ASSESSMENT OF INDIAN OCEAN BLACK MARLIN (*MAKAIRA INDICA*) 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 black marlin (*Makaira indica*) based on alternative specifications of the Pella-Tomlinson model type that incorporated three differing CPUE input data series, three differing r priors and associated input values of B_{MSY}/K and two different values for process error. A general increase in black marlin catches is evident from 1990 onward with steep increases from 2010. Relative abundance (CPUE) trajectories show a steady decline from 1979 until 2005, after which signals of an increasing trend become apparent. The ‘drop one’ sensitivity analysis on CPUE indices indicates that omitting any index has a negligible influence on the management reference point estimates. However, the retrospective analysis produced an undesirable retrospective pattern as evident by systematic negative departures from the full model - the pattern becomes particularly strong from 2014 onward when the increase in total catch accelerated. Furthermore, an implausible trajectory is evident in all six Kobe biplots, which suggest that black marlin B/B_{MSY} increases with an associated increase in F/F_{MSY} for the period 2010-2016. These diagnostics highlight the poor performance with regard to the robustness of estimates and forward projections of B/B_{MSY} and F/F_{MSY} in this assessment and suggest model misspecification due to a simultaneous increase of both catch and CPUE, which is in conflict with the basic population dynamics principles. As such, resultant management reference points should be treated with caution.

KEY WORDS

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

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1. Introduction

In 2018, the Indian Ocean Commission (IOTC) carried out an assessment for black marlin (*Makaira indica*) using only the Bayesian State-Space Surplus Production Model, JABBA. Four scenarios were selected in that assessment, which incorporated two alternative catch series, and three different priors for the intrinsic population growth rates *r*. All scenarios incorporated four standardized CPUE series: Taiwanese (NE and NW), Japanese, and Indonesian. The assessment was characterized by model uncertainty; the model estimated posterior distribution of *K* was very wide and the retrospective analysis produced an undesirable pattern likely caused by the inconsistent trend between the CPUE and catch series (e.g., the observed increasing CPUE and catch since 2010). Consequently, the black marlin stock was classified as "*Not assessed/Uncertain*" in 2018.

Prior to this, the 2016 assessment for black marlin used two different model types; the Surplus Production Model ASPIC and a Bayesian State Space Production Model (BSPM). The ASPIC results indicated that the black marlin stock was overfished and subjected to overfishing (F/F_{MSY} = 2.02 and B/B_{MSY} = 0.59). Risk assessments derived from ASPIC suggested that even if catch were reduced by 40% of the current catch level there was still a high risk (>70%) that F/F_{MSY} would remain above 1 (Yokoi and Nishida, 2016). Results from the BSPM model indicated that the black marlin stock had been overfished during the last 10-15 years (Andrade, 2016). Furthermore, in 2014 a Stock Reduction Analysis based only on catch data was used to assess the status of Indian Ocean black marlin, which was then classified as "subject to overfishing".

Here we provide an updated assessment of the Indian Ocean black 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 black 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 three fishing fleets: Japan, Taiwan,China and Indonesia (Table 1). For this assessment, the Taiwan,China CPUE index was spatially limited to the northern Indian Ocean, and further disaggregated into the North-East and North-West regions. Taiwan,China provided alternative time-series for two periods 1979-2020 and 2005-2020 – the former provides a continuity for the 2018 BLM assessment but concerns as to whether the index is an appropriate measure of abundance prior to 2005 have been raised. Furthermore, Japan provided a separate historical time-series (1979-1993) but this too was omitted from the 2018 assessment on the advice of the authors of the CPUE standardization document. This resulted in a total of seven standardized CPUE series which were available for analysis (Table 1).

2.2. *JABBA stock assessment model*

This 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 black marlin, we considered six alternative specifications of the Pella-Tomlinson model type based on three differing combinations of CPUE input data, three differing *r* priors and associated input values of B_{MSY}/K and two different values for process error. 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*. As a reference case, we chose the *r* prior associated with B_{MSY}/K = 0.37 (h = 0.5), as was used in the 2018 assessment reference case. 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 2). This resulted in the formulation of the following six scenario specifications:

- **S1 (Cont.):** for B_{MSY}/K = 0.37 (h = 0.5), *r* prior *LN* ~ (log (0.19), 0.30)), CPUE = TWN_NW_hist, TWN_NE_hist, JPN, IND.

- **S2 (Ref.):** for B_{MSY}/K = 0.37 (h = 0.5), *r* prior *LN* ~ (log (0.19), 0.30)), CPUE = TWN_NW, TWN_NE, JPN, IND.

- **S3 (Hist):** for B_{MSY}/K = 0.37 (h = 0.5), r prior LN ~ (log (0.19), 0.30)), CPUE = TWN_NW_hist, TWN_NE_hist, JPN_hist, JPN, IND.

- **S4 (Low):** for B_{MSY}/K = 0.41 (h = 0.4), r prior LN ~ (log (0.16), 0.30)), CPUE = TWN_NW, TWN_NE, JPN, IND.

- **S4 (High):** for B_{MSY}/K = 0.34 (h = 0.6), r prior LN ~ (log (0.21), 0.30)), CPUE = TWN_NW, TWN_NE, JPN, IND.

- **S6 (Proc.):** for B_{MSY}/K = 0.37 (h = 0.5), r prior LN ~ (log (0.19), 0.30)), CPUE = TWN_NW, TWN_NE, JPN, IND, 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 for the Reference Case (S2) we ran a sensitivity analysis by iteratively removing a single CPUE time-series and comparing the predicted vectors of biomass B_y, fishing mortality F, 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 Reference Case S2 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 black marlin in the Indian Ocean were relatively low prior to 1990, and only exceeded 10,000 tons for the first time in 2004 (Figure 1). Thereafter, catches increased significantly to a maximum of 22,403 tons in 2015. Relative abundance (CPUE) estimates steadily decline from 1979 until 2005, after which signals for a general positive (increasing) trend become evident – as such the omission of historical time-series limits CPUE data inference to the recent positive trends and negates historical declines. Nevertheless, all CPUE trends in the Reference Case (S2) showed a reasonable fit to the observed data.

The 'drop one' sensitivity analysis performed on the Reference Case indicates that omitting any index (TWN_NW, TWN_NE, JPN, IND) has negligible influence on the management reference point estimates B/B_{MSY} and F/F_{MSY} (Figure 3). The relatively short period of all the CPUE time-series available in S2 may be the reason for the limited deviations observed in the sensitivity analyses.

The retrospective analysis produced highly variable stock status estimates with strong evidence of an undesirable retrospective pattern (Figure 4). Departures from the full model (data up to 2019) predictions are notable, particularly from 2014 onward, all of which result in a more pessimistic outlook of the stock status than the full model. Of particular concern is the plasticity of the surplus production function and the subsequent estimates of biomass. The 2014 biomass estimate in the full model is almost double that estimated when only data up to 2014 is fitted. These diagnostics highlight the poor performance with regards to the robustness of estimates and forward projections of B/B_{MSY} and F/F_{MSY} in this assessment.

Scenarios that include historical CPUE data produce B/B_{MSY} trajectories that steadily declined from the late 1980s to the lowest values in 2005, after which B/B_{MSY} increases (Figure 6). In scenarios that do not include historical CPUE, the decline B/B_{MSY} starts later in 1993 but has a similar pattern thereafter. In contrast, F/F_{MSY} increased steadily from 1990 to 2019 with a brief period of stability between 2004 and 2010. The scenario with increased process error (S6) is considerably more pessimistic than the other scenarios. The MSY estimates ranged between 11,354 (S6) and 18,655 (S5) tons for all six scenarios (Table 3) and the corresponding range of B_{MSY} estimates was between 61,780 tons (S6) and 108,642 tons (S4). The range of median F/F_{MSY} estimates were between 0.45 (S5) and 1.15 (S6) and the Reference Case F_{MSY} estimate was 0.53. The range of median estimates for B/B_{MSY} was 1.42 - 2.13 and the range for B/K median estimates was 0.53 - 0.74 (Table 3).

Individual Kobe biplots were similar for scenarios S1-S5 in that all had the highest probability of the terminal (2019) point being in the "green" quadrant. However, S6 differs in that the terminal point has the highest probability (52.9%) of being in the "orange" quadrant and is characterized by high uncertainty as a result of the inflated process error (Figure 7). Notably, an implausible trajectory is evident in all six Kobe biplots 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 this assessment of black marlin suggest severe model misspecification which is likely a result of poor quality input data (catch and CPUE). The observed increasing CPUE trend in conjunction with a significant increase in catch since ~2010 pushes the limits of biological plausibility. As a result, the surplus production function exhibits a strong, systematic retrospective pattern, which arises from compensating for simultaneous increases in catch and relative abundance by inflating the pristine biomass estimate (*K*). The observed systematic deviations in the retrospective analysis results provide little confidence in the predictive capabilities of the assessment.

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 black 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 Indian Ocean	1979-1993	JPN_hist
Japan Indian Ocean	1994-2019	JPN
Indonesia Indian Ocean	2005-2019	IND

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

Parameter	Description	Prior	*m*	CV	Scenario
K	Unfished biomass	lognormal	50,000	300%	All
r (ref *h*)	Population growth rate	lognormal	0.19	30%	S1, S2, S3, S6
r (low *h*)		lognormal	0.16	30%	S4
r (high *h*)		lognormal	0.21	30%	S5
ψ (*psi*)	Initial depletion	lognormal	1	10%	All
s^2 *(proc)*	Process error variance	fixed	0.7	-	S1-S5
s^2 (high *proc)*	Process error variance	fixed	0.2	-	S6
B_{MSY}/K (ref *h*)	Ratio Biomass at MSY to *K*	fixed	0.37	-	S1, S2, S3, S6
B_{MSY}/K (low *h*)		fixed	0.41	-	S4
B_{MSY}/K (high *h*)		fixed	0.34	-	S5

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

	Scenario 1 (Cont.)			Scenario 2 (Ref.)		
Estimates	Median	2.50%	97.50%	Median	2.50%	97.50%
K	200880	129901	351553	236149	145419	453156
r	0.20	0.12	0.34	0.20	0.12	0.35
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}	0.20	0.12	0.34	0.20	0.12	0.34
B_{MSY}	74341	48073	130101	87393	53816	167702
MSY	14678	10430	22297	17301	10979	35024
B_{1959}/K	0.96	0.77	1.12	0.96	0.77	1.12
B_{2019}/K	0.62	0.49	0.78	0.73	0.53	0.95
$B_{2019}/B_{\mathrm{MSY}}$	1.68	1.33	2.10	1.98	1.42	2.57
$F_{2019}/F_{\mathrm{MSY}}$	0.73	0.41	1.20	0.53	0.22	1.05
	Scenario 3 (Hist.)			Scenario 4 (low h)		
Estimates	Median	2.50%	97.50%	Median	2.50%	97.50%
K	212196	134535	355119	264946	167133	527612
r	0.17	0.10	0.30	0.18	0.10	0.30
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	1.25	1.25	1.25
F_{MSY}	0.17	0.10	0.30	0.14	0.08	0.24
B_{MSY}	78529	49788	131421	108642	68534	216350
MSY	13521	9605	20238	15289	9353	29142
B_{1959}/K	0.96	0.77	1.12	0.96	0.77	1.12
B_{2019}/K	0.59	0.45	0.74	0.74	0.54	0.95
$B_{2019}/B_{\mathrm{MSY}}$	1.59	1.23	2.00	1.80	1.30	2.32
$F_{2019}/F_{\mathrm{MSY}}$	0.84	0.47	1.41	0.65	0.29	1.33
	Scenario 5 (high h)			Scenario 6 (proc. error)		
Estimates	Median	2.50%	97.50%	Median	2.50%	97.50%
K	221599	142440	408355	166941	102031	323609
r	0.21	0.12	0.36	0.18	0.10	0.32
ψ (*psi*)	0.97	0.81	1.14	0.97	0.81	1.17
σ_{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}	0.25	0.14	0.42	0.18	0.10	0.31
B_{MSY}	75365	48443	138880	61781	37759	119760
MSY	18655	11726	34938	11354	7010	19184
B_{1959}/K	0.96	0.77	1.12	0.87	0.59	1.12
B_{2019}/K	0.73	0.53	0.93	0.53	0.28	0.83
$B_{2019}/B_{\mathrm{MSY}}$	2.13	1.56	2.74	1.42	0.76	2.25
$F_{2019}/F_{\mathrm{MSY}}$	0.45	0.20	0.91	1.15	0.50	2.29

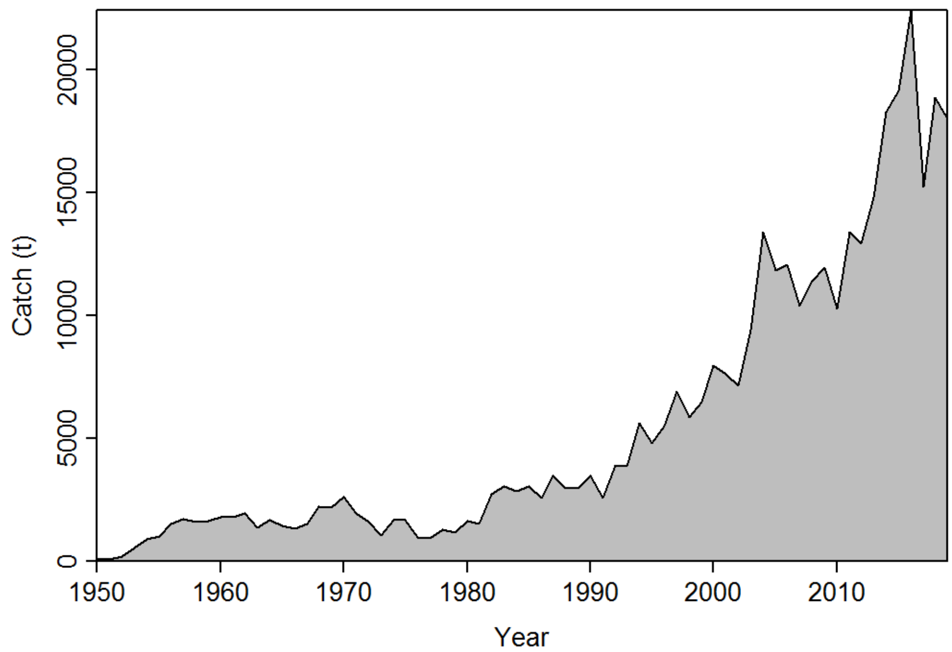

Figure 1. Time-series of estimated catch in metric tons (t) for Indian Ocean black marlin (1950-2019) used in the 2021 JABBA assessment.

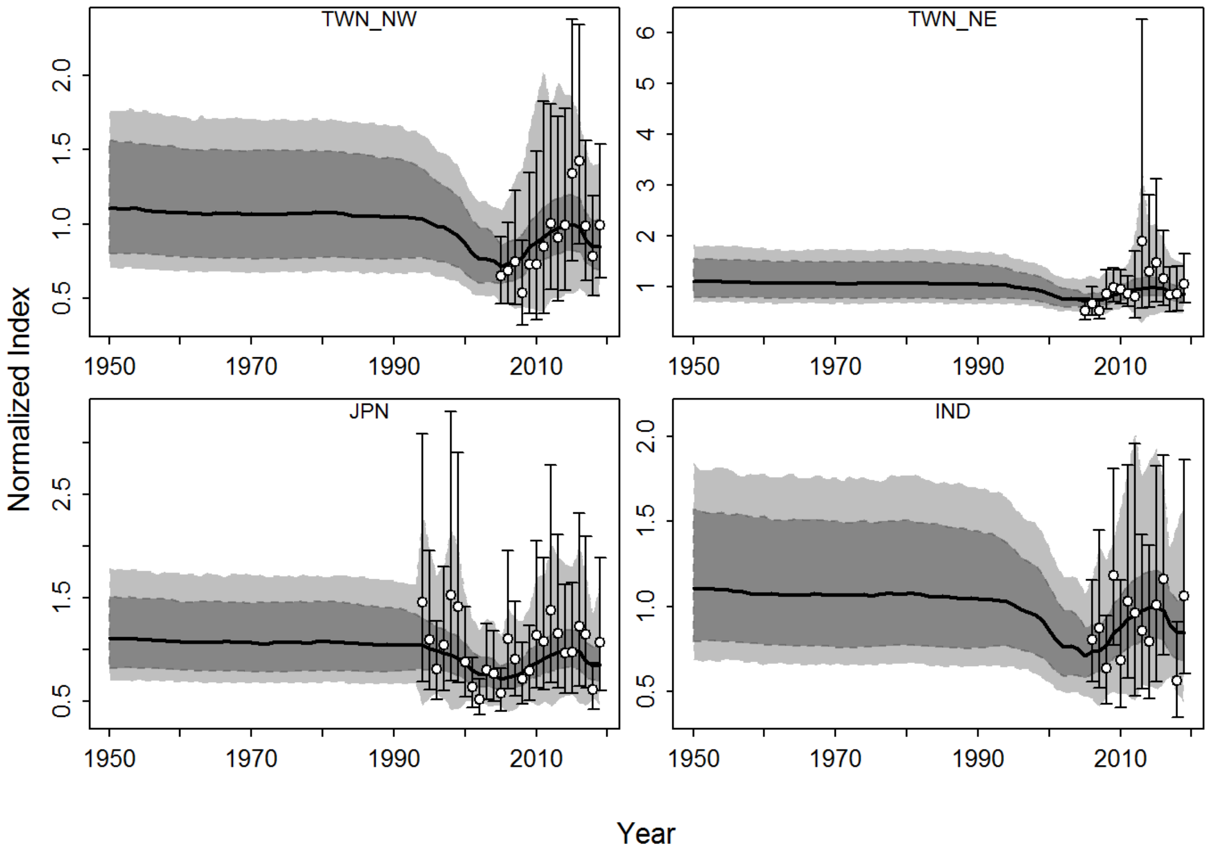

Figure 2. Time-series of observed (circle and SE error bars) and predicted (solid line) of black marlin in the Indian Ocean CPUE indices used in the Reference Case scenario (S2) of the JABBA assessment. Shaded grey area indicates 95% C.I.

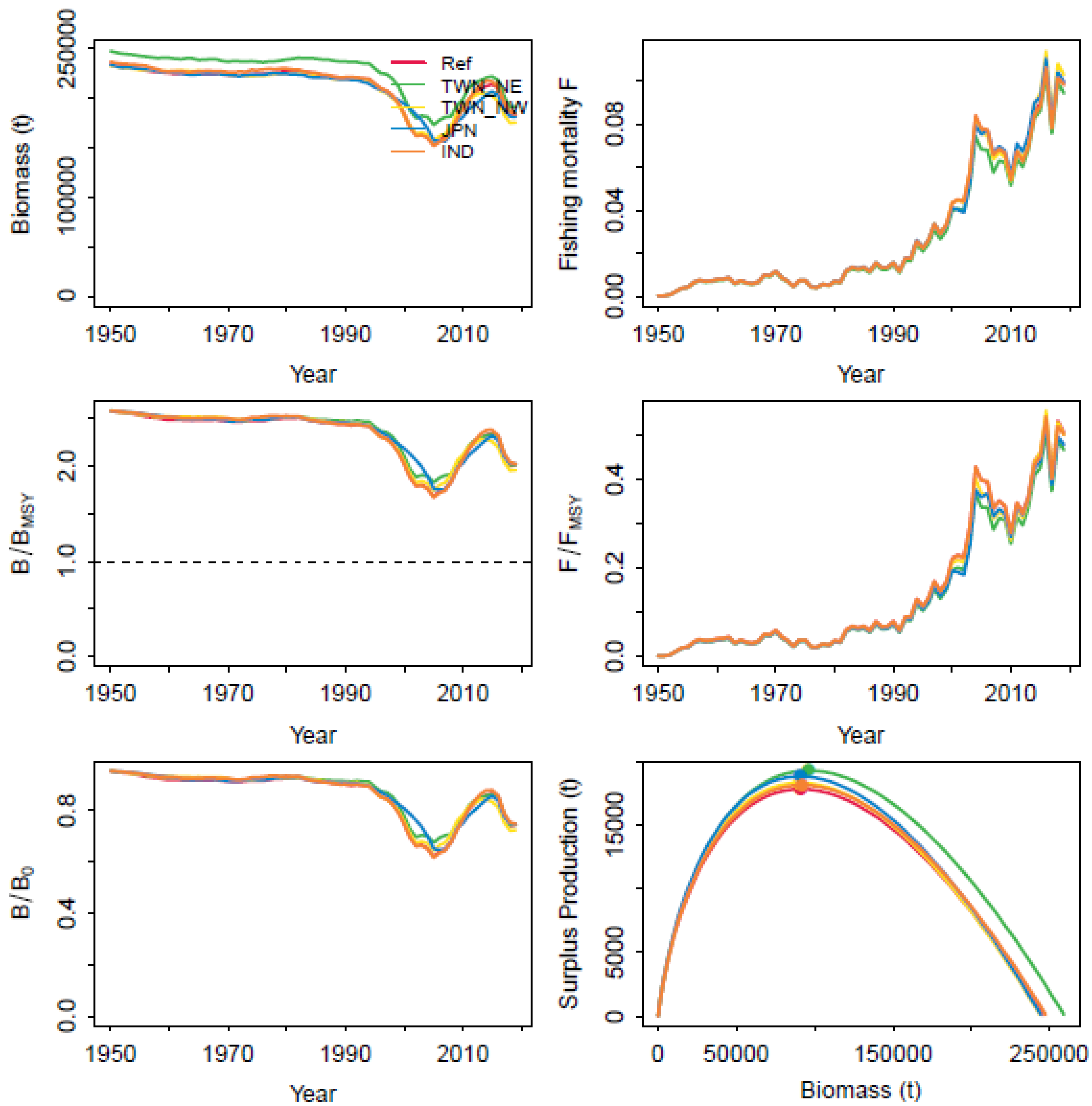

Figure 3. Sensitivity analysis showing the influence of removing one CPUE series at a time on predicted stock biomass (*B*), fishing mortality (*F*), proportion of pristine biomass (*B/K*), surplus production function (maximum = MSY) and the stock status trajectories F/F_{MSY} and B/B_{MSY} for the reference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

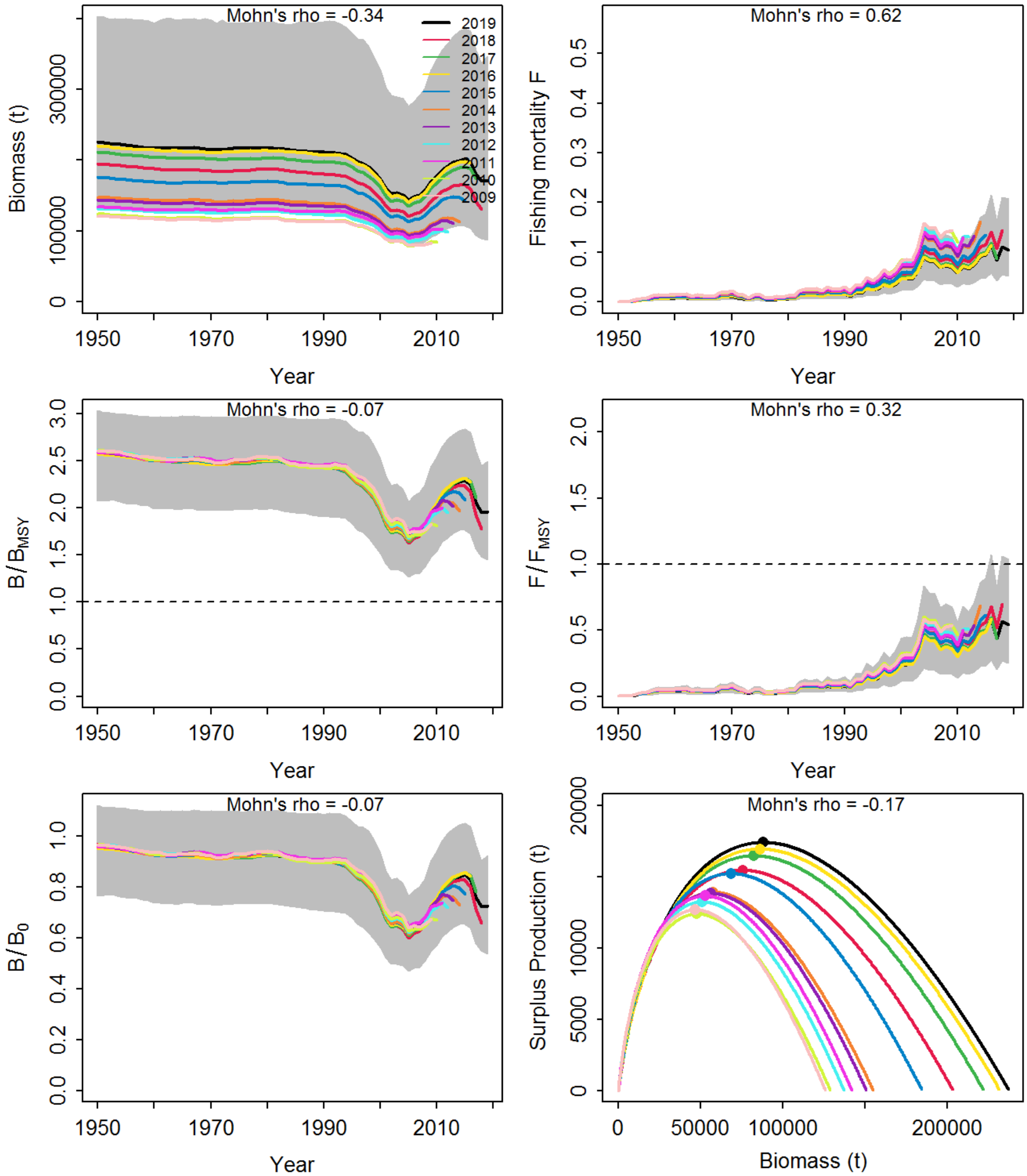

Figure 4. Retrospective analysis for stock biomass (t), surplus production function (maximum = MSY), *B/B*$_{MSY}$ and *F/F*$_{MSY}$ for the Indian Ocean black marlin JABBA Reference Scenario (S2). The label “Reference” indicates the reference case model fits and associated 95% CIs to the entire time series 1950-2017. 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.

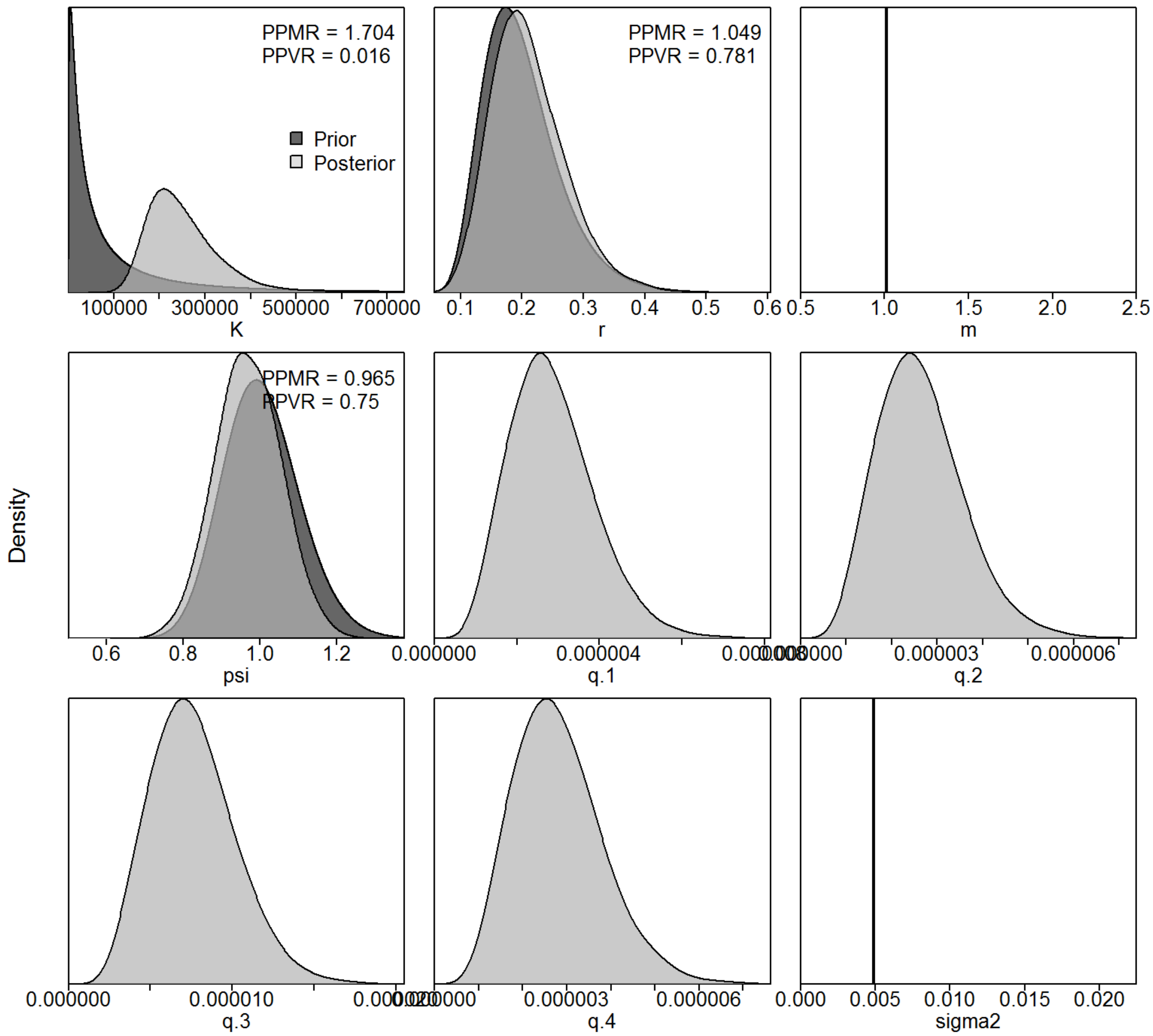

Figure 5. Prior and posterior distribution of various model and management parameters for the Bayesian state-space surplus production model Reference Case (S2) for black marlin in the Indian Ocean.

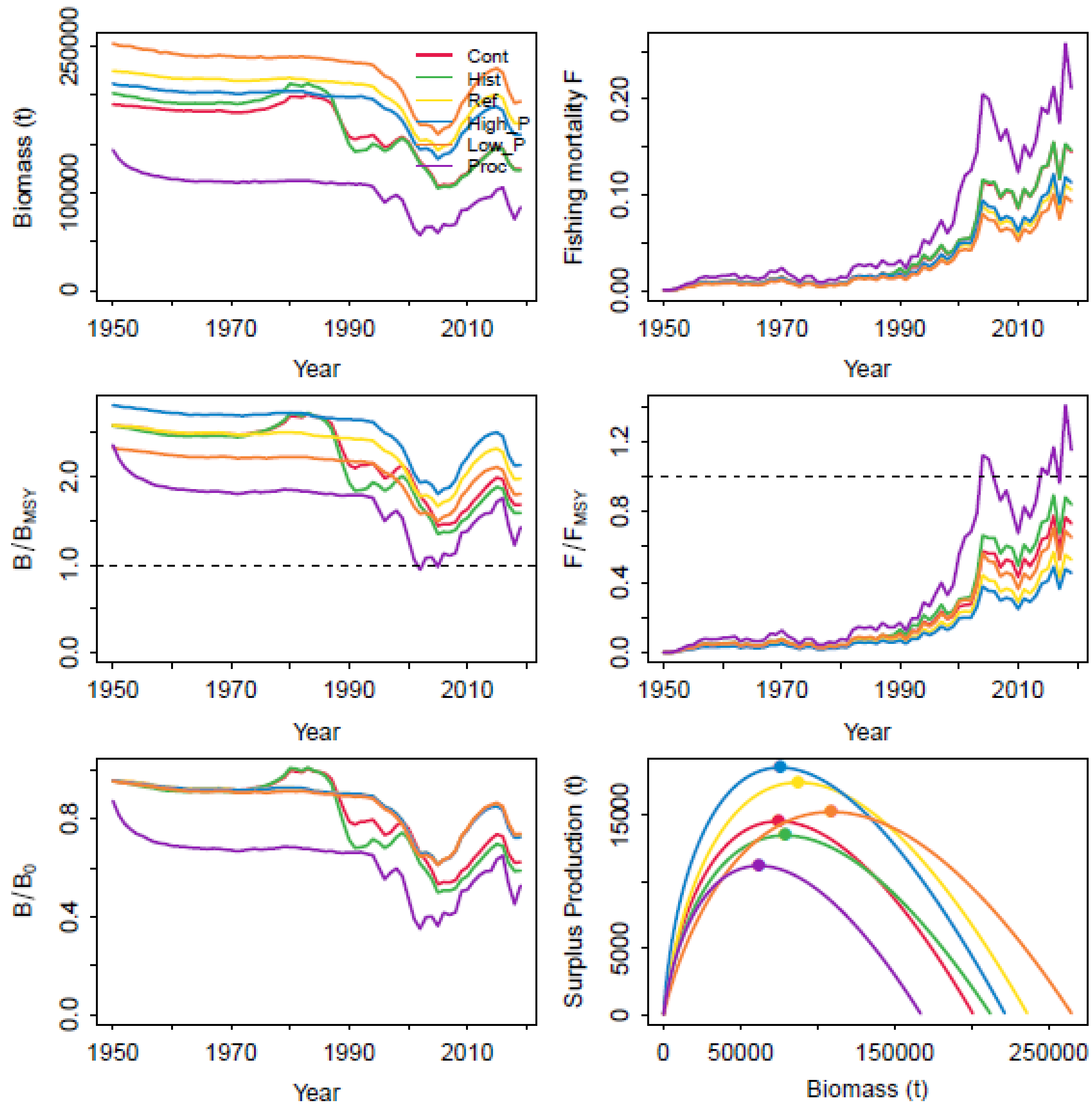

Figure 6. A comparison of stock biomass (t), fishing mortality (*F*), proportion of pristine biomass (*B/K*), surplus production function (maximum = MSY) and the stock status trajectories F/F_{MSY} and B/B_{MSY} between the four scenarios applied to the Indian Ocean black marlin assessment.

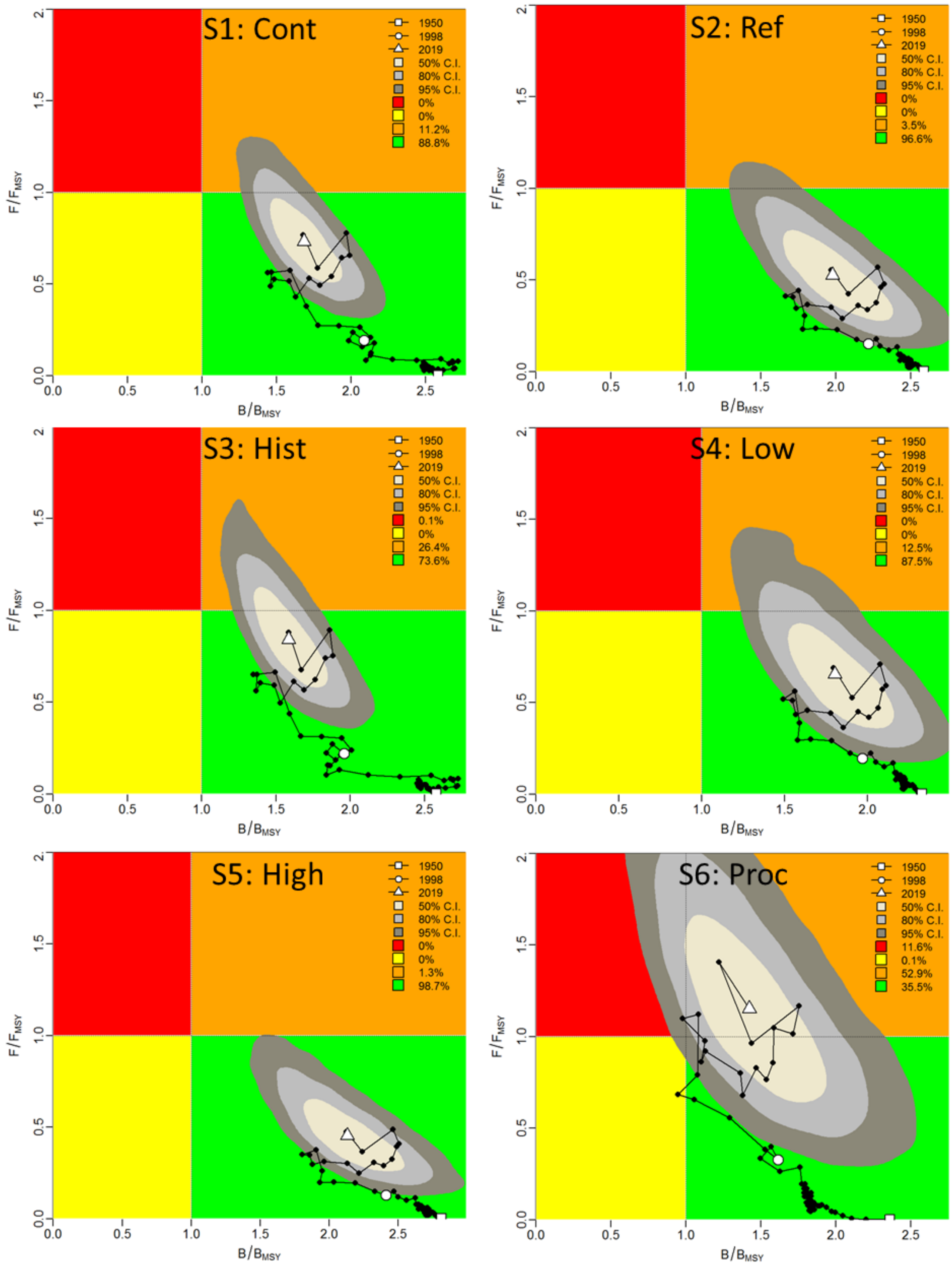

Figure 7. Kobe diagram showing the estimated trajectories (1950-2019) of B/B_{MSY} and F/F_{MSY} for all scenarios of the Bayesian state-space surplus production model for the Indian Ocean black marlin stock.