Stock assessment of Striped marlin (*Tetrapturus audax*) in the Indian Ocean using the JABBA

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ABSTRACT

In this study, the stock assessment for striped marlin in the Indian Ocean was conducted 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. Several scenarios were created based on the Pella-Tomlinson model, incorporating different assumptions related to CPUE indices, r priors, input values of B_{MSY}/K, and process error. The results from all scenarios indicated that the current status of striped marlin in the Indian Ocean may be overfished and subject to overfishing.

1. INTRODUCTION

In 2021, the stock assessment of striped marlin in the Indian Ocean was conducted using Just Another Bayesian Biomass Assessment (JABBA) and Stock Synthesis (SS) (IOTC, 2021). Both models were generally consistent with regards to stock status, indicating that the stock is subject to overfishing ($F>F_{MSY}$) and is overfished, with the biomass being below the level which would produce MSY ($B<B_{MSY}$) for over a decade. On the weight-of-evidence available in 2021, the stock status of striped marlin is determined to be overfished and subject to overfishing.

This study conducted the stock assessment for the striped marlin in the Indian Ocean based on the model specifications from scenario S2 of Parker (2021), which was adopted by WPB as a reference case, with additional scenarios based on the updated catches and standardized CPUE indices.

2. MATERIALS AND METHODS

2.1. Assessment model

The stock assessment analysis was conducted by fitting the catch data and standardized CPUE indices 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. (2018).

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 indices were available from Taiwanese (TWN by 2 areas, 2005-2022; Chen et al., 2024), and Japanese (JPN by 3 areas, 1979-2022; Matsumoto, 2024) longline fleets. In this study, the use of the standardized CPUE indices was based on scenario S2 of Parker (2021), i.e. TW_NW (2005-2022), TW_NE (2005-2022), JP_NW (1994-2010) and JP_NE (1994-2022), as the reference scenario.

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), we considered twelve alternative specifications of the Pella-Tomlinson model type based on a single nominal catch data time-series, three differing CPUE indices combinations, three differing r priors and associated input values of B_{MSY}/K, as well as a single scenario with inflated process error (Tables 1 and 2).

- **S1 (Ref.):** for B_{MSY}/K = 0.37 (h = 0.5), *r* prior *LN* ~ (log (0.25), 0.15)), CPUE = TW_NW, TW_NE, JP_NW, JP_NE

- **S2 (Low):** for B_{MSY}/K = 0.4 (h = 0.4), *r* prior *LN* ~ (log (0.21), 0.14)), CPUE = TW_NW, TW_NE, JP_NW, JP_NE

- **S3 (High):** for B_{MSY}/K = 0.23 (h = 0.86), *r* prior *LN* ~ (log (0.31), 0.16)), CPUE = TW_NW, TW_NE, JP_NW, JP_NE

- **S4 (Proc)** for B_{MSY}/K = 0.37 (h = 0.5), *r* prior *LN* ~ (log (0.25), 0.15)), CPUE = TW_NW, TW_NE, JP_NW, JP_NE, process error = 0.2.

- **S5-S8:** the same priors with S1-S4 but CPUE indices of JP_NW and JP_NE were replaced by JP_NW_all and JP_NE_all.

- **S9-S12:** the same priors and CPUE indices with S5-S8 but JP_NW_all was excluded.

The initial depletion ($\varphi = B_{1950}/K$) was set a lognormal prior with mean = 1 and CV of 10%. The unfished equilibrium biomass (K) was set as an informative lognormal prior with a mean of 50,000 metric tons and CV of 300%. All catchability parameters were formulated as uninformative uniform priors, while the observation variance was implemented by assuming inverse-gamma priors (Parker, 2021). Estimating the process error (sigma) can lead to large variance estimates, which can result in incredibly large changes in annual population biomass. Therefore, the process error was fixed at 0.07 (see Ono et al. 2012 for details) for scenarios except S4, S8 and S12 where it was fixed at 0.2 (Parker, 2021).

3. RESULTS AND DISCUSSION

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 posteriors for *r* and initial depletion (φ) were largely informed by the prior (Fig. 2 for S1 as an example).

The model did not appear to fit CPUE data well, as indicated by a root mean squared error (RMSE) S6 had the worst fit, with an RMSE of 52.3%. On the contrary, S4 and S12 fit CPUE better, with an RMSE below 40% (Fig. 3). Most scenarios showed no evidence ($p \geq 0.05$) to reject the hypothesis that the time series of residuals from CPUE fits were randomly distributed, except for the fits of JP_NW_all (S5-8). Therefore, scenarios S9-12 were conducted to investigate the effect of removing JP_NW_all on the assessment results. Results of the runs tests for CPUE fits in scenarios S1, S5, and S9 are shown in Figs. 4-6 as examples.

The estimated biomass and fishing mortality from S1 are illustrated in Fig. 7. The trajectory of biomass showed a sharp decrease since the late 1970s, a slight recovery from 1990 to 1995, followed by a steady decrease. Before the mid-1980s, F/F_{MSY} remained below 1 with relatively small changes. After that, F/F_{MSY} rapidly increased and has remained above 1 since the early 1990s.

The Kobe plots for all scenarios are shown in Figs. 8 and 9. The Kobe plots indicated that the median of F/F_{MSY} was higher than 1 and the median of B/B_{MSY} was less than 1. In addition, there is a very high probability that the current status of striped marlin may be overfished and be overfishing. The results of JABBA indicate that the current status of striped marlin in the Indian Ocean may be overfished and subject to overfishing. However, the scenarios assuming a high B_{MSY}/K = 0.23 (h = 0.86) resulted in very wide confidence intervals for the estimated quantities (Figs. 8 and 9 and Table 3).

Based on the hindcasting cross-validation, results for the JP_NE index suggest that the model has good prediction skill as judged by the MASE scores of approximately 0.8, which indicates that future projections are consistent with the reality of model-based scientific advice (Fig. 10 for S1 as an example).

Projections with future catch at constant levels from 40% to 160% indicated that the stock status of striped marlin in the Indian Ocean may be overfished and subject to overfishing when fishing exploitation can be maintained at current catch level (Fig. 11).

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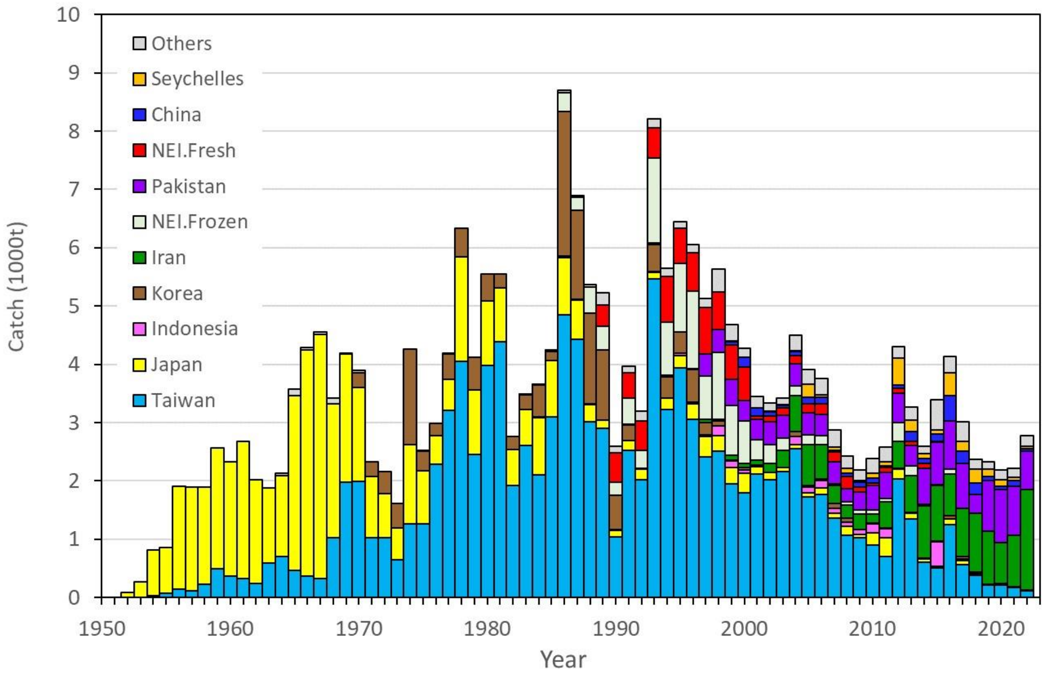

Fig. 1. Time-series of estimated catch in metric tons (t) for Indian Ocean striped marlin (1950-2022).

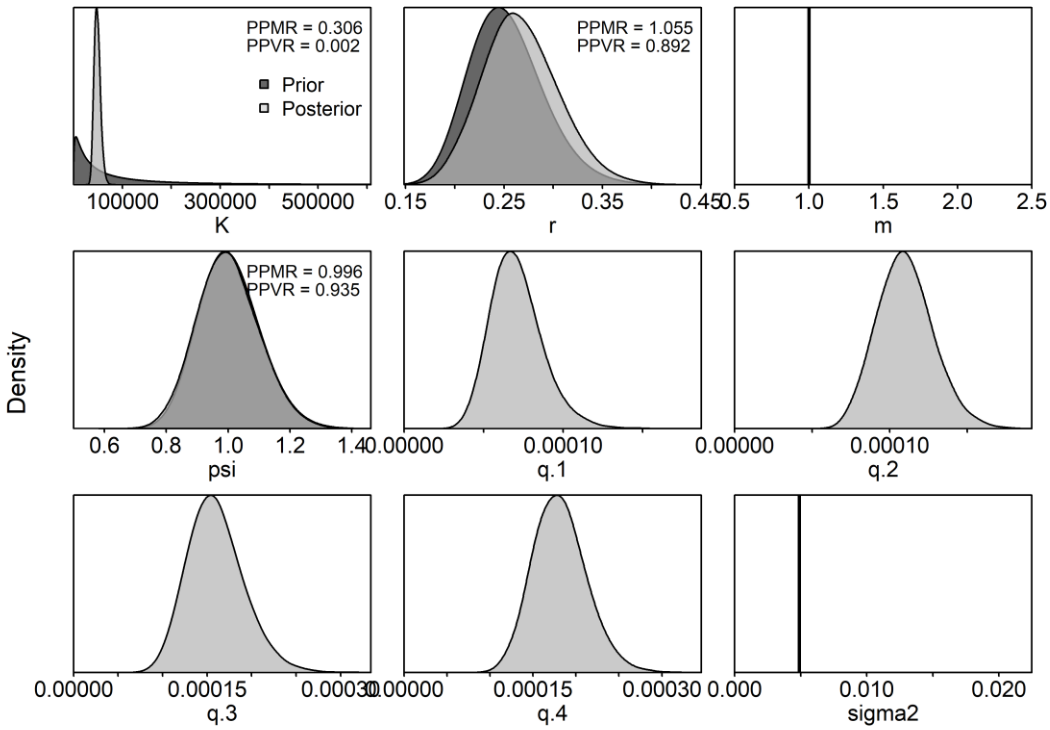

Fig. 2. Prior and posterior distributions for scenario S1 for striped marlin in the Indian Ocean. PPRM: Posterior to Prior Ratio of Means; PPRV: Posterior to Prior Ratio of Variances.

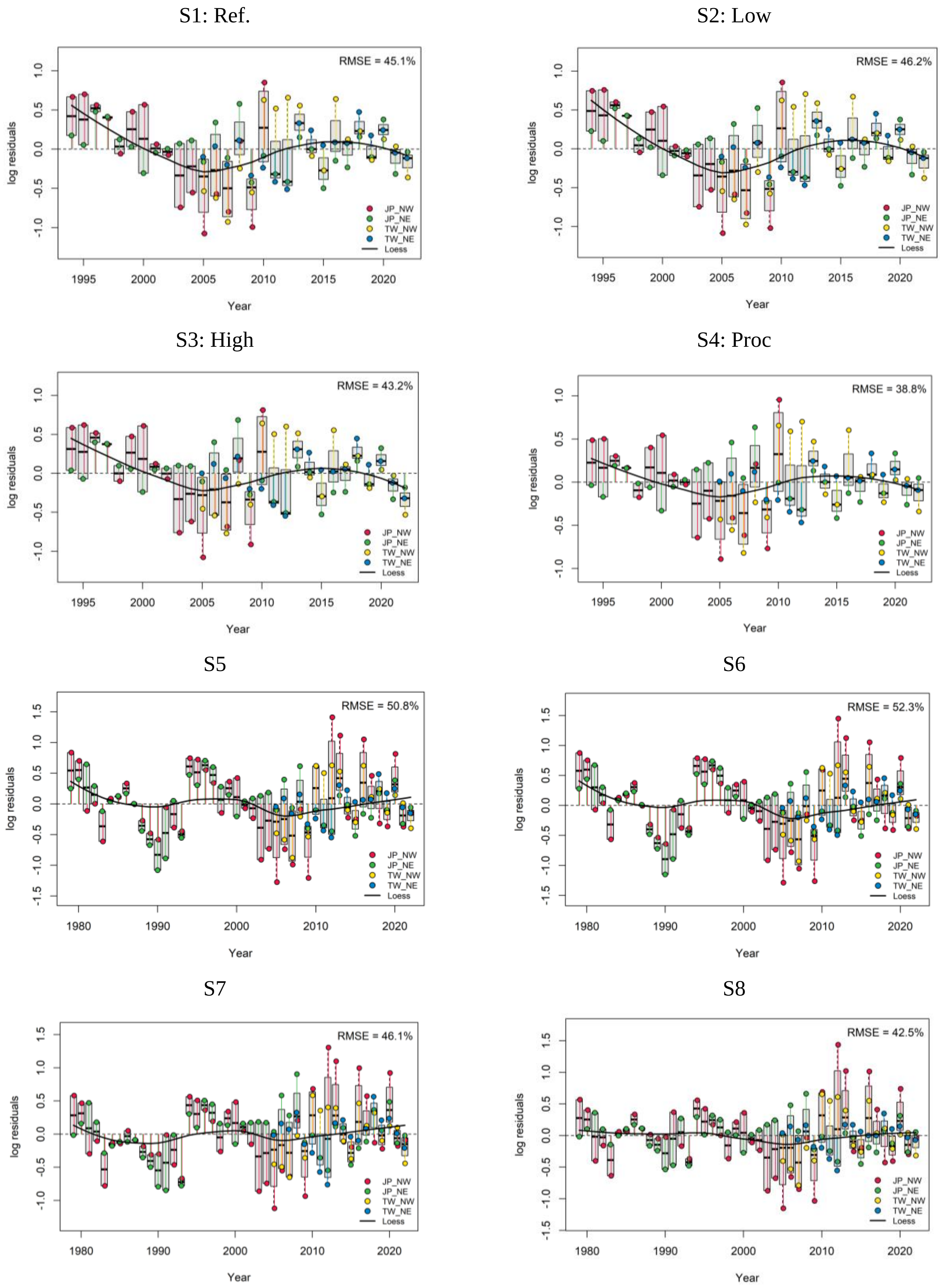

Fig. 3. Residual diagnostic plots of JABBA for all scenarios for CPUE indices for striped marlin in the Indian Ocean. Boxplots indicating the median and quantiles of all residuals available for any given year, and solid black lines indicate a loess smoother through all residuals.

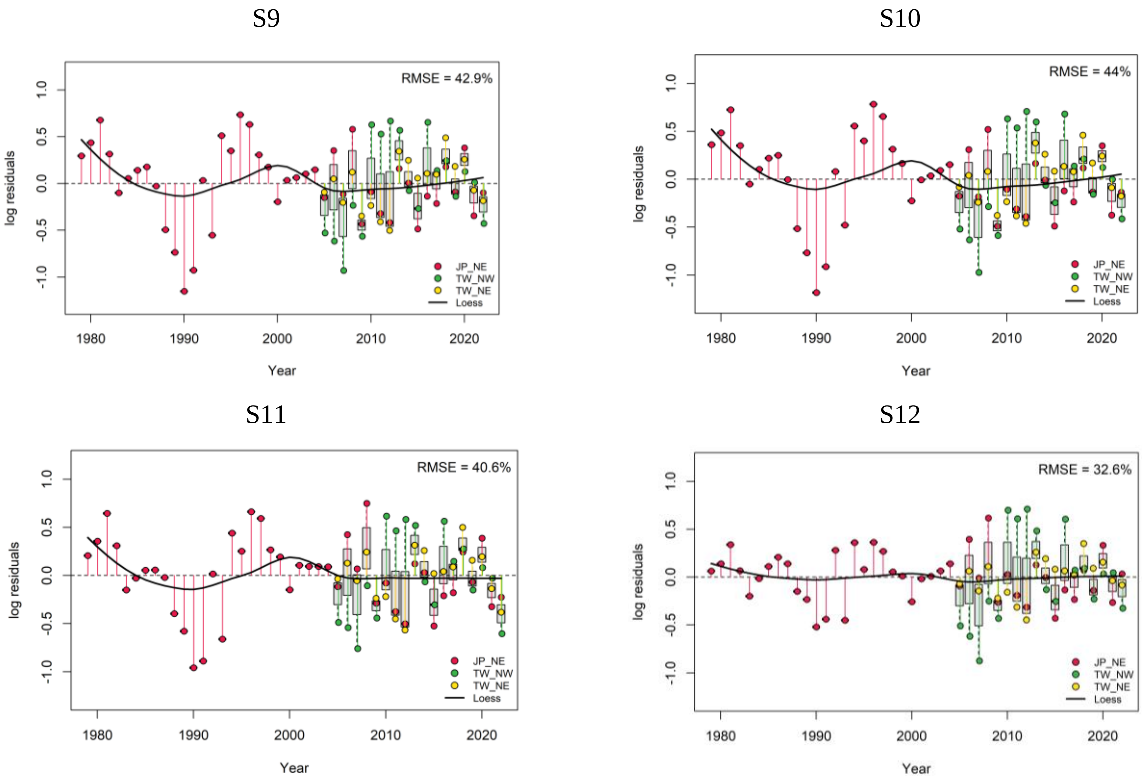

Fig. 3. (continued).

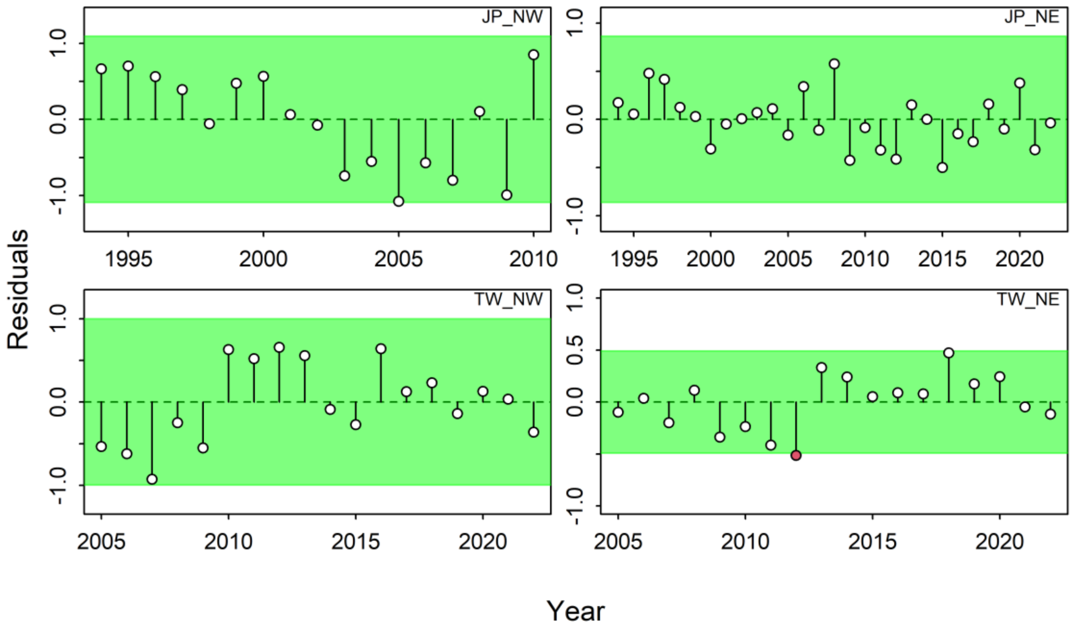

Fig. 4. Runs tests of JABBA for the randomness of the time series of CPUE residuals by fleet for striped marlin in the Indian Ocean from scenario S1. Green panels indicate no evidence of lack of randomness of time series residuals (p>0.05) while red panels indicate the opposite. The inner shaded area 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).

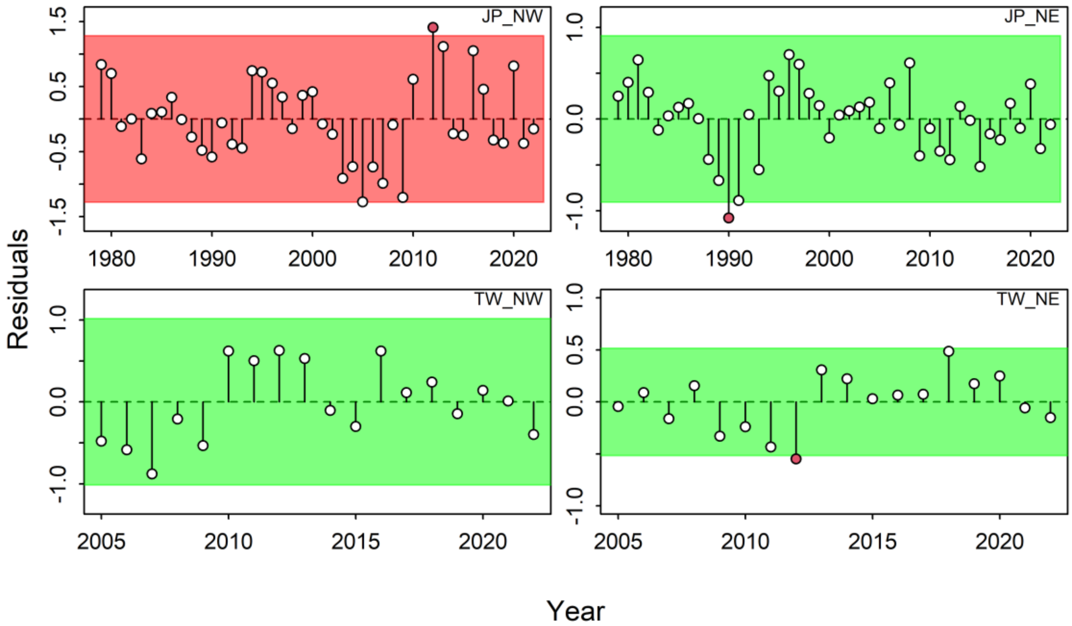

Fig. 5. Runs tests of JABBA for the randomness of the time series of CPUE residuals by fleet for striped marlin in the Indian Ocean from scenario S5. Green panels indicate no evidence of lack of randomness of time series residuals (p>0.05) while red panels indicate the opposite. The inner shaded area 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).

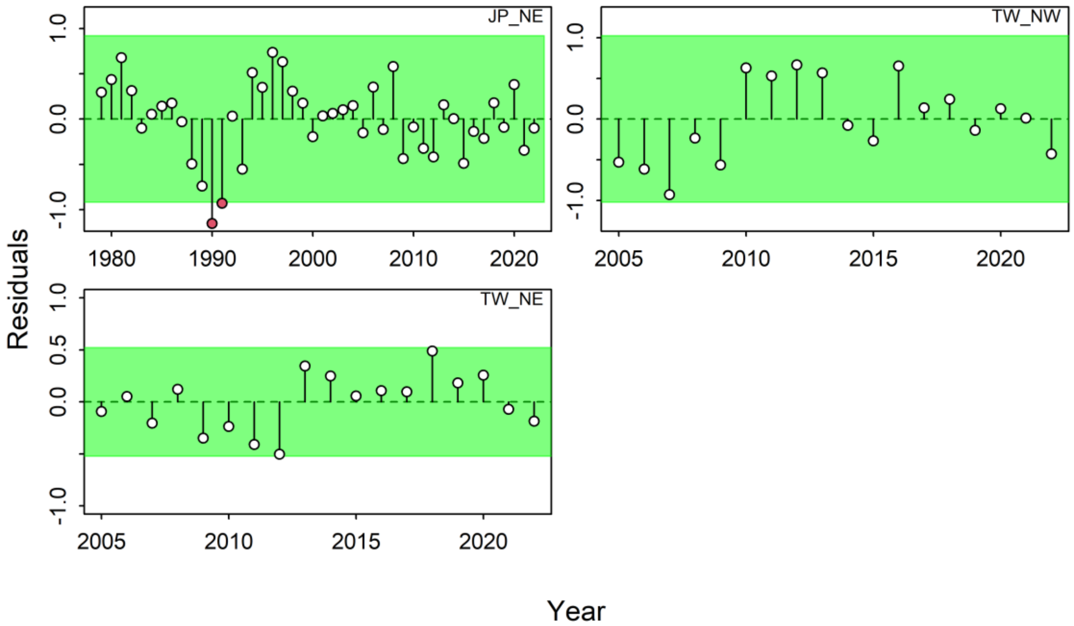

Fig. 6. Runs tests of JABBA for the randomness of the time series of CPUE residuals by fleet for striped marlin in the Indian Ocean from scenario S9. Green panels indicate no evidence of lack of randomness of time series residuals (p>0.05) while red panels indicate the opposite. The inner shaded area 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).

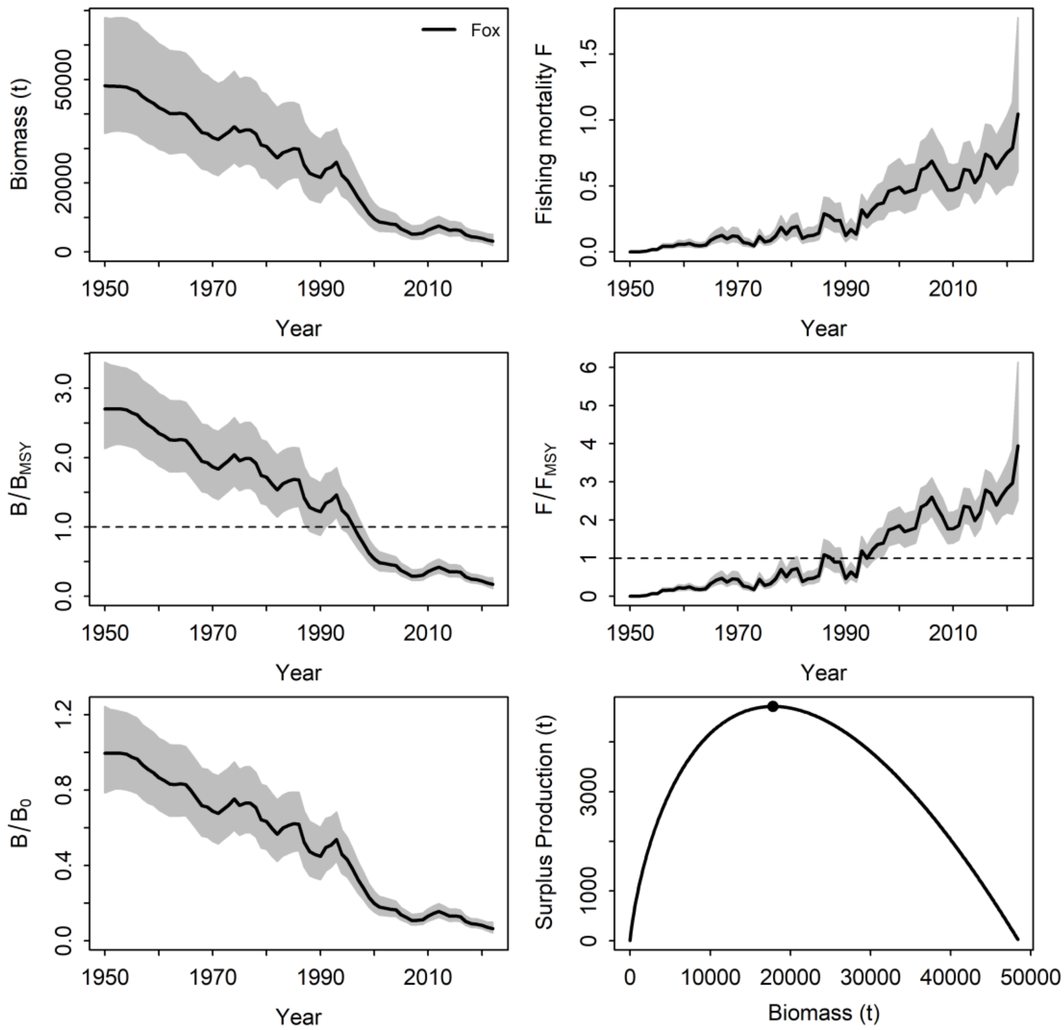

Fig. 7. The trajectories of the estimated biomass and fishing mortality with 95% confidence intervals obtained from JABBA for striped marlin in the Indian Ocean from scenario S1.

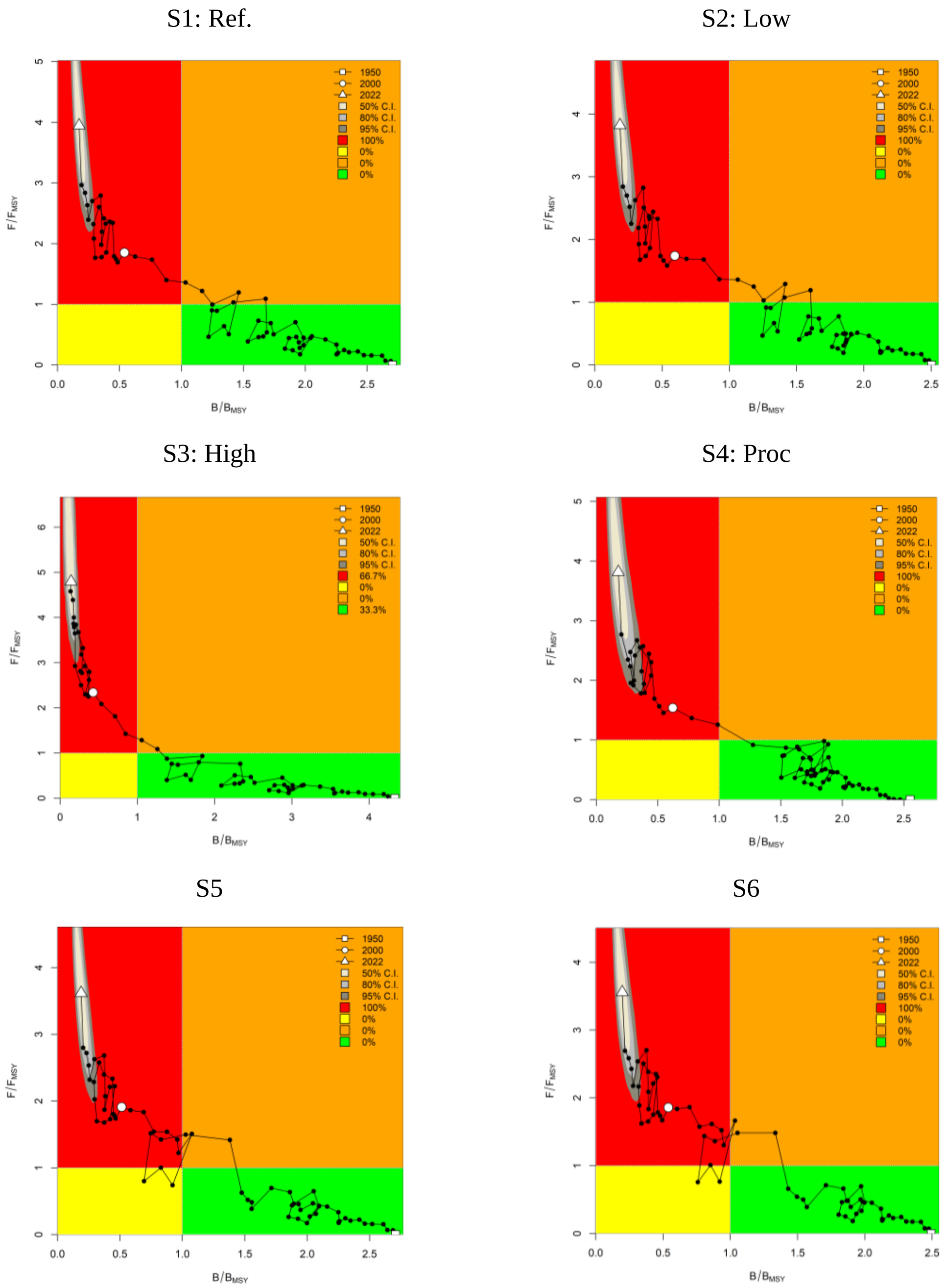

Fig. 8. Kobe plot with bootstrap confidence surfaces around 2022 estimates for striped marlin in the Indian Ocean obtained from JABBA for all scenarios.

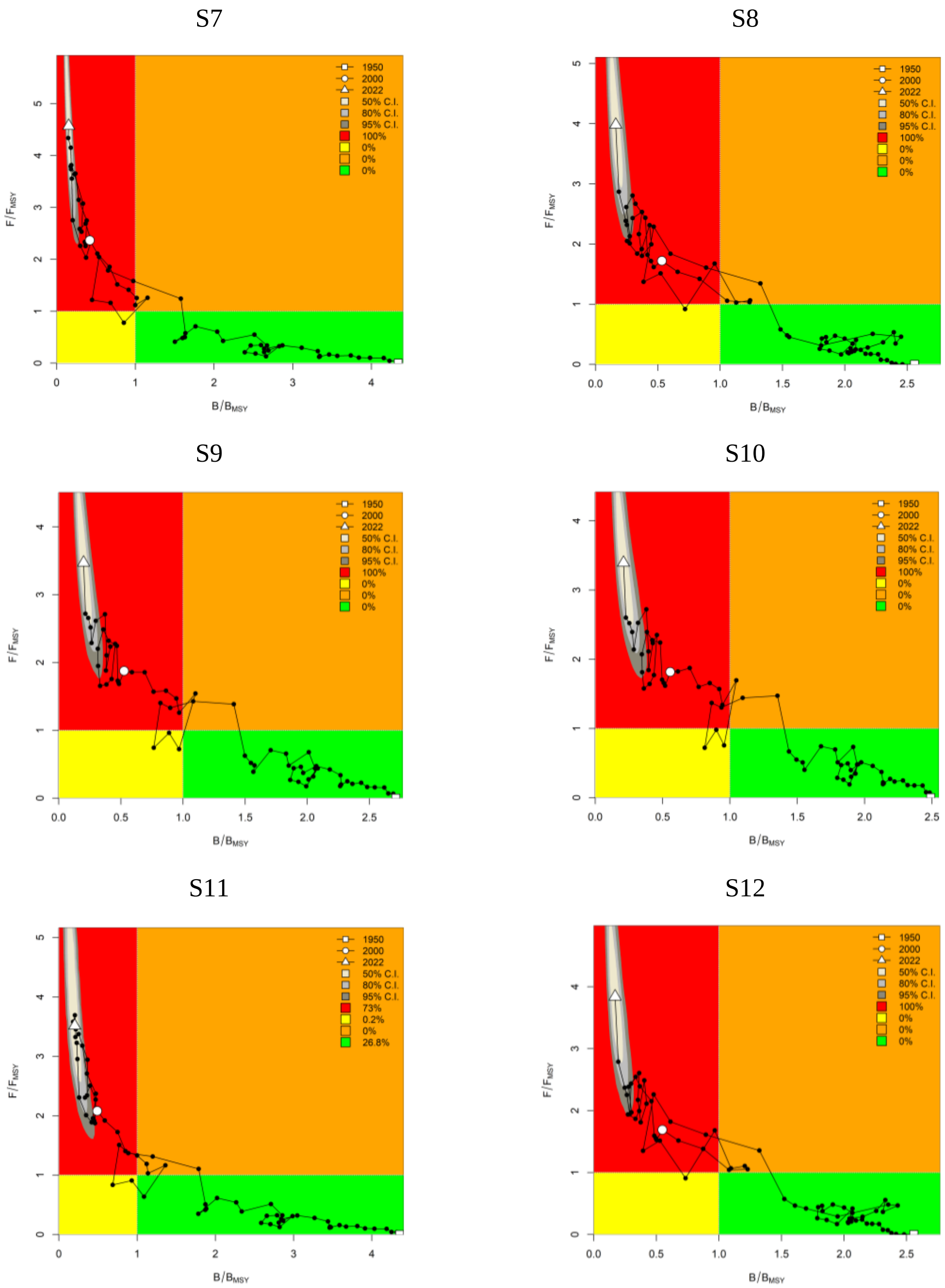

Fig. 8. (continued).

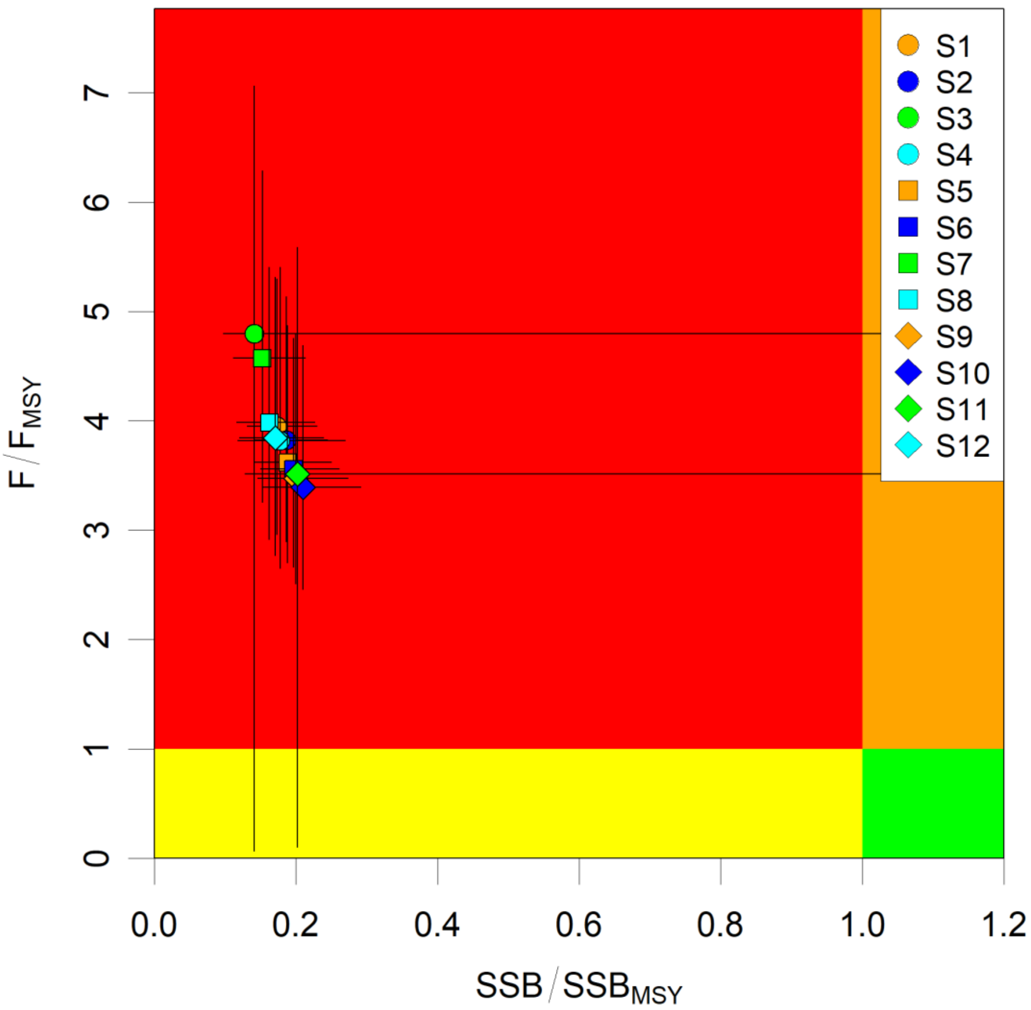

Fig. 9. Kobe plot of 2022 estimates of spawning biomass and fishing mortality relative to their MSY reference points from twelve scenarios for striped marlin in the Indian Ocean. The error bars represent the 80% confidence interval of the estimates.

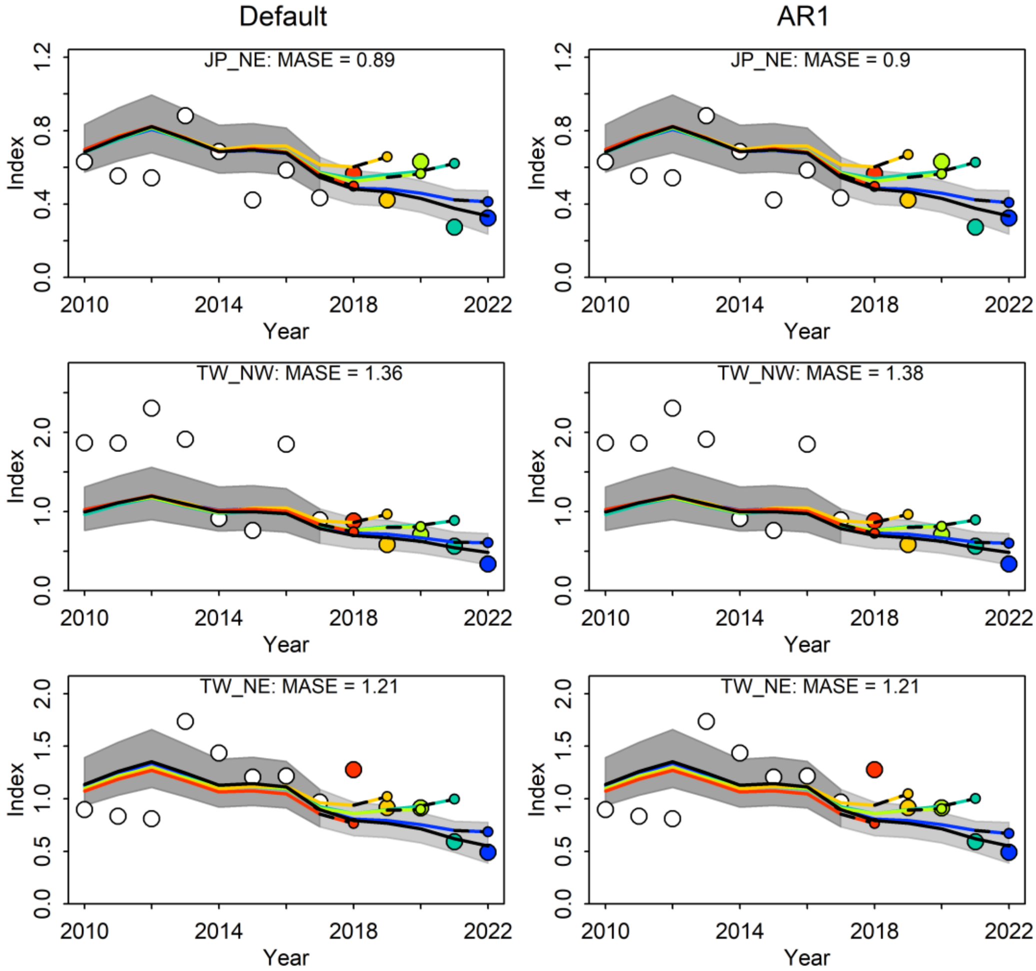

Fig. 10. Hindcasting cross-validation of JABBA (HCxval) for striped marlin in the Indian Ocean from scenario S1, showing one-year-ahead forecasts of CPUE values (2010-2022), performed with eight hindcast model runs relative to the expected CPUE. The CPUE observations, used for cross-validation, are highlighted 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).

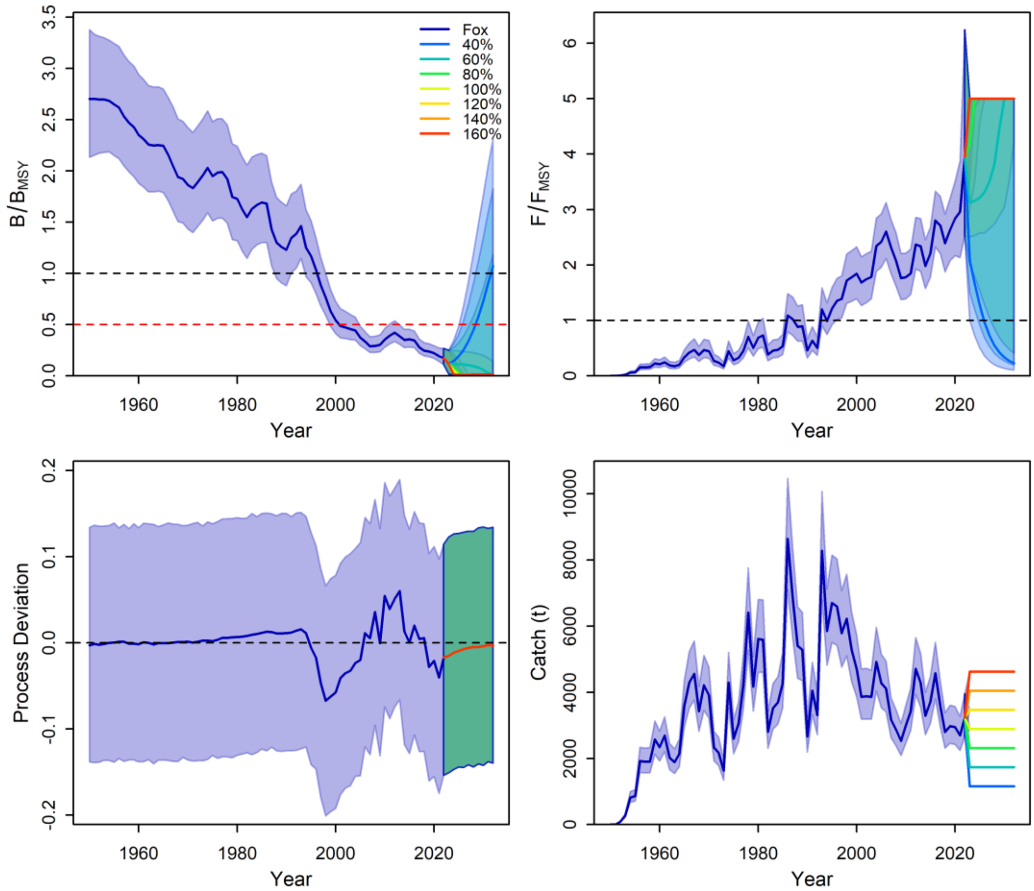

Fig. 11. Projections with 95% confidence intervals of JABBA based on the future catch set at constant levels from 40% to 160% for striped marlin in the Indian Ocean from scenario S1.

Table 1. Summary of catch-per-unit-effort (CPUE) indices considered in the 2022 JABBA assessment runs for Indian Ocean striped marlin.

Fleet and area	Period	Abbreviation
Taiwan, North-West Indian Ocean	2005-2022	TW_NW
Taiwan, North-East Indian Ocean	2005-2022	TW_NE
Japan, North-West Indian Ocean	1979-2022	JP_NW_all
Japan, North-East Indian Ocean	1979-2022	JP_NE_all
Japan, North-West Indian Ocean	1994-2010	JP_NW
Japan, North-East Indian Ocean	1994-2022	JP_NE

Table 2. Summary of prior and input parameter assumptions used in 2024 JABBA Indian Ocean striped 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 = 0.86 (see Parker, 2021).

Parameter	Description	Prior	mean	CV	Scenario
K	Unfished biomass	lognormal	50,000	300%	All
r (ref *h*)	Population growth rate	lognormal	0.25	14%	S1,S4, S5, S8, S9, S12
r (low *h*)		lognormal	0.21	14%	S2,S6, S10
r (high *h*)		lognormal	0.31	16%	S3,S7,S11
ψ (*psi*)	Initial depletion	lognormal	1	10%	All
s^2 (*proc*)	Process error variance	fixed	0.07	-	S1- S3, S5- S7, S9-S11
s^2 (high *proc*)	Process error variance	fixed	0.2	-	S4, S8, S12
B_{MSY}/K (ref *h*)	Ratio Biomass at MSY to K	fixed	0.37	-	S1, S4, S5, S8, S9, S12
B_{MSY}/K (low *h*)		fixed	0.4	-	S2, S6, S10
B_{MSY}/K (high *h*)		fixed	0.23	-	S3, S7, S11

Table 3. Summary of posterior quantiles denoting the 95% confidence intervals of parameters estimates for five scenarios in the JABBA assessment of striped marlin.

	Scenario 1 (Ref.)			Scenario 2 (low *h*)		
Estimates	Median	2.5%	97.5%	Median	2.5%	97.5%
K	48479.624	38034.72049	62962.92757	61921.17	47379.63	80400.15
r	0.264	0.199	0.347	0.218	0.166	0.29
ψ (*psi*)	0.997	0.82	1.203	1.001	0.823	1.209
s^2 (*proc*)	0.07	0.07	0.07	0.07	0.07	0.07
m	1.001	1.001	1.001	1.188	1.188	1.188
F_{MSY}	0.264	0.199	0.347	0.183	0.14	0.244
B_{MSY}	17843.571	13999.185	23174.343	24767.34	18950.99	32158.6
MSY	4725.673	4222.616	5235.872	4551.757	3977.131	5165.298
B_{1950}/K	0.995	0.785	1.244	1.001	0.79	1.254
B_{2022}/K	0.064	0.042	0.098	0.074	0.048	0.112
B_{2022}/B_{MSY}	0.173	0.113	0.265	0.186	0.121	0.28
F_{2022}/F_{MSY}	3.948	2.536	6.14	3.822	2.488	5.983
	Scenario 3 (high *h*)			Scenario 4 (*proc*)		
Estimates	Median	2.5%	97.5%	Median	2.5%	97.5%
K	41559.55	29792.41	145969.4	52770.24	37864	78022.28
r	0.252	0.177	0.372	0.2461	0.186	0.3221
ψ (*psi*)	0.999	0.822	1.202	0.985	0.816	1.186
s^2 (*proc*)	0.07	0.07	0.07	0.2	0.2	0.2
m	0.437	0.437	0.437	1.001	1.001	1.001
F_{MSY}	0.577	0.406	0.852	0.246	0.186	0.322
B_{MSY}	9552	6847.454	33549.44	19422.79	13936.35	28717.14
MSY	4871.648	4392.747	23168.89	4791.524	3737.09	6317.33
B_{1950}/K	0.996	0.786	1.247	0.939	0.619	1.291
B_{2022}/K	0.032	0.02	0.856	0.065	0.034	0.122
B_{2022}/B_{MSY}	0.141	0.088	3.726	0.178	0.093	0.332
F_{2022}/F_{MSY}	4.797	0.04	8.071	3.817	2.17	6.517

Table 3. (continued).

	Scenario 5			Scenario 6		
Estimates	Median	2.5%	97.5%	Median	2.5%	97.5%
K	46841.81	36675	60849.5	59983.87	47023	77744.99
r	0.275	0.208	0.361	0.229	0.175	0.298
ψ (*psi*)	0.998	0.822	1.205	0.998	0.821	1.203
s^2 (*proc*)	0.07	0.07	0.07	0.07	0.07	0.07
m	1.001	1.001	1.001	1.188	1.188	1.188
F_{MSY}	0.275	0.208	0.36	0.192	0.147	0.251
B_{MSY}	17240.75	13498.72	22396.47	23992.45	18808.34	31096.58
MSY	4753.286	4281.651	5224.119	4625.646	4069.419	5208.282
B_{1950}/K	0.997	0.785	1.247	0.997	0.784	1.248
B_{2022}/K	0.069	0.045	0.106	0.079	0.052	0.12
B_{2022}/B_{MSY}	0.188	0.122	0.287	0.197	0.129	0.3
F_{2022}/F_{MSY}	3.619	2.309	5.711	3.557	2.283	5.544
	Scenario 7			Scenario 8		
Estimates	Median	2.5%	97.5%	Median	2.5%	97.5%
K	35908.47	28555.55	45086.72	53169.2	38908.3	76441.74
r	0.245	0.191	0.316	0.255	0.193	0.338
ψ (*psi*)	0.998	0.822	1.203	0.986	0.815	1.1853
s^2 (*proc*)	0.07	0.07	0.07	0.2	0.2	0.2
m	0.437	0.437	0.437	1.001	1.001	1.001
F_{MSY}	0.562	0.438	0.723	0.255	0.193	0.338
B_{MSY}	8253.162	6563.176	10362.68	19569.63	14320.72	28135.4
MSY	4650.316	4338.736	4970.062	5024.185	4032.213	6361.408
B_{1950}/K	0.998	0.786	1.244	0.942	0.621	1.293
B_{2022}/K	0.035	0.022	0.058	0.06	0.035	0.098
B_{2022}/B_{MSY}	0.152	0.096	0.254	0.162	0.095	0.267
F_{2022}/F_{MSY}	4.573	2.7	7.327	3.983	2.448	6.329

Table 3. (continued).

	Scenario 9			Scenario 10		
Estimates	Median	2.5%	97.5%	Median	2.5%	97.5%
K	49463.91	39060.45	64809.72	62653.93	48568.74	80511.53
r	0.257	0.191	0.334	0.215	0.165	0.282
ψ (*psi*)	0.998	0.822	1.207	0.997	0.821	1.202
s^2 (*proc*)	0.07	0.07	0.07	0.07	0.07	0.07
m	1.001	1.001	1.001	1.188	1.188	1.188
F_{MSY}	0.257	0.191	0.334	0.181	0.139	0.238
B_{MSY}	18205.85	14376.72	23854.08	25060.43	19426.61	32203.15
MSY	4680.302	4166.795	5163.87	4547.987	3951.429	5170.553
B_{1950}/K	0.998	0.784	1.248	0.996	0.785	1.246
B_{2022}/K	0.073	0.045	0.119	0.084	0.052	0.137
B_{2022}/B_{MSY}	0.2	0.123	0.322	0.21	0.13	0.342
F_{2022}/F_{MSY}	3.473	2.126	5.7	3.393	2.075	5.549
	Scenario 11			Scenario 12		
Estimates	Median	2.5%	97.5%	Median	2.5%	97.5%
K	40510.61	31246.71	93615.05	54031.05	39458.02	77716.9
r	0.233	0.168	0.364	0.249	0.189	0.328
ψ (*psi*)	1.002	0.821	1.208	0.985	0.815	1.190
s^2 (*proc*)	0.07	0.07	0.07	0.2	0.2	0.2
m	0.437	0.437	0.437	1.001	1.001	1.001
F_{MSY}	0.534	0.384	0.834	0.248	0.189	0.328
B_{MSY}	9310.913	7181.708	21516.38	19886.85	14523.05	28604.74
MSY	4620.73	4163.33	14510.94	4959.643	4006.001	6238.324
B_{1950}/K	1.001	0.79	1.252	0.942	0.627	1.288
B_{2022}/K	0.046	0.024	0.8	0.063	0.037	0.104
B_{2022}/B_{MSY}	0.202	0.104	3.48	0.17	0.1	0.283
F_{2022}/F_{MSY}	3.514	0.068	6.927	3.842	2.318	6.341