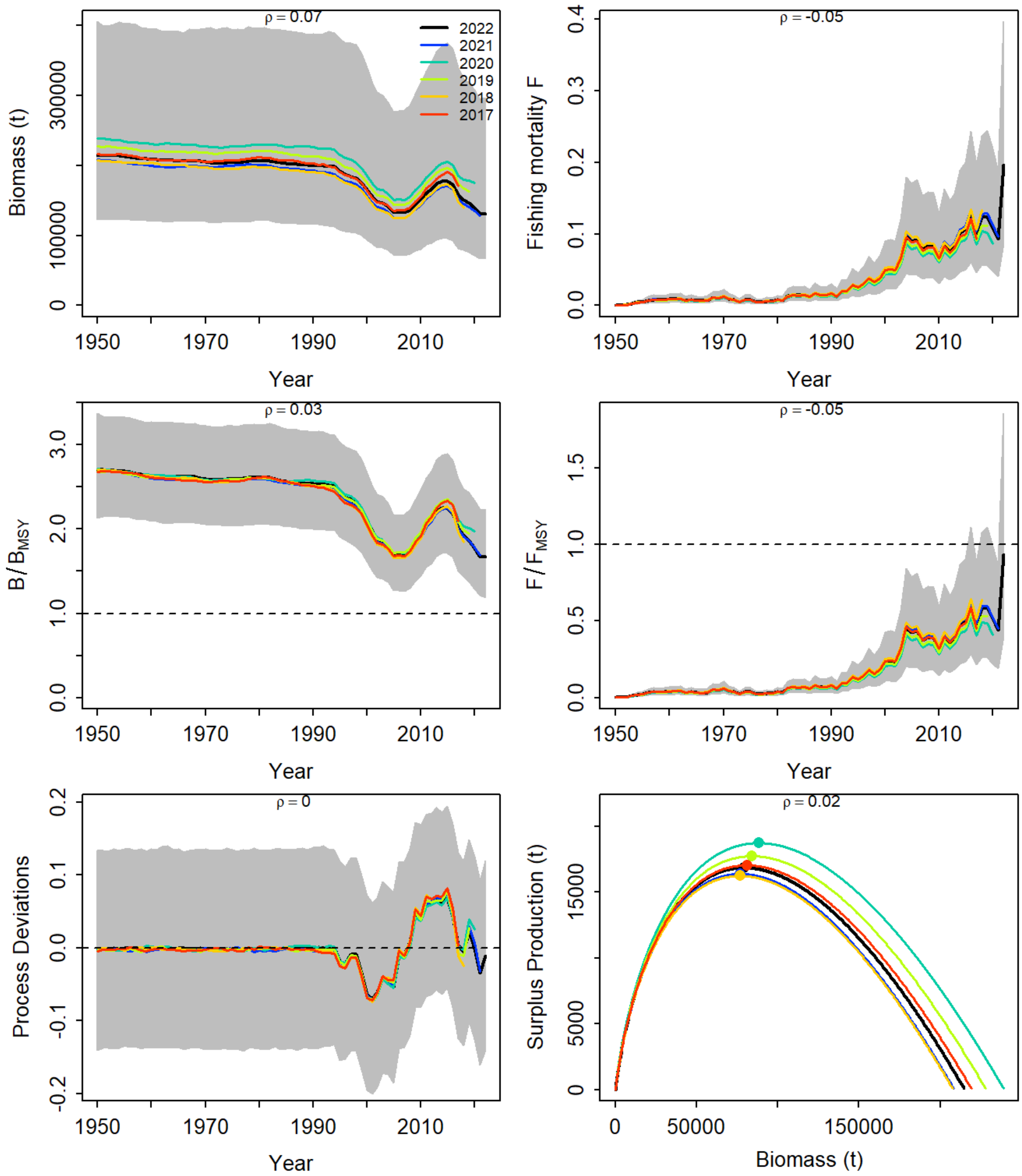


Fig. 7. Retrospective analysis for estimated biomass, fishing mortality, B/B_{MSY} and F/F_{MSY} with 95% confidence intervals and surplus production function (maximum = MSY) for the Indian Ocean black marlin JABBA reference scenario (S1). The numeric year label indicates the retrospective results from the retrospective 'peel', sequentially excluding CPUE data back to 2017.

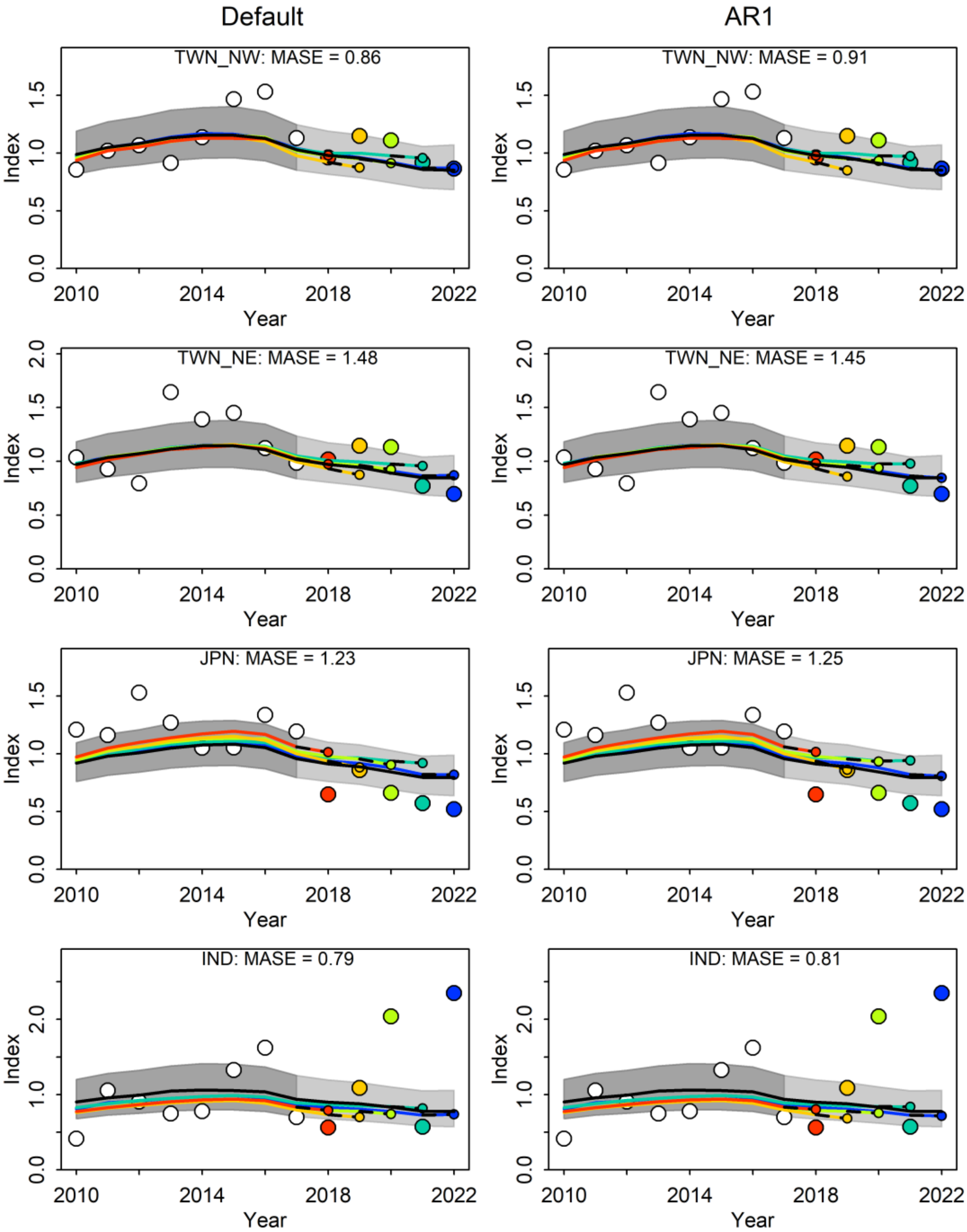


Fig. 8. Hindcasting cross-validation of JABBA (HCxval) reference scenario (S1) for black marlin in the Indian Ocean, showing one-year-ahead forecasts of CPUE values (2017-2022), performed with eight hindcast model runs relative to the expected CPUE. The CPUE observations, used for cross-validation, are highlighted as color-coded solid circles with associated light-grey shaded 95% confidence interval. The model reference year refers to the end points of each one-year-ahead forecast and the corresponding observation (i.e. year of peel + 1).

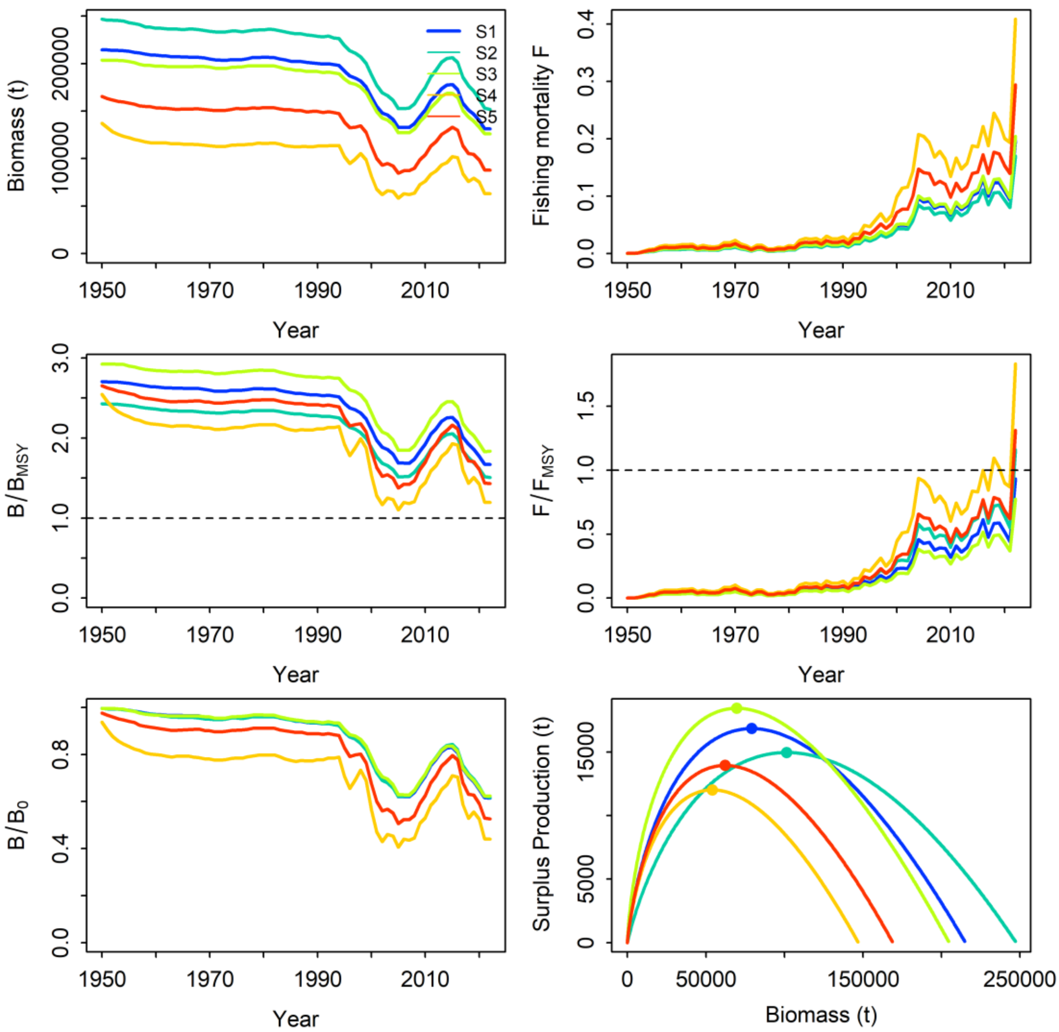


Fig. 9. A comparison of the trajectories of the estimated biomass, fishing mortality, B/B_{MSY}, F/F_{MSY}, proportion of pristine biomass (B/B_0) and surplus production function (maximum = MSY) obtained from JABBA between all scenarios for black marlin in the Indian Ocean.

S6

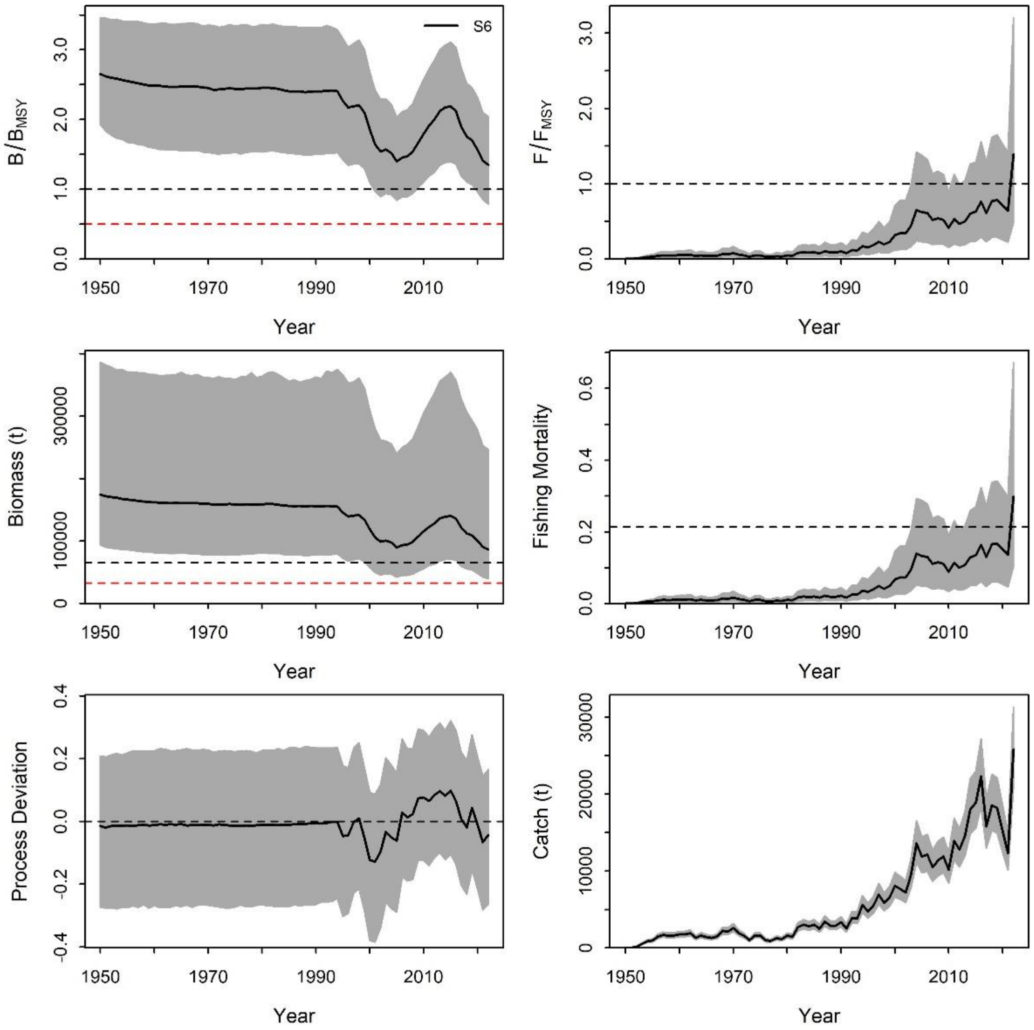
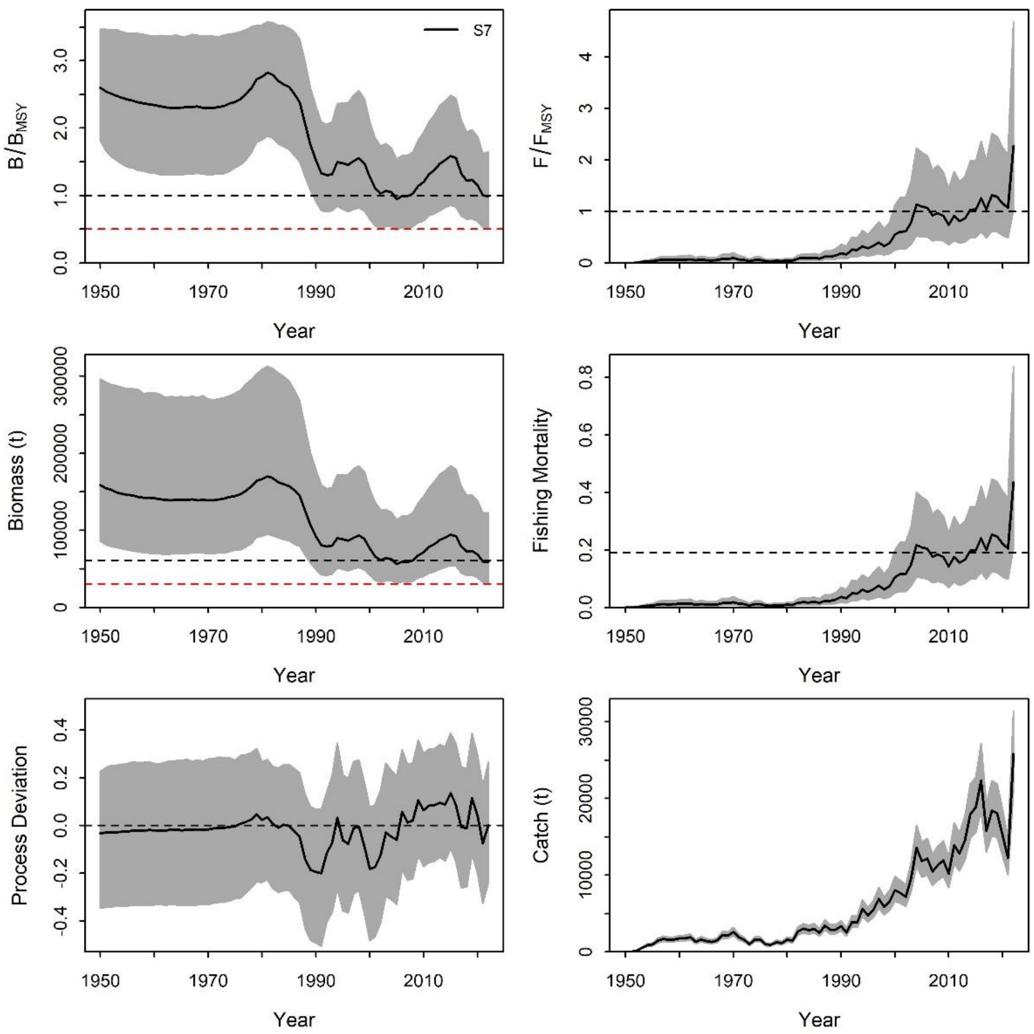


Fig. 9. (Continued).

S7



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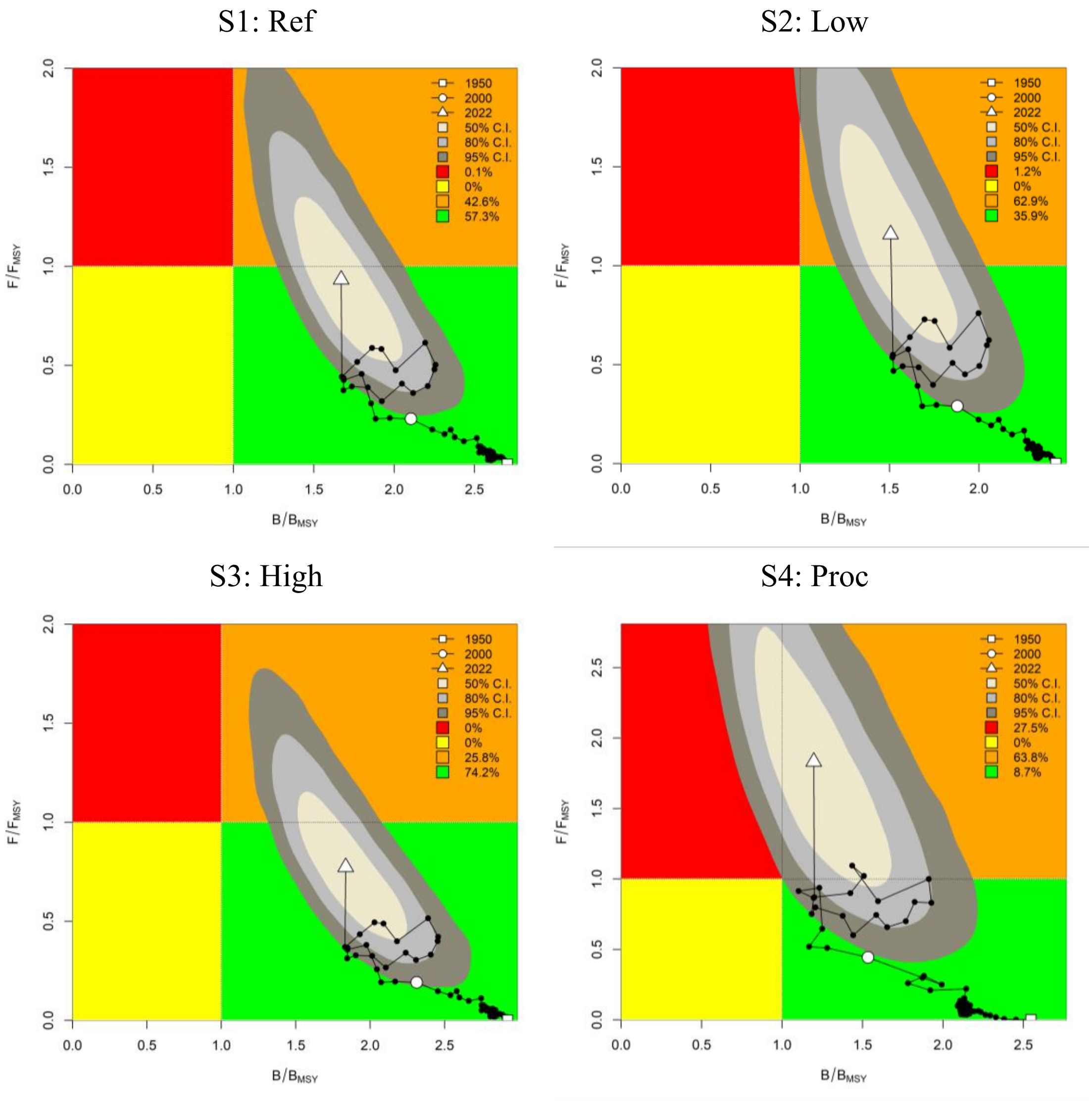
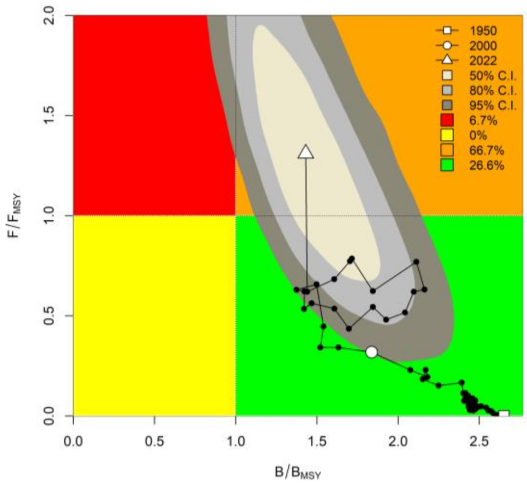
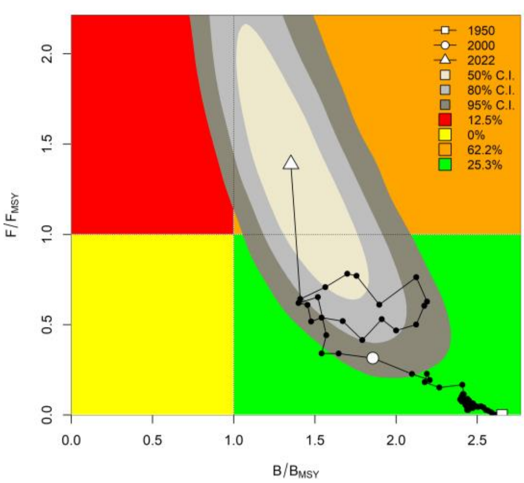


Fig. 10. Kobe plot with bootstrap confidence surfaces around 2022 estimates for black marlin in the Indian Ocean obtained from JABBA for all scenarios.

S5: Proc.est



S6: xIND



S7: JPN1

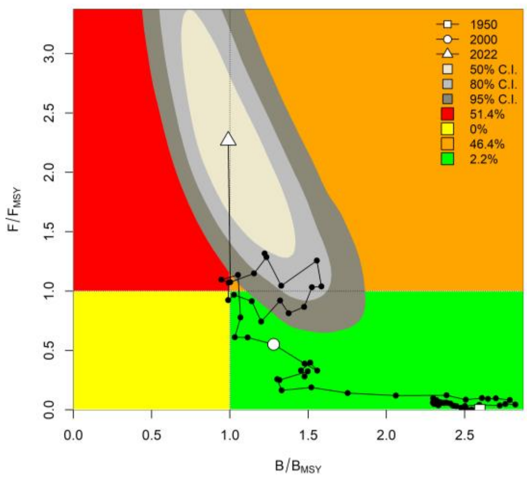


Fig 10. (continued).

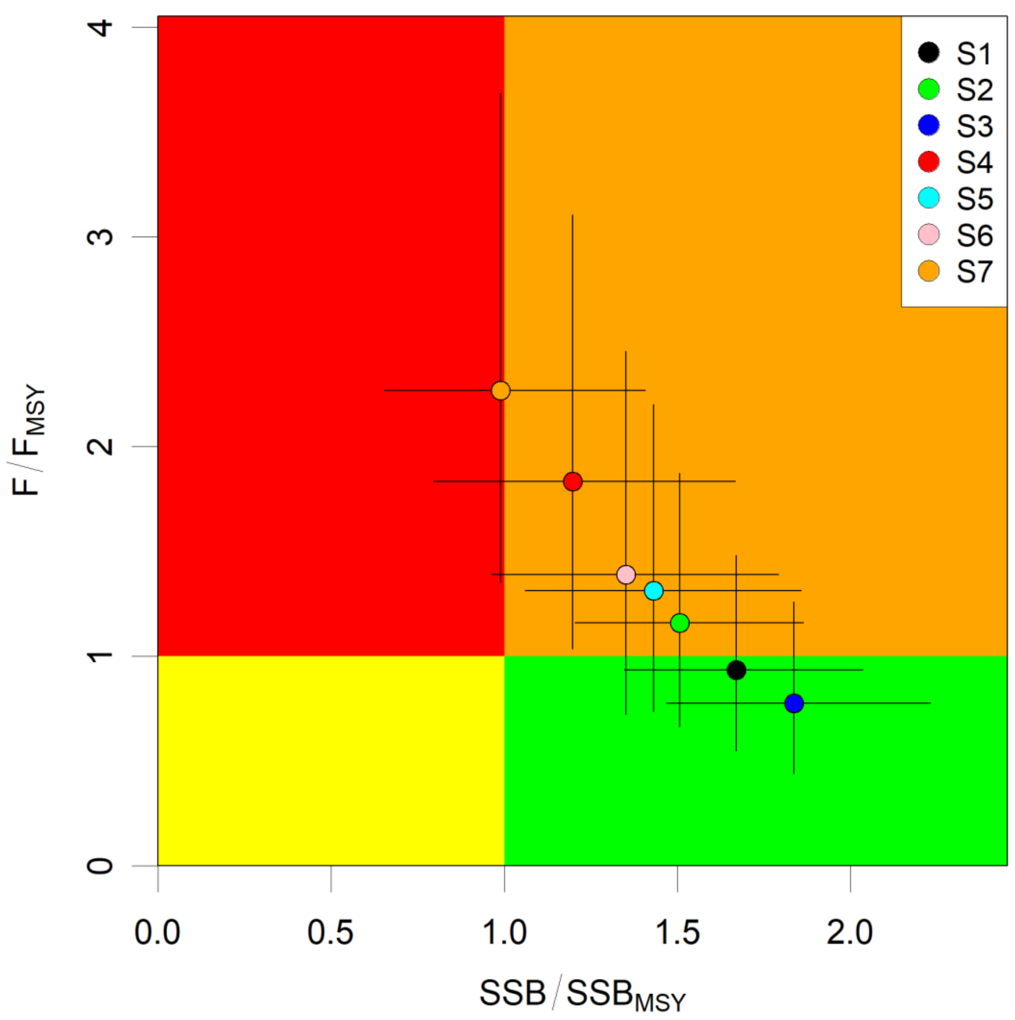


Fig. 11. Kobe plot of 2022 estimates of spawning biomass and fishing mortality relative to their MSY reference points from five scenarios for black marlin in the Indian Ocean. The error bars represent the 80% confidence interval of the estimates.

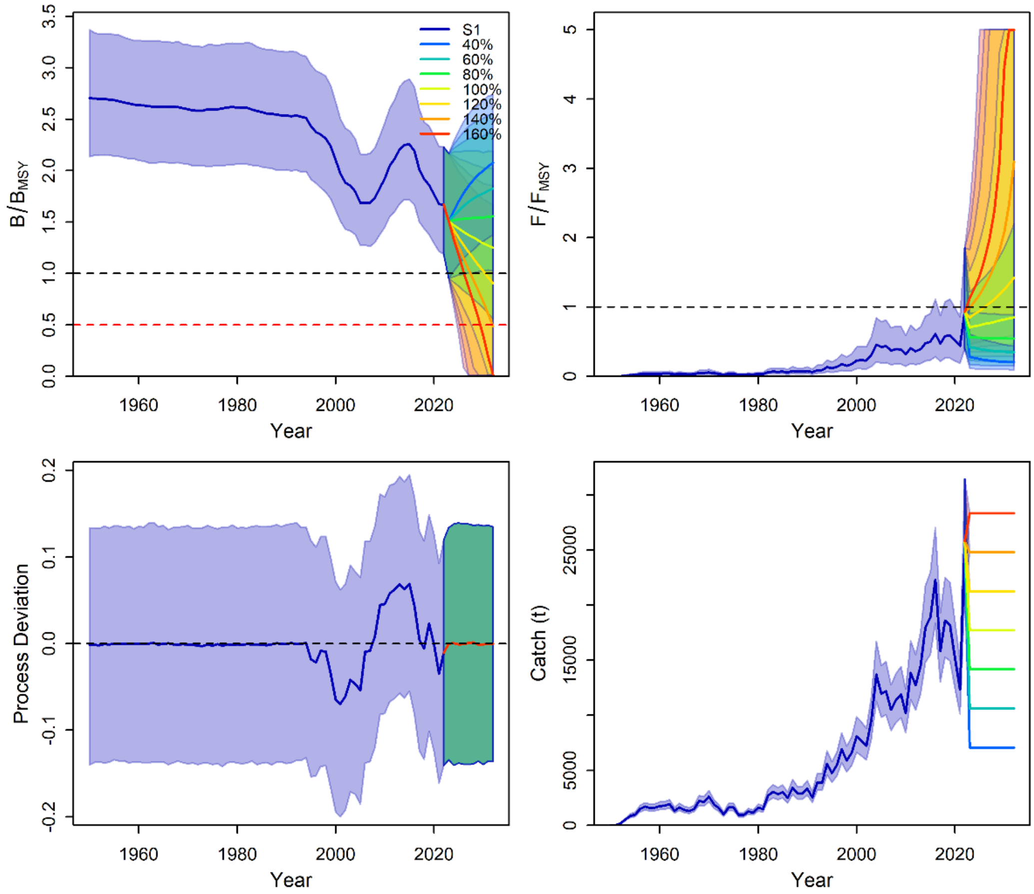


Fig. 12. Projections with 95% confidence intervals of JABBA reference scenario (S1) based on the future catch set at constant levels from 40% to 160% for black marlin in the Indian Ocean.

Table 1. Summary of prior and input parameter assumptions used in 2024 JABBA Indian Ocean black marlin assessment. (ref *h*): Reference scenario corresponding to a Beverton and Holt stock-recruitment steepness parameter of h = 0.5 and B_{MSY}/K ratio of a Fox Surplus Production model; (low *h*): lower *r* run corresponding to h = 0.4; (high *h*): higher *r* run corresponding to h = 0.6 (see Parker, 2021).

Parameter	Description	Prior	mean	CV	Scenario
K	Unfished biomass	lognormal	50,000	300%	All
r (ref *h*)	Population growth rate	lognormal	0.19	30%	S1, S4, S5
r (low *h*)		lognormal	0.16	30%	S2
r (high *h*)		lognormal	0.21	30%	S3
ψ (*psi*)	Initial depletion	lognormal	1	10%	All
s^2 (*proc*)	Process error variance	fixed	0.07	-	S1, S2, S3
s^2 (high *proc*)		fixed	0.2	-	S4
s^2 (estimated *proc*)		inverse-gamma	0.07	1%	S5
B_{MSY}/K (ref *h*)	Ratio Biomass at MSY to K	fixed	0.37	-	S1, S4, S5
B_{MSY}/K (low *h*)		fixed	0.41	-	S2
B_{MSY}/K (high *h*)		fixed	0.34	-	S3

Table 2. Summary of posterior quantiles denoting the 95% confidence intervals of parameters estimates for five scenarios in the JABBA assessment of black marlin.

	Scenario 1 (Ref.)			Scenario 2 (low *h*)		
Estimates	Median	2.5%	97.5%	Median	2.5%	97.5%
K	215268	130902	394217	247570	152254	483872
r	0.21	0.12	0.36	0.18	0.11	0.31
ψ (*psi*)	1.00	0.82	1.20	1.00	0.82	1.20
s^2 (*proc*)	0.07	0.07	0.07	0.07	0.07	0.07
m	1.01	1.01	1.01	1.25	1.25	1.25
F_{MSY}	0.21	0.13	0.36	0.15	0.09	0.25
B_{MSY}	79232	48180	145097	101517	62432	198414
MSY	16644	11121	30127	14772	9545	28472
B_{1950}/K	1.00	0.79	1.24	1.00	0.79	1.24
B_{2022}/K	0.62	0.44	0.82	0.62	0.44	0.84
B_{2022}/B_{MSY}	1.67	1.19	2.23	1.51	1.06	2.06
F_{2022}/F_{MSY}	0.93	0.40	1.86	1.16	0.46	2.34
	Scenario 3 (high *h*)			Scenario 4 (*proc*)		
Estimates	Median	2.5%	97.5%	Median	2.5%	97.5%
K	204933	128653	397681	147103	90956	287694
r	0.23	0.14	0.37	0.22	0.12	0.40
ψ (*psi*)	1.00	0.82	1.20	0.99	0.81	1.19
s^2 (*proc*)	0.07	0.07	0.07	0.20	0.20	0.20
m	0.86	0.86	0.86	1.01	1.01	1.01
F_{MSY}	0.26	0.16	0.43	0.22	0.12	0.40
B_{MSY}	69697	43754	135249	54143	33477	105890
MSY	18143	12075	35782	12108	7691	21053
B_{1950}/K	1.00	0.79	1.25	0.94	0.62	1.29
B_{2022}/K	0.62	0.44	0.84	0.44	0.23	0.72
B_{2022}/B_{MSY}	1.84	1.31	2.46	1.20	0.62	1.94
F_{2022}/F_{MSY}	0.77	0.31	1.59	1.83	0.74	4.04
	Scenario 5 (estimate *proc*)					
Estimates	Median	2.5%	97.5%			
K	169063	103158	337689			
r	0.22	0.13	0.38			
ψ (*psi*)	0.99	0.81	1.19			
s^2 (*proc*)	0.12	0.08	0.19			
m	1.01	1.01	1.01			
F_{MSY}	0.22	0.13	0.38			
B_{MSY}	62226	37969	124291			
MSY	13939	8922	25502			
B_{1950}/K	0.98	0.71	1.27			
B_{2022}/K	0.53	0.32	0.77			
B_{2022}/B_{MSY}	1.43	0.88	2.09			
F_{2022}/F_{MSY}	1.31	0.53	2.88			