ASSESSMENT OF INDIAN OCEAN STRIPED MARLIN (*TETRAPTURUS AUDAX*) STOCK USING JABBA

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SUMMARY

Six scenarios were run using the Bayesian State-Space Surplus Production Model JABBA to assess the Indian Ocean striped marlin (*Tetrapturus audax*). A 'drop one' sensitivity analysis indicated that omitting any of the "new" CPUE time-series would not significantly alter the stock status. Similarly, a retrospective analysis produced highly consistent results for stock status estimates back to 2009 and therefore provided no evidence for an undesirable retrospective pattern. The omission of historical CPUE time-series was considered on the advice of CPC scientists providing the CPUE standardization analyses, and so data from 1970 was only included in two scenarios: S1 and S3. The results for the six alternative scenarios estimated *MSY* between 4,430 and 4,826 tons, median estimates of B/B_{MSY} ranged between 0.26 - 0.32 and estimates of *B/K* were between 0.06 - 0.13. All scenarios produce B/B_{MSY} trajectories that steadily declined from the late 1970s to 2010 before leveling at the approximate current B/B_{MSY} estimates. There has been a steady increase of F/F_{MSY} since the 1970s, which has only recently showed signs of slowing. Individual Kobe biplots were similar among all scenarios and each indicated a >96% probability that the Indian Ocean striped marlin stock is *overfished* and *subject to overfishing* – which is a result comparable with the 2018 assessment for this species.

KEY WORDS

Stock status, CPUE fits, diagnostics, process error, stochastic biomass dynamics

1. Introduction

In 2018, the Indian Ocean Commission (IOTC) carried out an assessment for striped marlin (*Tetrapturus audax*) using two different models: 'JABBA' and the statistical age-structured model Stock Synthesis (ss3) (IOTC, 2018). Both models were very consistent, indicating that the stock is *overfished* and *subject to overfishing* (Parker et al, 2018; Wang 2018). The results also suggest that biomass estimates had been below the level which would produce MSY for the past decade, confirming the results from 2012, 2013, 2015 and 2017 assessments. Furthermore, projections from the 2018 assessments reiterate that the stock will remain in overfished status unless catches are substantially decreased.

Prior to this, the 2017 assessment for striped marlin (*Tetrapturus audax*) used four different model types: Stock Reduction Analysis (SRA), the Surplus Production Models (SPMs) ASPIC without process error, a Bayesian State Space Production Model (SSBSP) with process error, and the statistical age-structured model Stock Synthesis (ss3). Results for all models included in the 2017 assessment were consistent in that the stock biomass is well below the B_{MSY} level and the stock status of striped marlin was determined to be *overfished* and *subject to overfishing*.

Here we provide an updated assessment of the Indian Ocean striped marlin stock using the Bayesian State-Space Surplus Production Model software 'JABBA' (Winker et al. 2018a; Just Another Bayesian Biomass Assessment). JABBA is implemented as a flexible, user-friendly open-source tool that is hosted on GitHub (https://github.com/jabbamodel) that was has been applied in a number of RFMO stock assessments, including most of the IOTC billfish species assessments: striped marlin (Parker et al., 2018a), black marlin (Parker et al., 2018b), blue marlin (Parker et al., 2019), and swordfish (Parker 2020). Model diagnostics are presented in the form of a sensitivity analysis, a retrospective analysis and prior vs posterior plots. Details of the JABBA model results for six alternative scenarios are discussed in terms of robustness and inference about the stock status.

2. Material and Methods

2.1. *Fishery input data*

Total nominal catch by fleet was obtained from the IOTC Secretariat in preparation to assess the Indian Ocean striped marlin at WPB19. In contrast to previous assessments, only a single nominal catch scenario was proposed (*IOTC-2021-WPB19-DATA03-NC*) which spanned from 1950 to 2019. Relative abundance indices were made available in the form of standardized catch-per-unit-of-effort (CPUE) time-series, which were assumed to be proportional to biomass. The standardized CPUE series covered two fishing fleets, Japan and Taiwan,China (Table 1). Taiwan,China provided alternative time-series for two periods 1979-2020 and 2005-2020 – the former provides a continuity for the 2018 MLS assessment but concerns regarding whether the index is an appropriate measure of abundance prior to 2005 have been raised for this time-series. Furthermore, the Japanese CPUE time-series was provided separately for the periods 1979-1993 and 1994-2019, where the 1994-2019 CPUE represented an update compared to the 2018 assessment. In addition to CPUE time-series from the north Indian Ocean, Japan provided an index for the SW Indian Ocean. This resulted in a total of ten standardized CPUE series (Table 1).

2.2. *JABBA stock assessment model*

This initial stock assessment was implemented using the Bayesian state-space surplus production model framework JABBA, version v1.2 (Winker et al., 2018a). JABBA's inbuilt options include: (1) automatic fitting of multiple CPUE time-series and associated standard errors; (2) estimating or fixing the process variance, (3) optional estimation of additional observation variance for individual or grouped CPUE time-series, and (4) specifying a Fox, Schaefer or Pella-Tomlinson production function by setting the inflection point B_{MSY}/K and converting this ratio into the shape parameter *m*. A full description of the JABBA model, including formulation and state-space implementation, prior specification options and diagnostic tools is available in Winker et al. (2018a).

To assess striped marlin, we considered six alternative specifications of the Pella-Tomlinson model type based on a single nominal catch data time-series, three differing CPUE time-series combinations, three differing *r* priors and associated input values of B_{MSY}/K, as well as a single scenario with inflated process error. The input priors were objectively derived from the ASEM simulations (Winker et al. 2008b; Winker et al. 2018c), which allowed approximating the parameterizations considered for age-structured stock synthesis model (ss3) based on range of stock recruitment steepness values for the stock recruitment relationship (h = 0.4, h = 0.5 and h = 0.86), while admitting reasonable uncertainty about the natural mortality *M*. The continuity scenario follows that of the 2018 assessment reference base case, from which the *r* prior choice associated with B_{MSY}/K = 0.37 (h = 0.5) to approximate the Fox model parameterization used in the 2017 assessment (Winker et al. 2018c). In addition, a scenario was run with a *r* prior that corresponds to high steepness value of h = 0.86 to match the reference case assumption for the 2017 SS3 assessment model, while low resilience prior formulation was based on h = 0.4 (Table 2). This resulted in the formulation of the following five scenario specifications:

- **S1 (Cont.):** for B_{MSY}/K = 0.37 (h = 0.5), *r* prior *LN* ~ (log (0.25), 0.15)), CPUE = TWN_NW_hist, TWN_NE_hist, JPN_NW, JPN_NE

- **S2 (New):** for B_{MSY}/K = 0.37 (h = 0.5), *r* prior *LN* ~ (log (0.25), 0.15)), CPUE = TWN_NW, TWN_NE, JPN_NW, JPN_NE

- **S3 (Hist):** for B_{MSY}/K = 0.37 (h = 0.5), r prior LN ~ (log (0.25), 0.15)), CPUE = TWN_NW_hist, TWN_NE_hist, JPN_NW_hist, JPN_NE_hist, JPN_NW, JPN_NE

- **S4 (Low):** for B_{MSY}/K = 0.4 (h = 0.4), r prior LN ~ (log (0.21), 0.14)), CPUE = TWN_NW, TWN_NE, JPN_NW, JPN_NE

- **S5: (High):** for B_{MSY}/K = 0.23 (h = 0.86), r prior LN ~ (log (0.31), 0.16)), CPUE = TWN_NW, TWN_NE, JPN_NW, JPN_NE

- **S6: (Proc)** for B_{MSY}/K = 0.37 (h = 0.5), r prior LN ~ (log (0.25), 0.15)), CPUE = TWN_NW, TWN_NE, JPN_NW, JPN_NE, process error = 0.2.

For K, we assumed a vaguely informative lognormal prior with a mean 50,000 metric tons and CV of 300%. Initial depletion was estimated using a lognormal prior ($\varphi = B_{1950}/K$; for details see Winker et al., 2018a) with mean = 1 and CV of 10%. All catchability parameters were formulated as uninformative uniform priors, while the observation variance was implemented by assuming inverse-gamma priors. Initial trials indicated that estimating the process error (sigma) resulted in large variance estimates that would result implausible large variations in annual stock biomass. Instead, the process error was therefore fixed at 0.07 (see Ono et al., 2012 for details) for all scenarios except S6, where it was fixed at 0.2.

JABBA is implemented in R (R Development Core Team, https://www.r-project.org/) with JAGS interface (Plummer, 2003) to estimate the Bayesian posterior distributions of all quantities of interest by means of a Markov Chains Monte Carlo (MCMC) simulation. The JAGS model is executed from R using the wrapper function jags() from the library r2jags (Su and Yajima, 2012), which depends on rjags. In this study, two MCMC chains were used. Each model was run for 30,000 iterations, sampled with a burn-in period of 5,000 for each chain and thinning rate of five iterations. Basic diagnostics of model convergence included visualization of the MCMC chains using MCMC trace-plots as well as Heidelberger and Welch (1992), Geweke (1992) and Gelman and Rubin (1992) diagnostics as implemented in the coda package.

To assess the relative influence of individual CPUE time-series on the stock status estimates, a sensitivity analysis was run by iteratively removing a single CPUE time-series and comparing the predicted vectors of biomass B_y, fishing mortality F_y, the ratios B_y/K, B_y/B_{MSY} and F_y/F_{MSY} and the sensitivity of the surplus production function. 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 "New" scenario by sequentially removing the most the recent year (retrospective 'peel') and refitting the model over a period of ten years (i.e. 2019 back to 2009).

3. Results and Discussion

Nominal catches of striped marlin in the Indian Ocean were highly variable, peaking in 1987 with a total of 8,729 tons (Figure 1). Fits were generally comparable among all six scenarios, which was also supported by a relatively narrow range RMSE values (RMSE = 49.1%-58.2%), suggesting that the goodness-of-fits were similar. The Japanese NE CPUE index showed a good fit between the observed and predicted values (Figures 2), and these are seemingly more informative to the model than any of the indices (Figure 4). Models that included historical CPUE data fail to fully describe the high catch rates, and associated high variability, observed in the early 1980s. This resulted in some moderate data conflicts but, in general, the historical CPUE indices were consistent in showing a period of decline from the 1970s until attaining a minimum around 2010. However, the "new" CPUE time-series (TWN: 2005-2019; JPN: 1994-2019) contains comparably little information on historical abundance trends.

A 'drop one' sensitivity analysis was only performed on the "New" CPUE time-series. The results indicate that omitting the Japanese NE index would result in a more optimistic assessment outcome. Contrastingly, the omission of either the Taiwan,China and/or the Japanese NW indices would produce a more pessimistic assessment in terms of B/B_{MSY} and F/F_{MSY}– the results of these three sensitivity runs are remarkably similar in terms of B/B_{MSY} (Figure 3). However, none of the sensitivity runs would alter the stock status as the most optimistic sensitivity estimate for B/B_{MSY} remains well below 1. The retrospective analysis produced highly consistent stock status estimates back to 2009, showing only negligible departures of retrospective peel from the reference predictions through to 2019 (Figure 4). There was therefore no evidence for an undesirable retrospective pattern.

The *MSY* estimates showed little variation, ranging between 4,430 and 4,826 tons for all six scenarios (Table 3). In contrast, B_{MSY} varied substantially among scenarios, with S5 (8,998 t) being approximately a third of that estimated from S4 (24,499 t) – the high and low productivity scenarios, respectively. Estimates of B_{MSY} from S1, S2, S3 and S6 were more comparable (17,377 – 19,415). The F/F_{MSY} estimates ranged between 2.10 and 2.49 for S2 and S5, respectively. The range of median estimates for B/B_{MSY} from the six scenarios was 0.26 - 0.32 and the range for *B/K* median estimates was 0.06 - 0.13 (Table 3).

All scenarios produce B/B_{MSY} trajectories that steadily declined from the late 1970s to around 2010 before leveling at the approximate current B/B_{MSY} estimates, which are well below 1 (Figure 6). A steady increase of F/F_{MSY} has occurred since the 1970s, and only recently has this declined slowed. Individual Kobe biplots were similar among all scenarios and each indicated a >96% probability that the Indian Ocean striped marlin stock is overfished and currently subjected to overfishing (Figure 7). A characteristic of Kobe biplots depicting depleted stocks is evident in this assessment in that there is high uncertainty in F/F_{MSY} estimates and relatively high confidence in the B/B_{MSY} estimates. Constant catch projections based on the "New" scenario (S2) indicate that the biomass of striped marlin will not decline further if catches are below 3,000 tons per annum. However, if the objective is stock recovery then a substantially lower annual catch would be required.

The results of this initial JABBA assessment are comparable with the 2018 assessment for the Indian Ocean striped marlin stock, indicating that the stock remains *overfished* and *subject to overfishing*.

4. References

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Table 1. Summary of catch-per-unit-effort (CPUE) indices considered in the 2021 JABBA assessment runs for Indian Ocean striped marlin.

CPUE indices and period	Period	Abbreviation
Taiwan,China North-West Indian Ocean	1979-2019	TWN_NW_hist
Taiwan,China North-East Indian Ocean	1979-2019	TWN_NE_hist
Taiwan,China North-West Indian Ocean	2005-2019	TWN_NW
Taiwan,China North-East Indian Ocean	2005-2019	TWN_NE
Japan North-West Indian Ocean	1979-1993	JPN_NW_hist
Japan North-East Indian Ocean	1979-1993	JPN_NE_hist
Japan South-West Indian Ocean	1979-1993	JPN_SW_hist
Japan North-West Indian Ocean	1994-2010	JPN_NW
Japan North-East Indian Ocean	1994-2019	JPN_NE
Japan South-West Indian Ocean	1994-2019	JPN_SW

Table 2. Summary of prior and input parameter assumptions used in the 2021 JABBA Indian Ocean striped marlin assessment. (cont *h*): Continuity 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 Winker et al. 2018c).

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

Table 3. Summary of posterior quantiles denoting the 95% credibility intervals of parameters estimates for the six initial JABBA scenarios for Indian Ocean striped marlin.

	Scenario 1 (Cont.)			Scenario 2 (New)		
Estimates	Median	2.50%	97.50%	Median	2.50%	97.50%
K	48463	38398	62581	49587	38322	64271
r	0.26	0.20	0.34	0.25	0.19	0.34
ψ (*psi*)	0.97	0.81	1.14	0.97	0.81	1.14
σ_{proc}	0.07	0.07	0.07	0.07	0.07	0.07
m	1.01	1.01	1.01	1.01	1.01	1.01
F_{MSY}	0.26	0.20	0.33	0.25	0.19	0.33
B_{MSY}	17935	14210	23160	18351	14182	23785
MSY	4607	4150	5053	4574	4114	5026
B_{1959}/K	0.96	0.77	1.12	0.96	0.78	1.12
B_{2019}/K	0.11	0.07	0.16	0.12	0.08	0.18
B_{2019}/B_{MSY}	0.29	0.20	0.42	0.31	0.21	0.48
F_{2019}/F_{MSY}	2.27	1.59	3.17	2.10	1.41	3.02
	Scenario 3 (Hist.)			Scenario 4 (low h)		
Estimates	Median	2.50%	97.50%	Median	2.50%	97.50%
K	46956	36529	61106	61250	48269	79555
r	0.28	0.21	0.36	0.21	0.16	0.28
ψ (*psi*)	0.97	0.82	1.14	0.97	0.81	1.14
σ_{proc}	0.07	0.07	0.07	0.07	0.07	0.07
m	1.01	1.01	1.01	1.19	1.19	1.19
F_{MSY}	0.28	0.21	0.36	0.18	0.14	0.23
B_{MSY}	17377	13518	22614	24499	19307	31821
MSY	4786	4359	5235	4430	3929	4965
B_{1959}/K	0.96	0.78	1.13	0.96	0.77	1.12
B_{2019}/K	0.10	0.07	0.14	0.13	0.09	0.19
B_{2019}/B_{MSY}	0.26	0.18	0.38	0.32	0.22	0.47
F_{2019}/F_{MSY}	2.37	1.66	3.36	2.12	1.44	3.05
	Scenario 5 (high h)			Scenario 6 (proc. error)		
Estimates	Median	2.50%	97.50%	Median	2.50%	97.50%
K	39149	30463	53487	52463	37601	77001
r	0.22	0.17	0.30	0.25	0.19	0.33
ψ (*psi*)	0.97	0.81	1.15	0.97	0.81	1.17
σ_{proc}	0.10	0.10	0.10	0.20	0.20	0.20
m	0.44	0.44	0.44	1.01	1.01	1.01
F_{MSY}	0.51	0.39	0.69	0.25	0.19	0.33
B_{MSY}	8998	7002	12293	19415	13915	28496
MSY	4609	4191	5407	4826	3818	6354
B_{1959}/K	0.94	0.73	1.13	0.88	0.60	1.12
B_{2019}/K	0.06	0.04	0.40	0.11	0.06	0.19
B_{2019}/B_{MSY}	0.26	0.17	1.74	0.28	0.15	0.52
F_{2019}/F_{MSY}	2.49	0.29	3.82	2.22	1.29	3.47

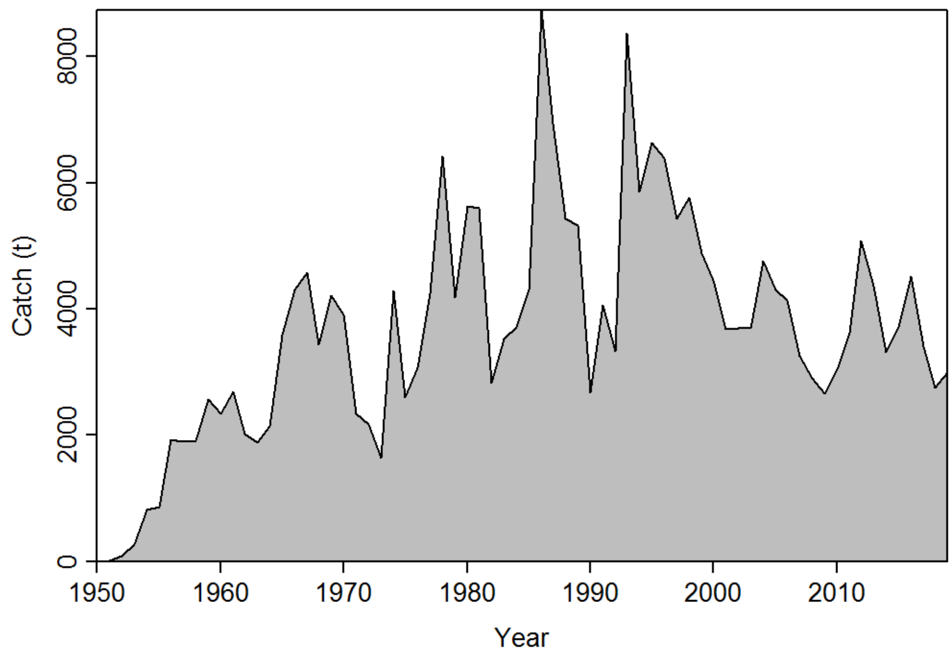

Figure 1. Time-series of estimated catch in metric tons (t) for Indian Ocean striped marlin (1950-2019).

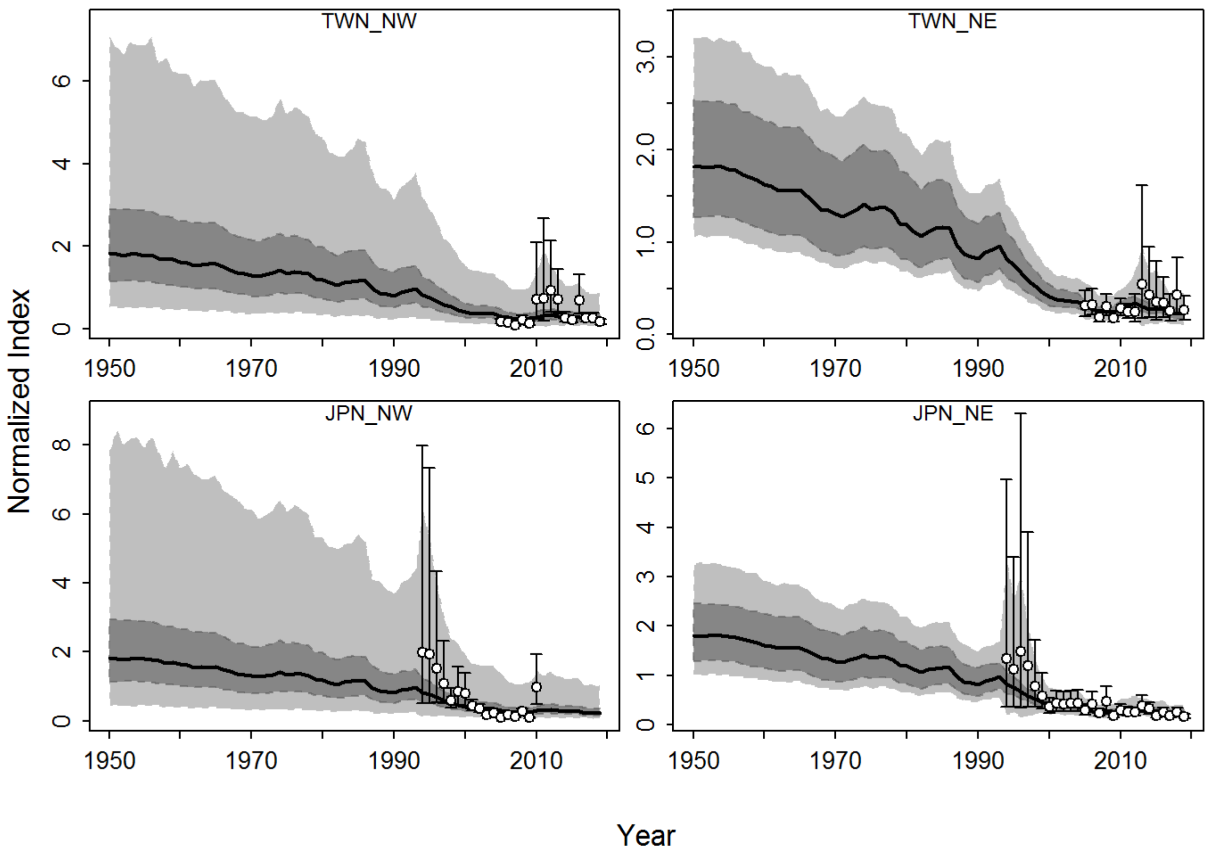

Figure 2. Time-series of observed (circle and SE error bars) and predicted (solid line) of striped marlin in the Indian Ocean CPUE indices used in the "New" scenario (S2) of the JABBA assessment. Shaded grey area indicates 95% C.I.

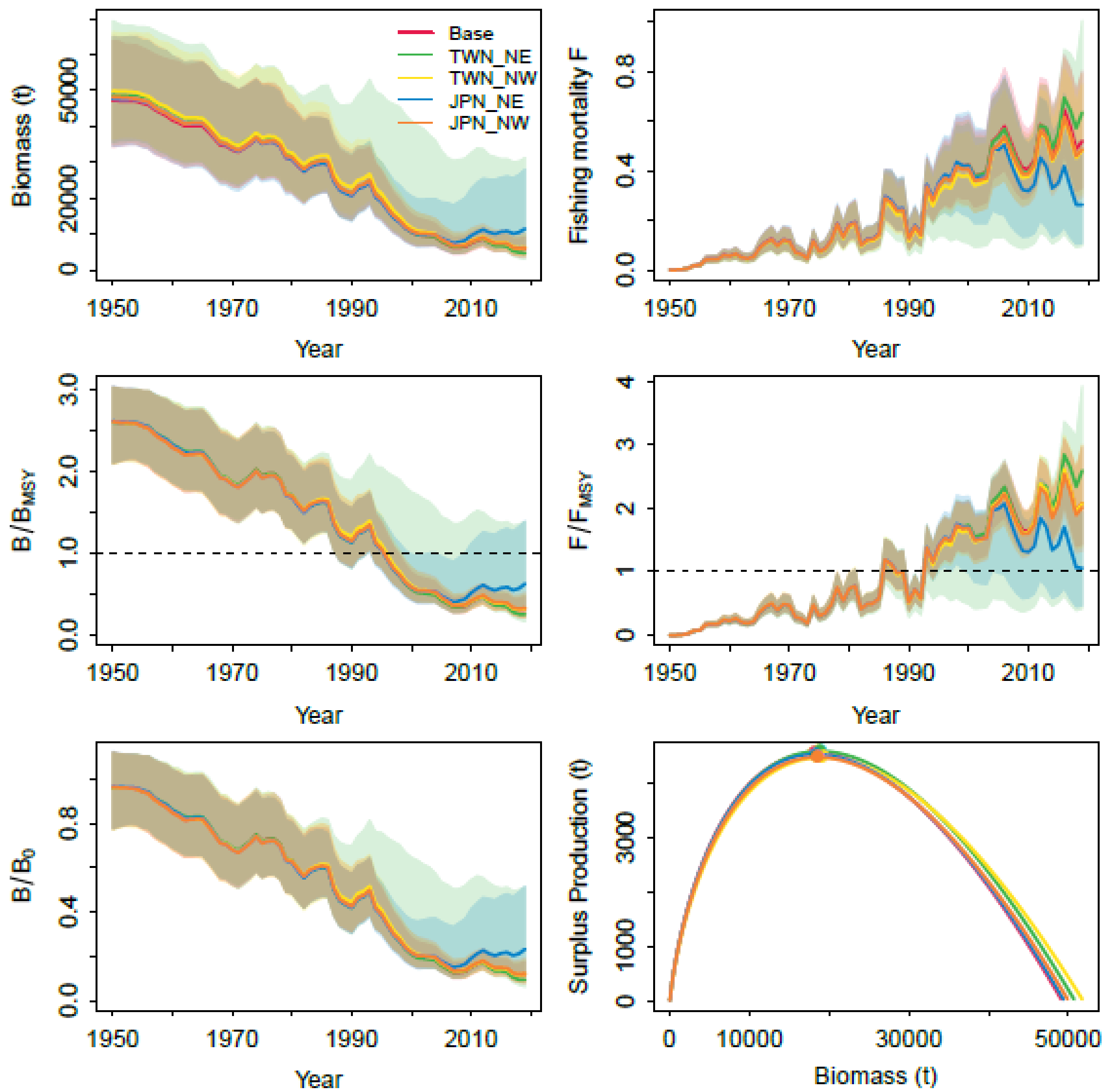

Figure 3. Sensitivity analysis showing the influence of removing one CPUE series at a time on predicted stock biomass (*B*), fishing mortality (*F*), proportion of pristine biomass (*B/K*), surplus production function (maximum = *MSY*) and the stock status trajectories F/F_{MSY} and B/B_{MSY} for the "New" scenario (S2) for Indian Ocean striped marlin.

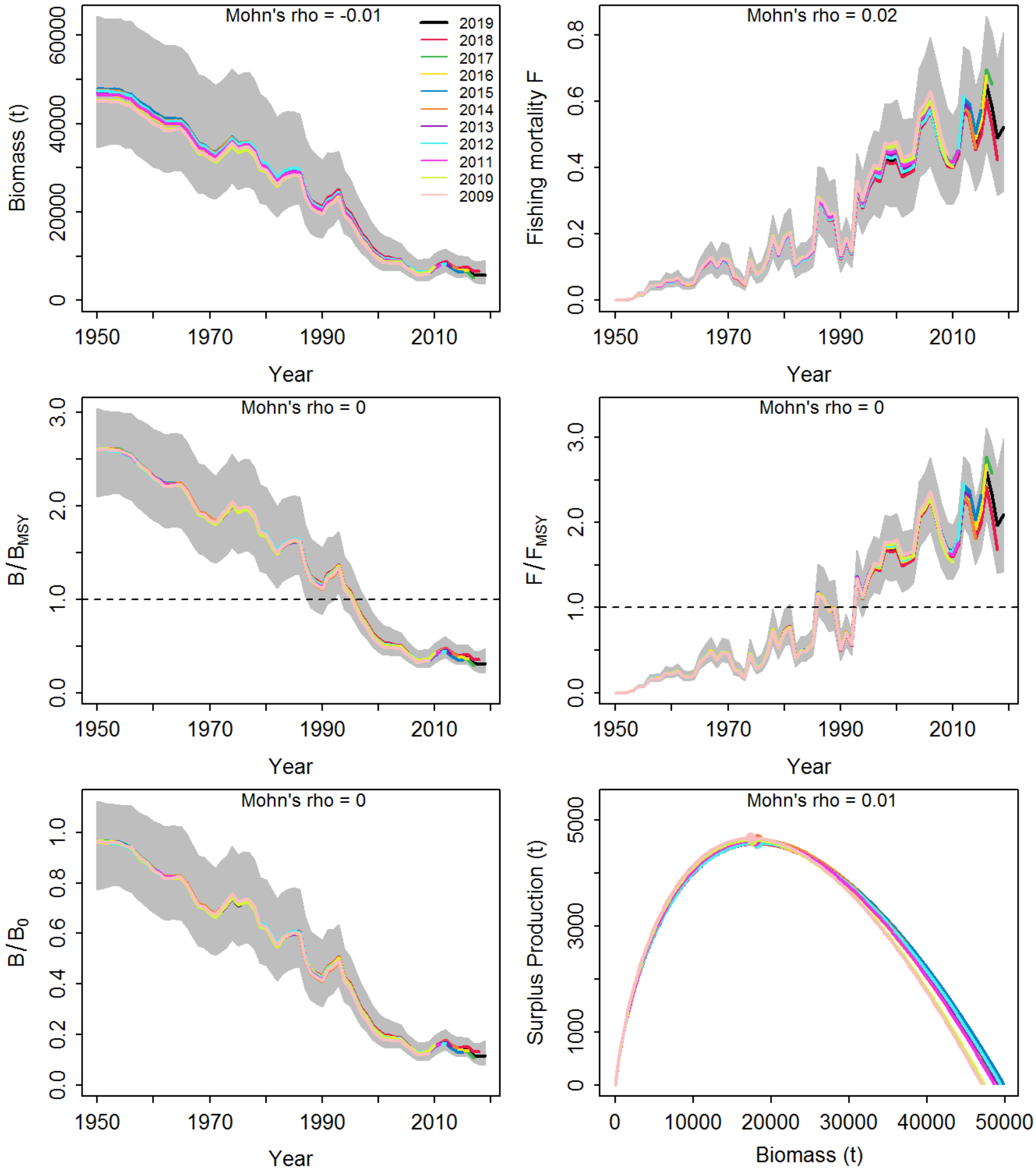

Figure 4. Retrospective analysis for stock biomass (t), surplus production function (maximum = MSY), *B/B_{MSY}* and *F/F_{MSY}* for the Indian Ocean striped marlin JABBA "New" scenario (S2). The label "Reference" indicates the reference case model fits and associated 95% CIs to the entire time series 1950-2019. The numeric year label indicates the retrospective results from the retrospective 'peel', sequentially excluding CPUE data back to 2009. Grey shaded areas denote the 95% Cis.

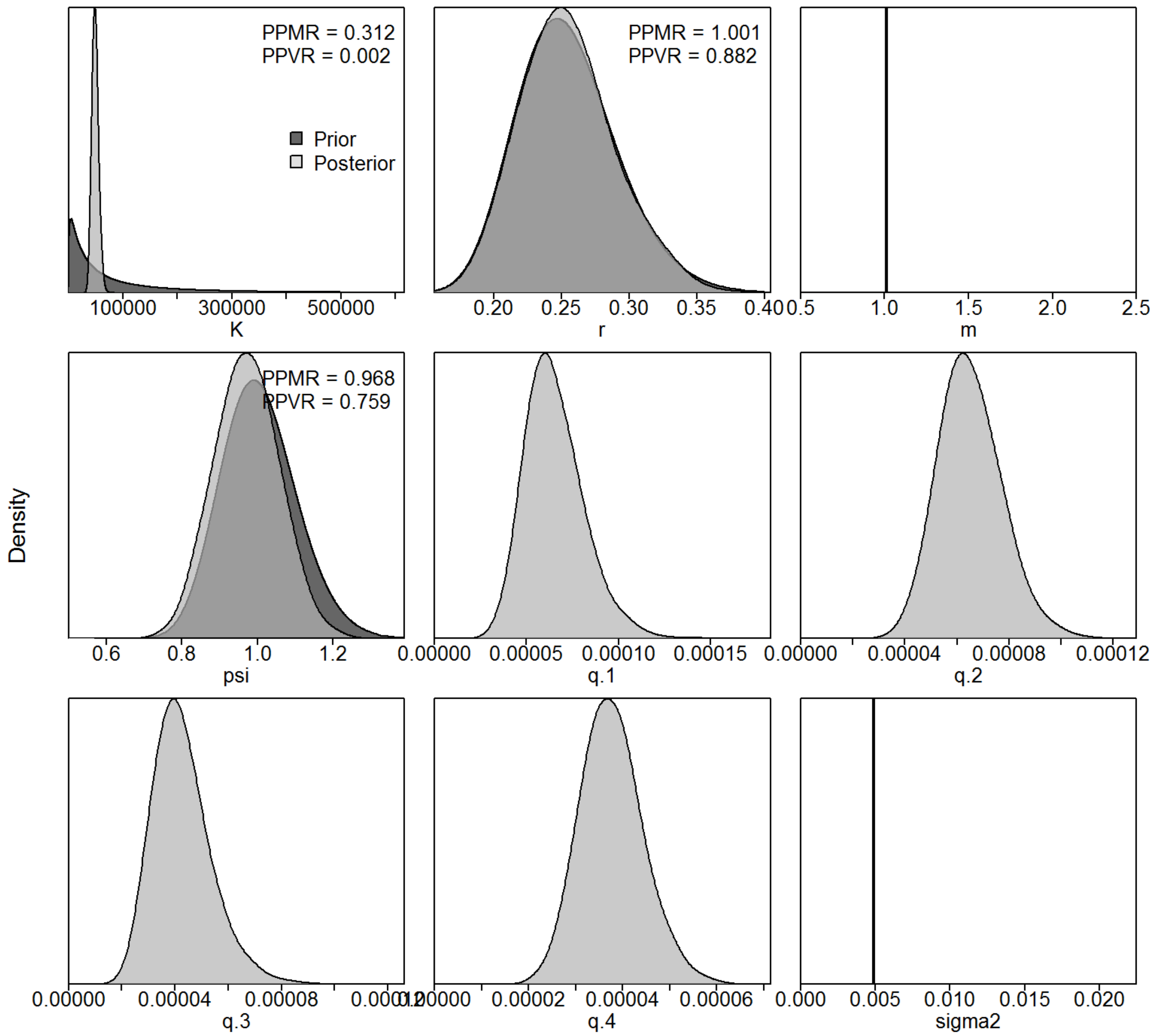

Figure 5. Prior and posterior distribution of various model and management parameters for the "New" scenario (S2) in the JABBA assessment of striped marlin in the Indian Ocean.

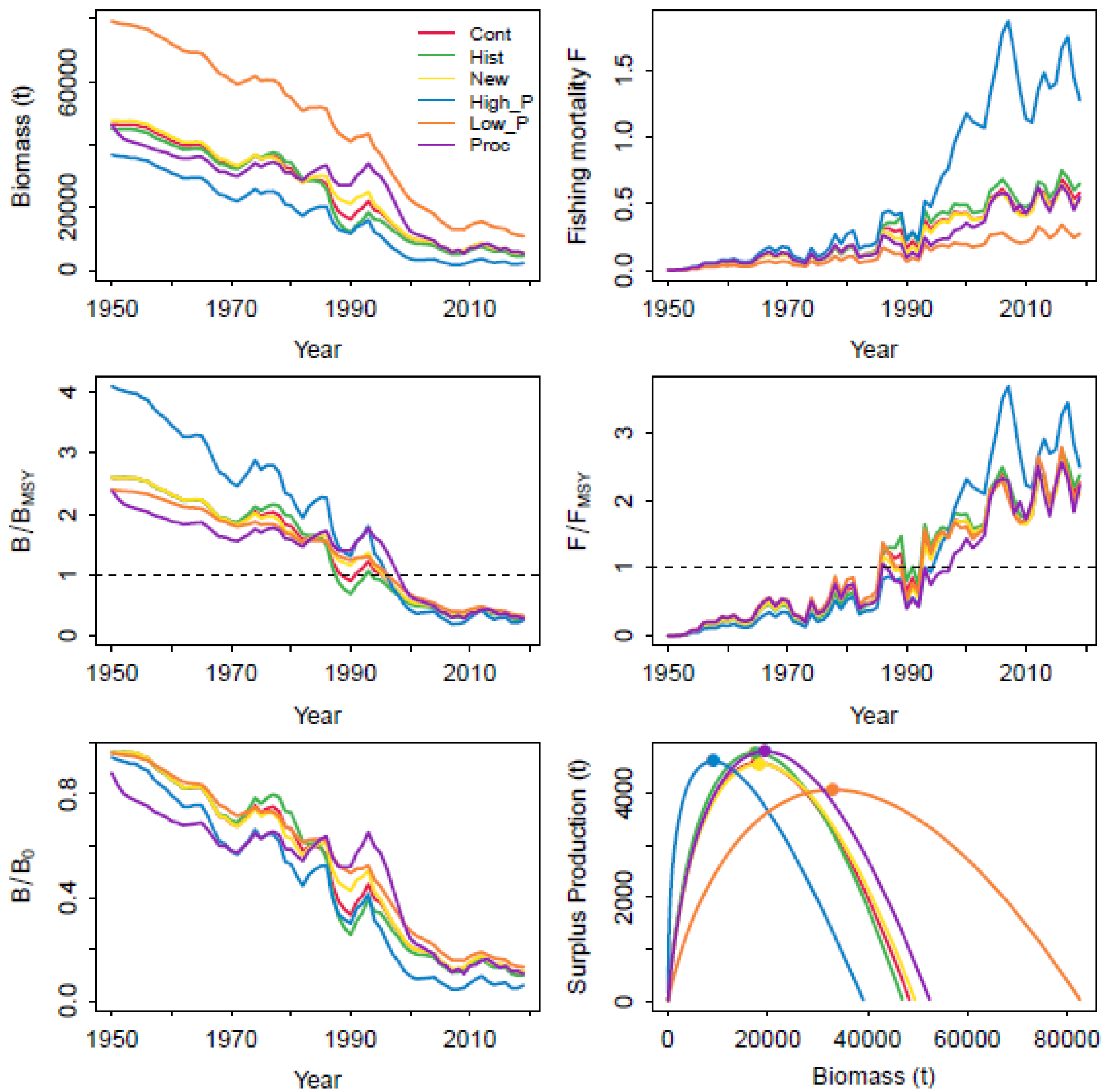

Figure 6. A comparison of stock biomass (t), fishing mortality (*F*), proportion of pristine biomass (*B/K*), surplus production function (maximum = MSY) and the stock status trajectories F/F_{MSY} and B/B_{MSY} between the four scenarios applied to the Indian Ocean striped marlin assessment.

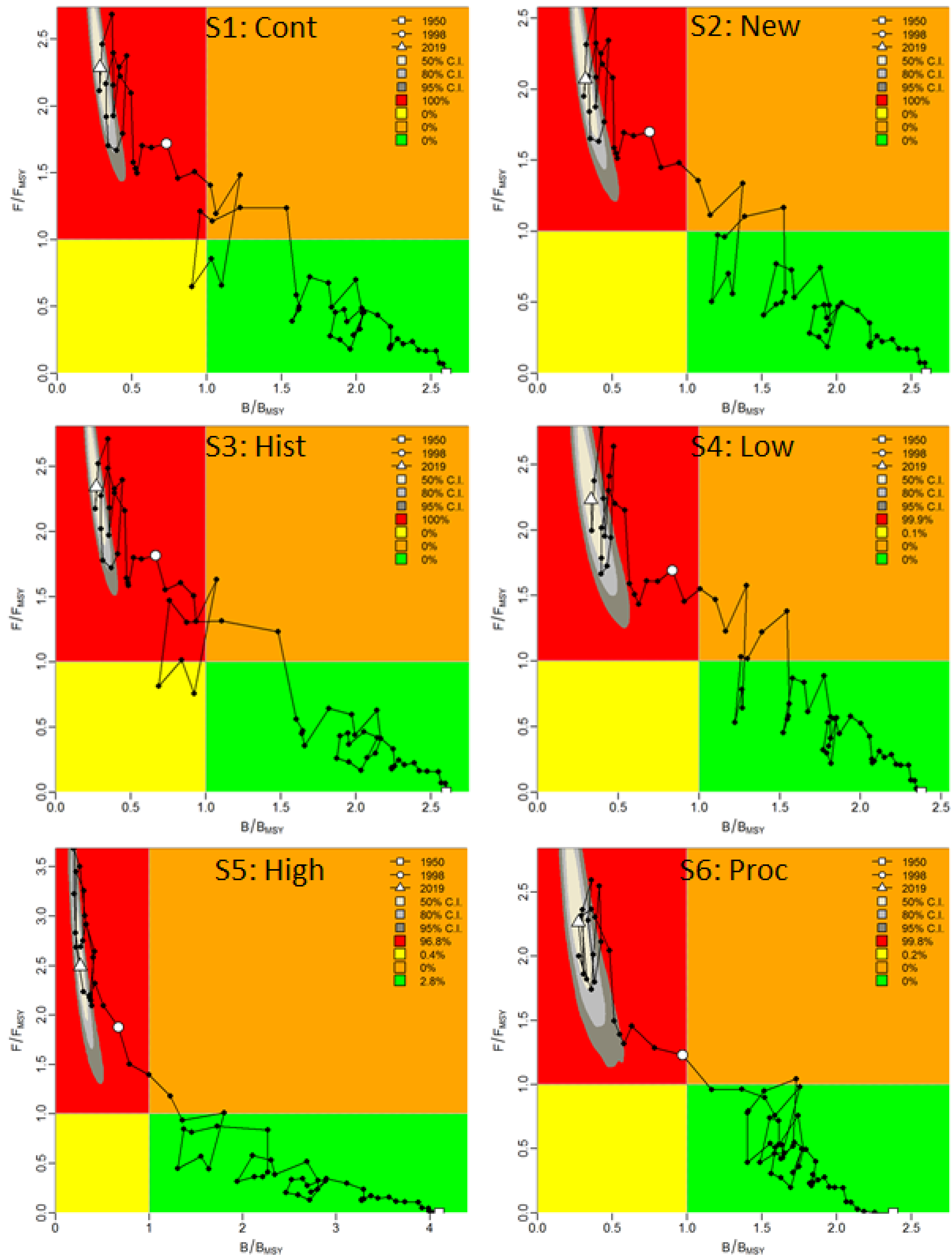

Figure 7. Kobe diagram showing the estimated trajectories (1950-2019) of B/B_{MSY} and F/F_{MSY} for all six scenarios of the JABBA assessment of Indian Ocean striped marlin stock.

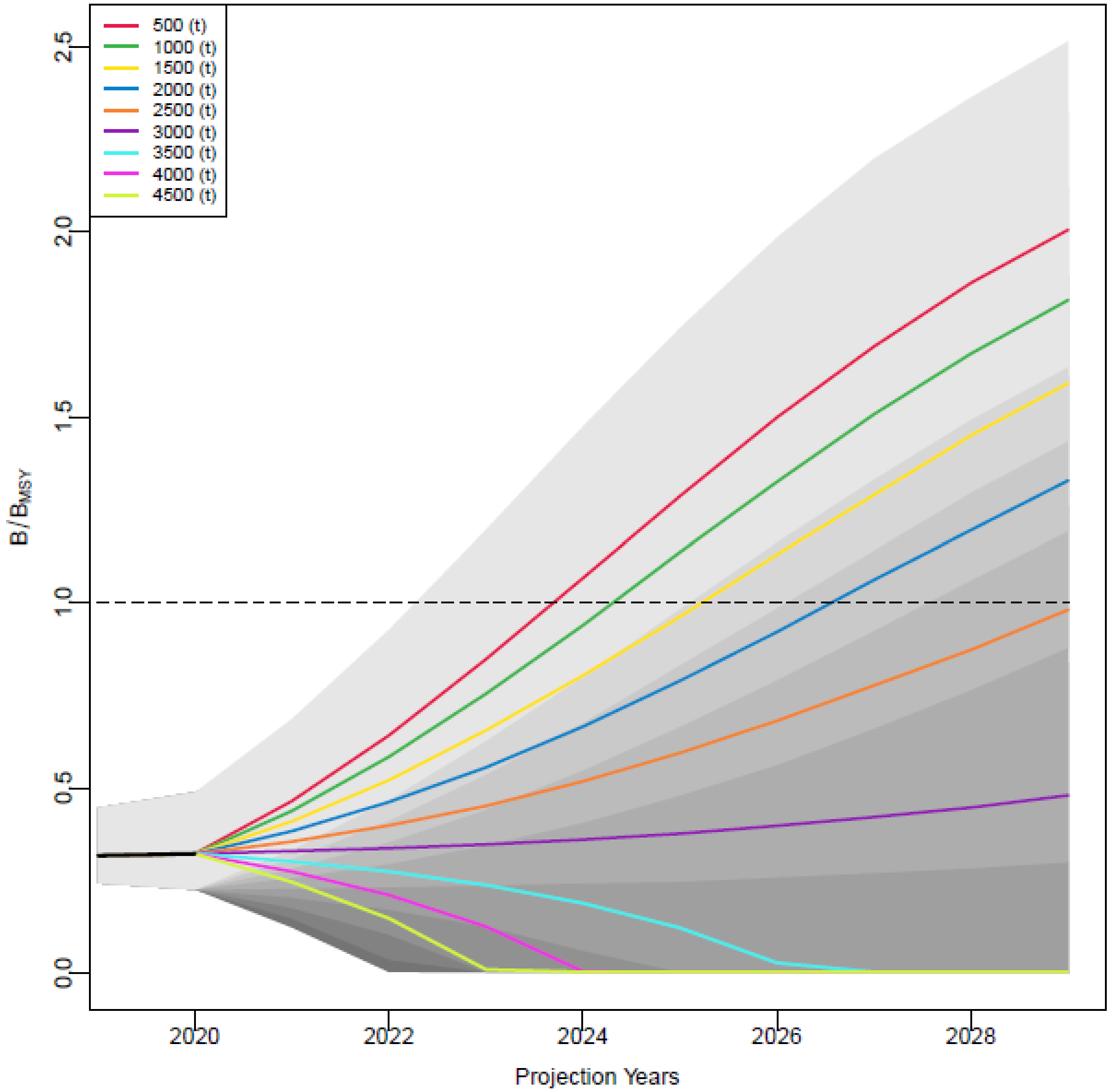

Figure 8. Projections based on the JABBA "New" scenario (S2) for Indian Ocean striped marlin for various levels of future catch. The dashed line denotes BMSY. The average catch over the past three years (2017-2019) is 3054 tons.