STOCK ASSESSMENT OF BLUE MARLIN (*MAKAIRA NIGRICANS*) IN THE INDIAN OCEAN USING *JABBA*

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SUMMARY

Five Bayesian State-Space Surplus Production Model scenarios were run to assess blue marlin (*Makaira nigricans*) in the Indian Ocean in the open-source stock assessment environment, JABBA (Just Another Bayesian Biomass Assessment). A ‘drop one’ sensitivity analysis indicated that omitting any of the CPUE time-series would not significantly alter the stock status. As such, all CPUE time-series were used for the *Base case* scenario. Similarly, a retrospective analysis produced highly consistent results for stock status estimates back to 2006 and therefore provided no evidence for an undesirable retrospective pattern. The *Base case* scenario estimated medians of MSY at 9,984 t (8,178 – 11,855 t), B/B_{MSY} at 0.82 (0.56 - 1.15) and H/H_{MSY} at 1.47 (0.96 - 2.35). The B/B_{MSY} trajectory declined from the mid-1980s to 2007. A short-term increase in B/B_{MSY} occurred from 2007 to 2012, which is thought to be linked to the NW Indian Ocean Piracy period. Thereafter, the B/B_{MSY} trajectory again declines to the current estimate. A steady increase of F/F_{MSY} since the mid-1980s has continued unabated. The Kobe plot indicated 87% probability that the blue marlin stock in the Indian Ocean is “overfished” and “subject to overfishing”. The results of the retrospective analysis provide a degree of confidence in the predictive ability of the assessment model for future projections under alternative quotas to inform management decisions.

KEY WORDS

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

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1. Introduction

In 2016, the Indian Ocean Commission (IOTC) carried out an assessment for blue marlin (*Makaira nigricans*) by employing three different model types; the Surplus Production Model (SPM) software ASPIC (Prager 1994) without process error, customized Bayesian State Space Production Model (BSPM) with process error (Andrade 2016), and the statistical age-structured model Stock Synthesis (Methot and Wetzel, 2013) . Management advice was based on the results from the Bayesian State Space Production Model (BSPM) with a Schaefer-type production function, which indicated that the catches in 2016 (15,706 t) were above MSY and that the stock was overfished in the past and that currently it is subject to overfishing.

To ensure continuity with the previous assessment (Andrade 2016), we initially recreated the 2016 BSPM assessment of the Indian Ocean blue marlin stock in JABBA (IOTC-2019-WPB17-20a). The results of the initial assessment indicate that JABBA is able to provide a suitable continuity run to the Andrade (2016) assessment as the results are comparable. Continuity of assessments is important to evaluate the efficacy of previous management recommendations to the IOTC Commission.

Here, we provide an updated (2019) assessment of blue marlin in the Indian Ocean 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 has also been included in the ICCAT stock catalogue (https://github.com/ICCAT/software/wiki/2.8-JABBA), following a number a number of recent tuna RFMO stock assessments, including the 2018 striped marlin and black marlin assessments for the IOTC (Parker et al., 2018a &2018b). Model diagnostics are presented in the form of sensitivity analysis, retrospective analysis and prior vs posterior plots.

2. Material and Methods

Data

Catch data were provided by the IOTC secretariat and took the form of time series of aggregated catches (1950-2017). The following standardized catch-per-unit-effort (CPUE) time series were included:

- Japan North-West (1979-2010)
- Japan Central-East (1979-2017)
- Taiwan North-West (1979-2010)
- Taiwan North-East (1979-2010)
- Indonesia (2006-2017)

Both catch and CPUE time series were extracted from the IOTC stock assessment dataset repository of the 17th Meeting on of Working Party on Billfish (https://www.iotc.org/meetings/17th-working-party-billfish-wpb17). Details on the standardization procedure of CPUE indices for Japan (JPN), Taiwan (TWN) and Indonesia (IDN) are presented in Taki et al. (2019) and Wang (2019) and Setyadji (2019), respectively. It must be noted that there was considerable data conflict among the CPUE indices and JPN and TWN indices were reviewed after discussions in the WPB17 meeting.

Model Scenarios

A number of alternative scenarios were provided to the delegates during the WPB17 meeting, most of which pertained to alternative combinations of CPUE indices. To provide continuity to the Andrade (2016) assessment, the WPB17 agreed that the blue marlin *Base case* for the JABBA assessment would be a Schaefer model with an informative lognormal prior for the intrinsic rate of population increase *r*, specified by a mean of log(0.4) and a standard deviation of 0.3 (Table 1). The state-space framework enables to simultaneously estimate the process and observation variance. Andrade (2016) assumed that both associated with the same vaguely informative inverse-gamma priors with scale and shape parameters of 8 and 0.1, respectively. For the purpose of this assessment, we adopted the same prior formulation as process variance prior, which corresponds to a prior mean of 0.44^2, with a CV of 153%. In JABBA, however, the observation variance is estimated by default with a non-informative inverse-gamma prior. To more closely resemble the observation prior variance by Andrade (2016), we instead assumed a additionally fixed, additive variance of 0.15^2 (Table 1; see Winker et al. 2018 for details). Like Andrade (2016), the observation variance was assumed to be common for both time series and thus estimated as a single parameter. Catchability parameters q_i for each CPUE index *i* were estimated separately assuming a wide uniform distribution (Table 2). For the *K* prior we assumed the same range of plausible values as in Andrade (2016), but, in contrast to Andrade (2016) , JABBA automatically converts uniform bounds into a 'flat' lognormal prior to optimize converge property (Winker et al. 2018). The JABBA prior choices for the process variance and *q* were those used by Andrade (2016). Full model parameterization is provided in Table 1.

JABBA stock assessment model

The continuity runs were conducted with the most recently updated version (v1.5 Beta) of JABBA, available under: www.github.com/henning-winker/JABBAbeta. Each model was run for 30,000 iterations, sampled with a burn-in period of 5,000 for each of two chains and subsequently saving every 5th step to attain a joint posterior of 10,000 save values. Basic diagnostics of model convergence of the MCMC chains, including visualization of the MCMC chains throughout trace-plots, Heidelberger and Welch (Heidelberger and Welch, 1992) and (Geweke, 1992) and Gelman and Rubin (1992), indicated that all continuity had converged adequately, associated with a run time of under 2 minutes per scenario.

To assess the relative influence of individual CPUE time-series on the stock status estimates for the *Base case* 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_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 *Base case* by sequentially removing the most the recent year (retrospective 'peel') and refitting the model over a period of ten years (i.e. 2017 back to 2007).

3. Results and Discussion

Nominal catches of blue marlin in the Indian Ocean were variable among years and peaked in 2012 with a total of 14,739 tons (Figure 1). The CPUE revealed moderate data conflict in two periods: 1990 – 1998 and 2010 onwards. Despite temporary conflicting trends, generally all of the JPN and TWN CPUE indices were consistent in showing an extended period of decline from 1979 until attaining a minimum around 2010. The IDN CPUE index is relatively short (2006-2017) and had no obvious trend.

The 'drop one' sensitivity analysis indicates that omitting either of the JPN indices would result in the most optimistic outcomes, while the omission of either the TWN NE or the IDN indices would produce the most pessimistic assessment result in terms of B/B_{MSY} (Figure 5). However, none of these deviations would significantly alter the stock status as the most optimistic sensitivity estimate for B/B_{MSY} remains below 1. The retrospective analysis produced highly consistent stock status estimates back to 2007, showing only negligible departures of retrospective peel from the reference predictions through to 2017. There was therefore no evidence for an undesirable retrospective pattern.

The current catches of blue marlin (average of 12,008 t in the last 3 years, 2015-2017) are higher than MSY (9,984 t). The *Base case* scenario produced a B/B_{MSY} trajectory that steadily declined from the mid-1980s to 2007, with a short-term increase occurring from 2007 to 2012 which is thought to be linked to the NW Indian Ocean Piracy period (Figure 8). Thereafter, the B/B_{MSY} trajectory again declines to the current estimate. In terms of F/F_{MSY} , a steady increase since the 1970s has continued unabated. The *Base case* scenario Kobe plot indicated 87% joint probability that the blue marlin stock in the Indian Ocean is overfished and subject to overfishing (Figure 9).

The results of the 2019 JABBA assessment for blue marlin in the Indian Ocean indicates that the stock is *overfished* and *subject to overfishing*. The robustness to the retrospective analysis results provides a degree of confidence in the predictive capabilities of the assessment and, therefore, the assessments ability to inform management decisions by means of future projections under alternative quota. In order to achieve the Commission objectives of being in the green zone of the Kobe Plot by 2027 ($F_{2027} < F_{MSY}$ and $B_{2027} > B_{MSY}$) with at least a 60% chance, the catches of blue marlin would have to be reduced by roughly 35% compared to the average of the last 3 years, to a maximum value of approximately 7,800 tons.

4. References

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5. Tables

Table 1. Summary of catch-per-unit-effort (CPUE) indices considered in the 2019 JABBA assessment runs for blue marlin in the Indian Ocean.

CPUE indices and period	Period	Abbreviation
Taiwan North-West Indian Ocean	1979-2010	TWN_NW
Taiwan North-East Indian Ocean	1979-2010	TWN_NE
Japan North-West Indian Ocean	1979-2010	JPN_NW
Japan Central-East Indian Ocean	1976-2017	JPN_NE
Indonesia North-East Indian Ocean	2006-2017	IDN

Table 2. Summary of JABBA prior specifications for the *Base case* scenario of the 2019 assessment of Indian Ocean blue marlin (*Makaira nigricans*).

Model	Parameter	Prior	Specification
Schaefer	Pop. growth rate	lognormal	$r \sim LN(\log(0.4),0.3)$
Schaefer	Unfished biomass	lognormal	$K \sim LN(\log(106557.8),0.75)$
Schaefer	Process variance	inv-gamma	$\sigma^2 \sim IG(8,0.1)$
Schaefer	Observation variance	inv-gamma	$\tau^2 \sim IG(0.001,0.001) + 0.15^2$
Schaefer	Catchability	uniform	$q \sim U(10^{-30},1000)$

Table 3. Summary of posterior quantiles denoting the 95% credibility intervals of parameters estimates for the *Base case* JABBA scenario for blue marlin in the Indian Ocean.

			Base case	
Estimates		**Median**	**2.50%**	**97.50%**
K	Carrying capacity	94033	59835	150731
r	Intrinsic rate of population increase	0.42	0.26	0.69
y (*psi*)	Initial depletion	0.98	0.90	1.08
σ_{proc}	Process variance	0.10	0.06	0.15
F_{MSY}		0.21	0.13	0.35
B_{MSY}		47017	29917	75365
MSY		9984	8178	11855
B_{1950}/K		0.93	0.76	1.04
B_{2017}/K		0.41	0.28	0.57
$B_{2017}/B_{\mathrm{MSY}}$		0.82	0.56	1.15
$F_{2017}/F_{\mathrm{MSY}}$		1.47	0.96	2.35

6. Figures

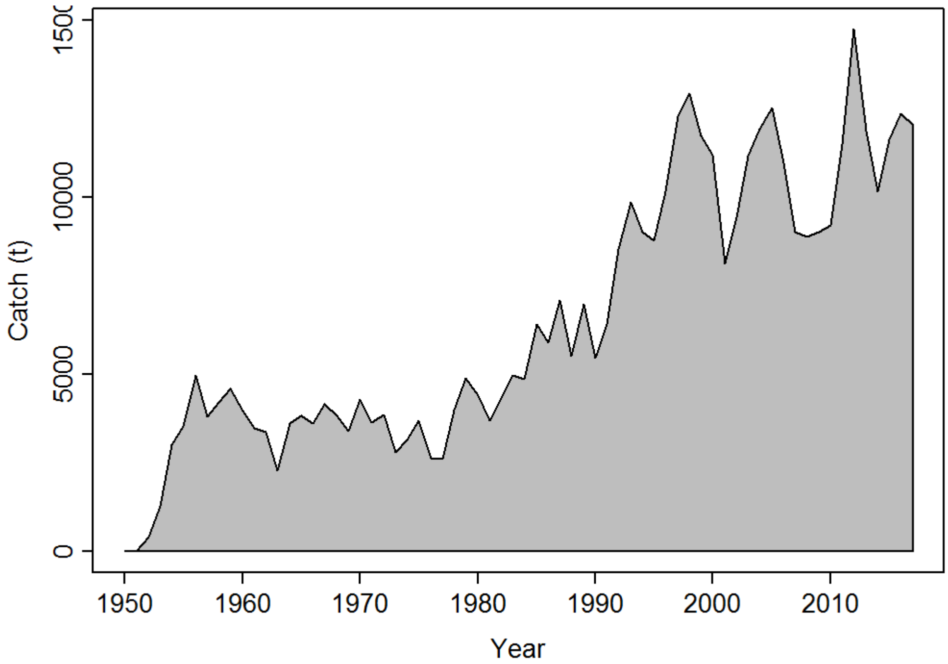

Figure 1. Time series of catch in metric tons (t) for blue marlin in the Indian Ocean (1950-2017).

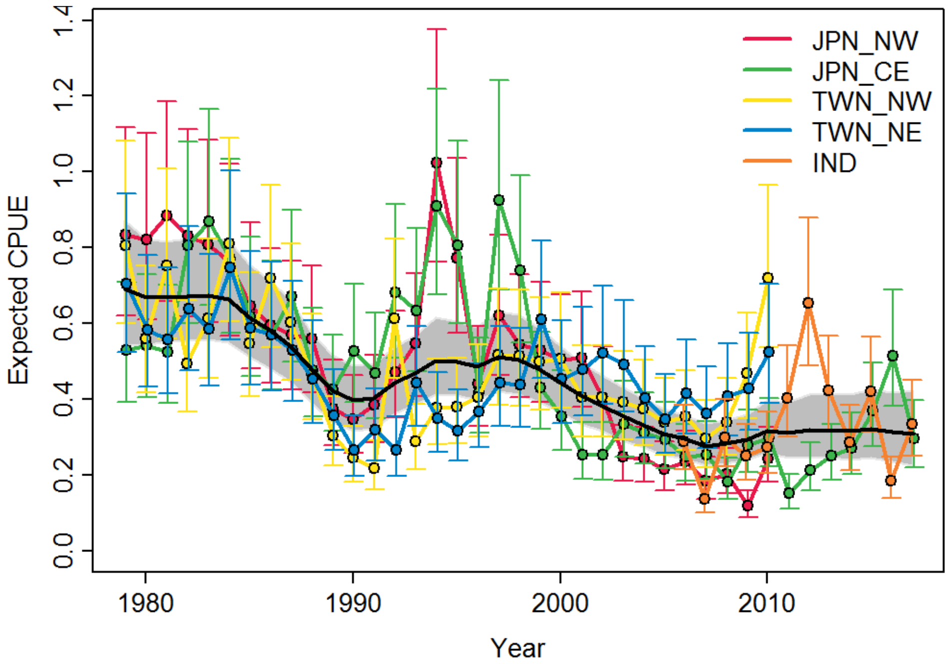

Figure 2. Time-series of the five standardized CPUE series included in the blue marlin assessment for the Indian Ocean, see Table 1. The mean CPUE trend (solid black line) was produced using the state-space CPUE averaging tool implemented in JABBA. The underlying abundance trend is treated as an unobservable state variable that follows a log-linear Markovian process, so that the current mean relative abundance was assumed to be a function of the mean relative abundance in the previous year, an underlying mean population trend and lognormal process error term. The CPUE indices are aligned with the base index via estimable catchability scaling parameters.

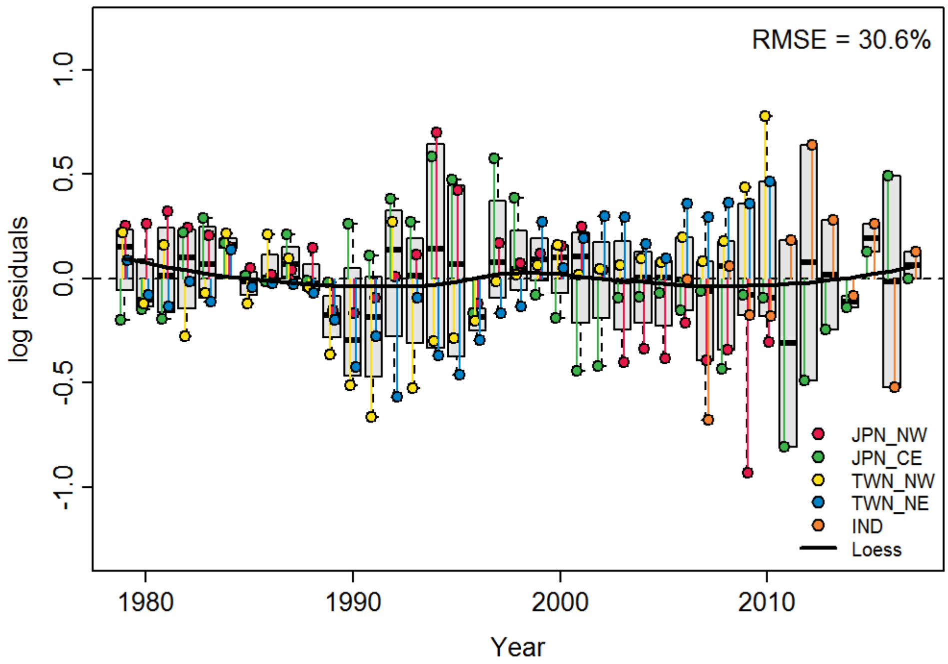

Figure 3. JABBA residual diagnostic plots for the *Base case* scenario. Boxplots indicate the median and quantiles of all residuals available for any given year, and solid black lines indicate a loess smoother through all residuals. RMSE denotes root mean square error, the standard deviation of residuals.

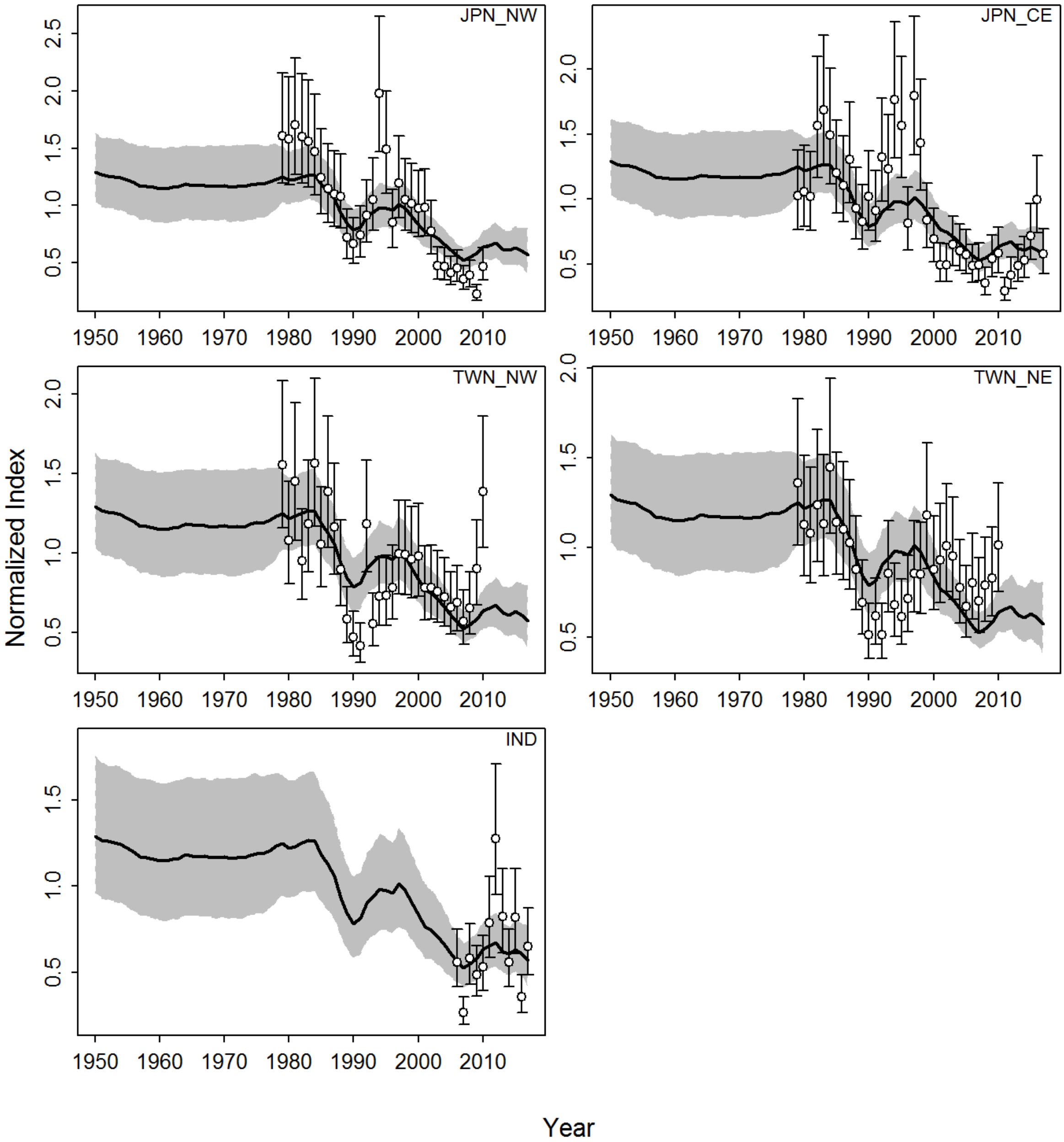

Figure 4. Time series of observed (circle and SE error bars) and predicted (solid line) CPUE of blue marlin in the Indian Ocean for the Bayesian state-space surplus production model JABBA. Shaded grey area indicates 95% C.I.

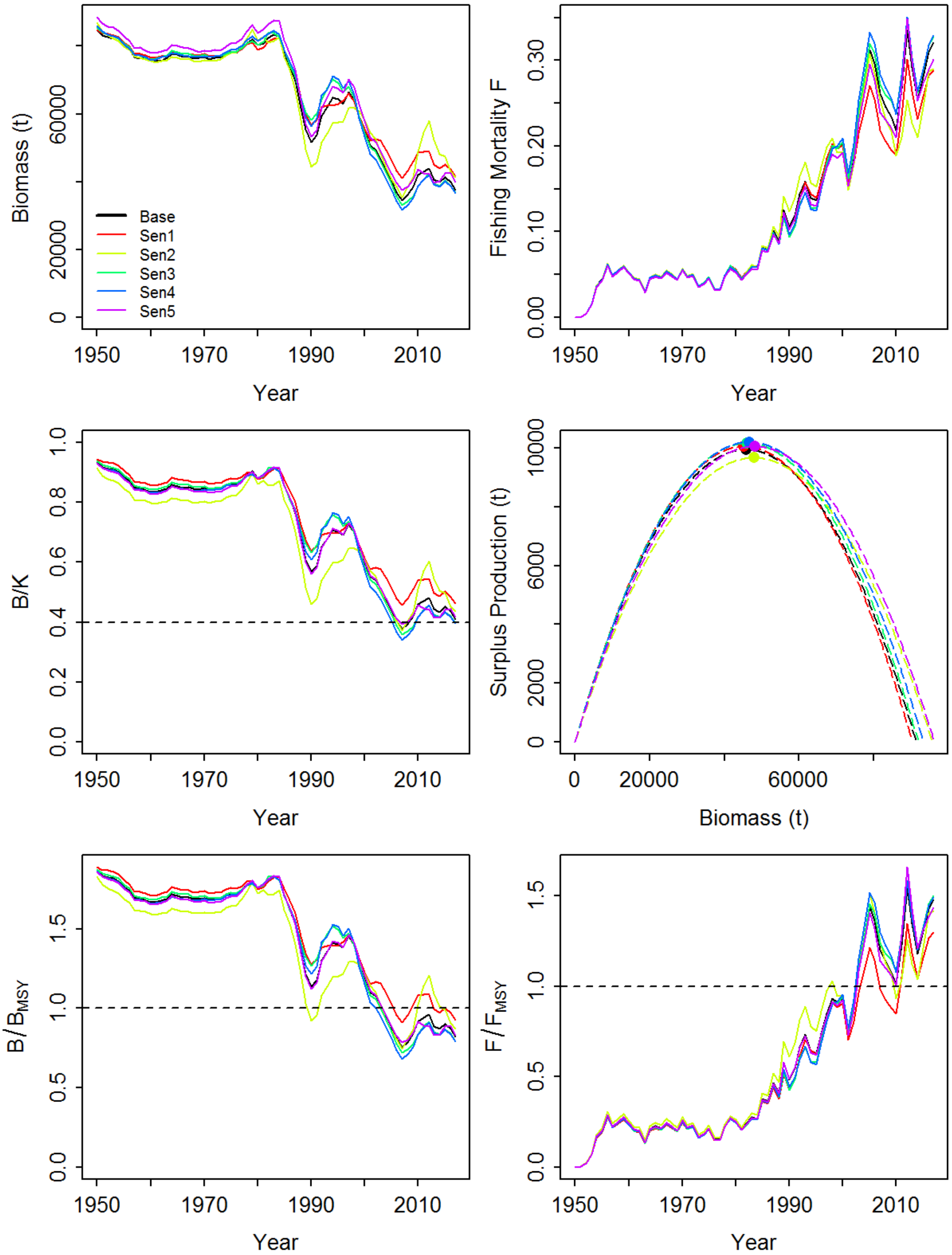

Figure 5. Sensitivity analysis showing the influence of removing one CPUE series at a time on predicted stock biomass (*B*), fishing mortality (*F*), proportion of pristine biomass (*B/K*), surplus production function (maximum = MSY) and the stock status trajectories F/F_{MSY} and B/B_{MSY} for the *Base case* (black) for blue marlin in the Indian Ocean. The following indices were dropped in each sensitivity scenario. Sen1: JPN_NW, Sen2: JPN_CE, Sen3: TWN_NW, Sen4: TWN_NE and Sen5: IDN.

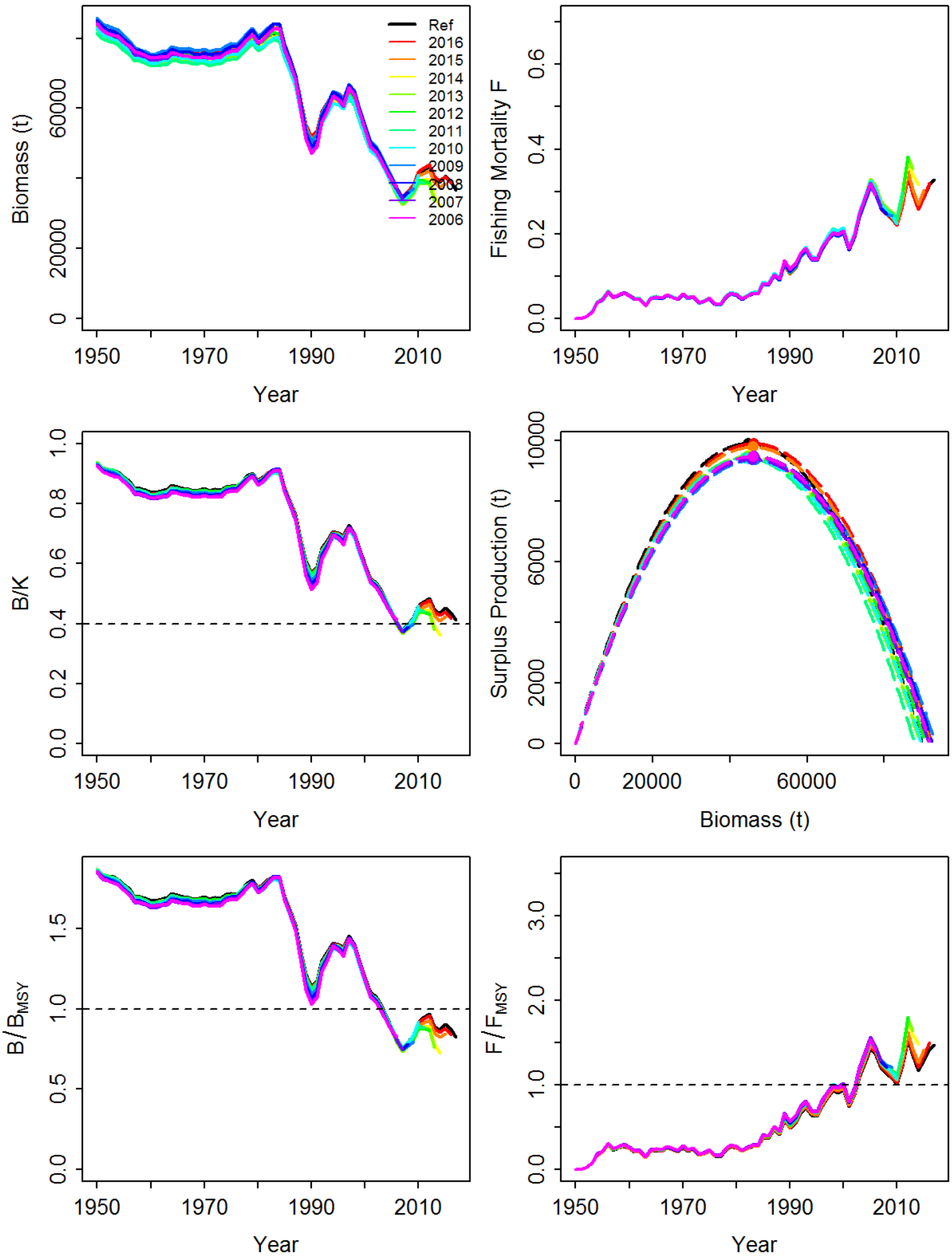

Figure 6. Retrospective analysis for stock biomass (t), surplus production function (maximum = MSY), B/B_{MSY} and F/F_{MSY} for the *Base case* scenario for the blue marlin Indian Ocean assessment. The label "Reference" indicates the reference case model fits and associated 95% CIs to the entire time series 1950-2017. The numeric year label indicates the retrospective results from the retrospective 'peel', sequentially excluding CPUE data back to 2006. Grey shaded areas denote the 95% CIs, which are indicated by crosshair for B_{MSY} and MSY defining the maximum of the surplus production curve.

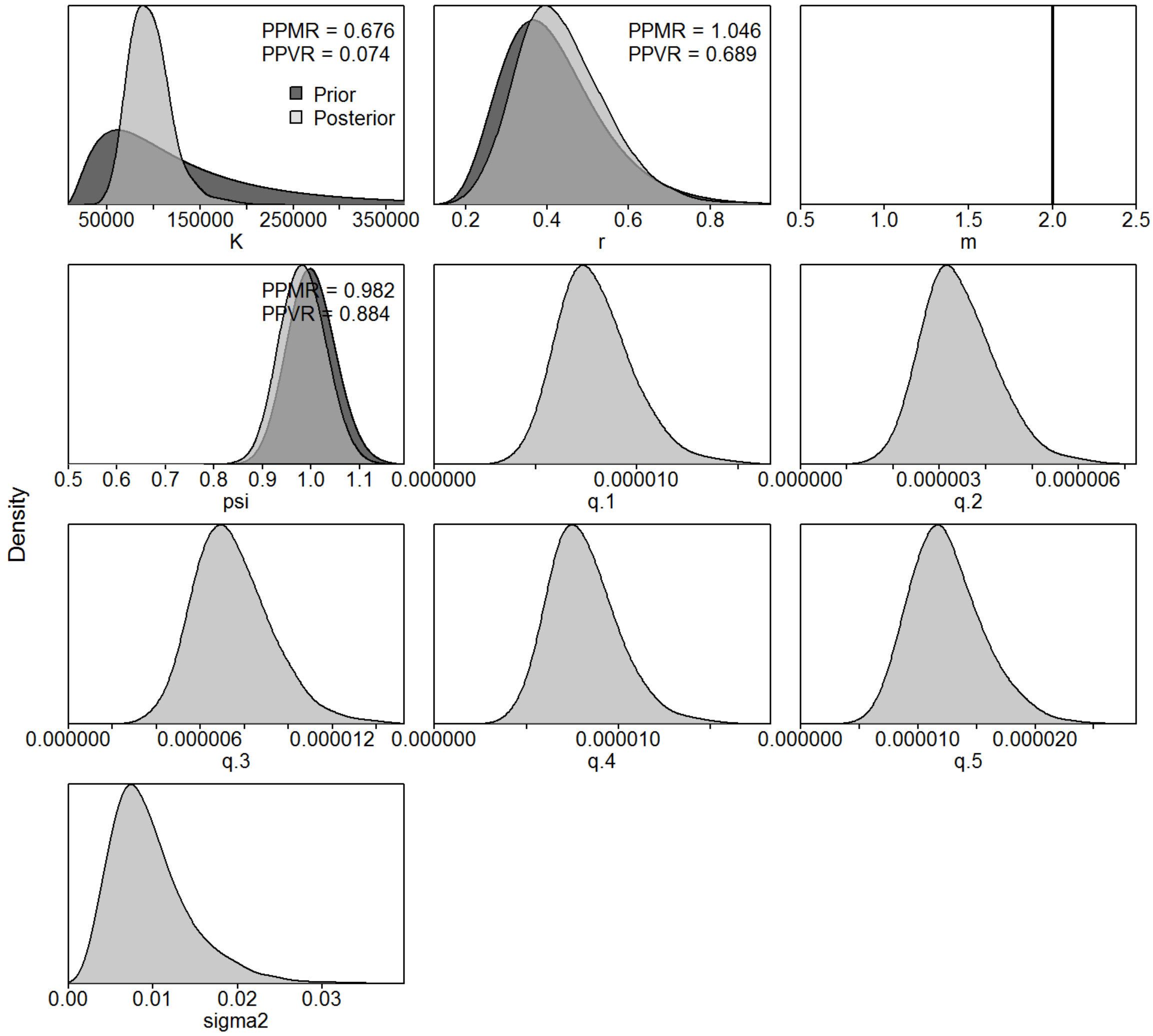

Figure 7. Prior and posterior distribution of various model and management parameters for the Bayesian state-space surplus production model *Base case* for the Indian Ocean blue marlin, where m = 2 is the shape parameter of the Schaefer production function and psi denotes the deterministic initial biomass depletion at the start of the catch time series (B/K). PPMR denotes Prior-Posterior Mean Ratio, PPVR denotes Prior Posterior Variance Ratio.

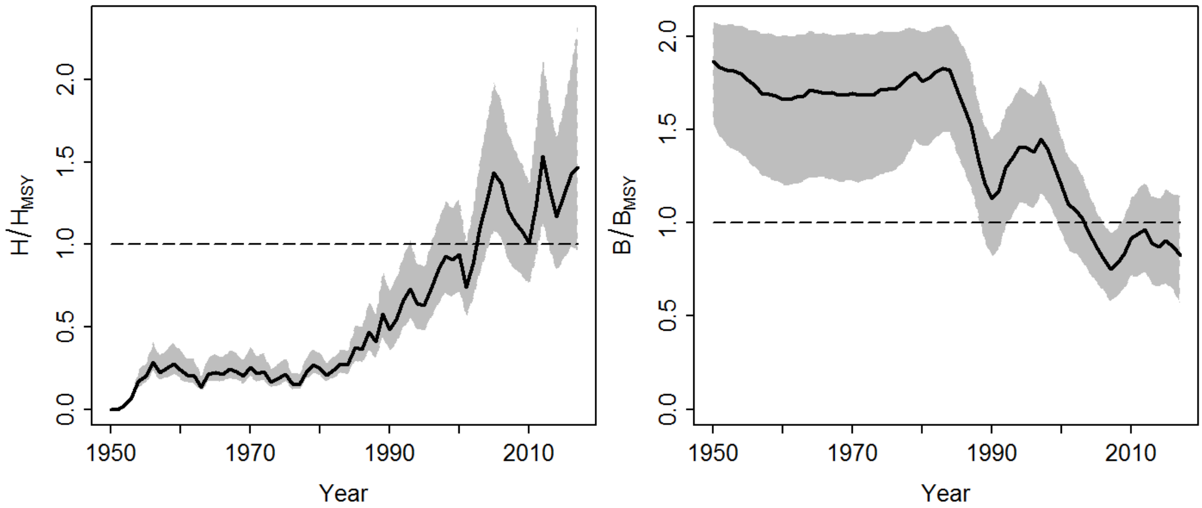

Figure 8. Predicted trajectories of F/F_{MSY} and B/B_{MSY} for the *Base case* scenario for the JABBA assessment for blue marlin in the Indian Ocean. Grey shaded areas denote 95% CIs.

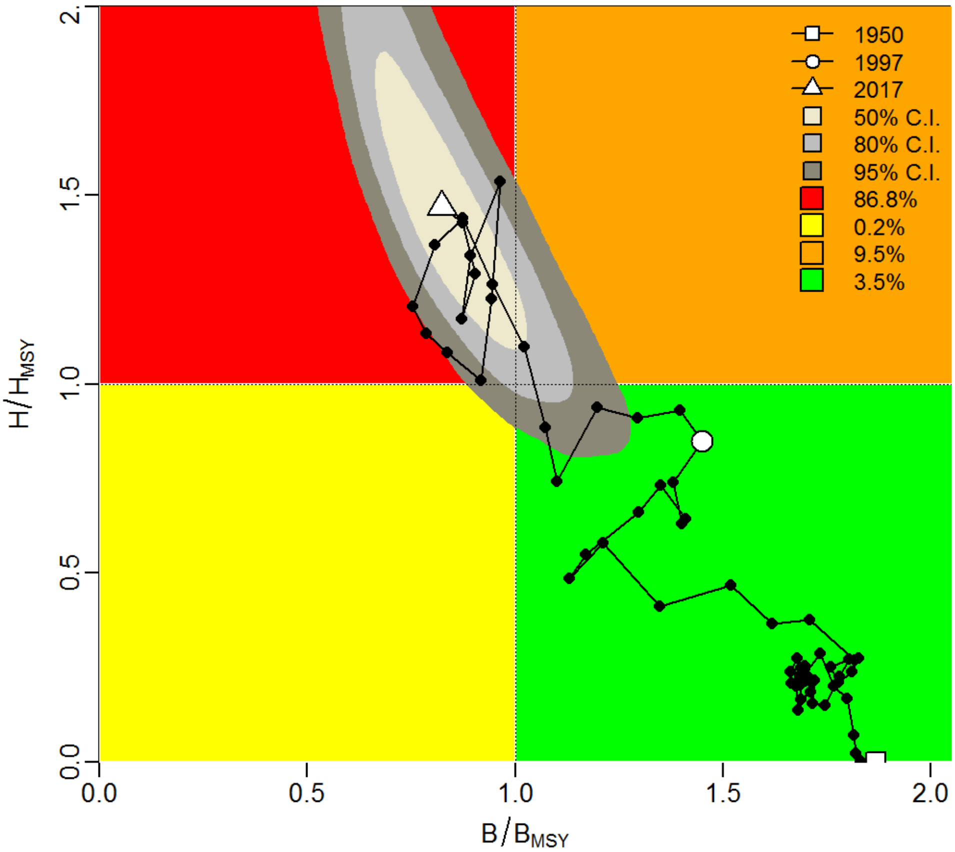

Figure 9. Kobe diagram showing the estimated trajectories (1950-2017) of B/B_{MSY} and F/F_{MSY} for the *Base case* scenario of the Bayesian state-space surplus production model for blue marlin in the Indian Ocean. The probability of terminal year points falling within each quadrant is indicated in the figure legend.

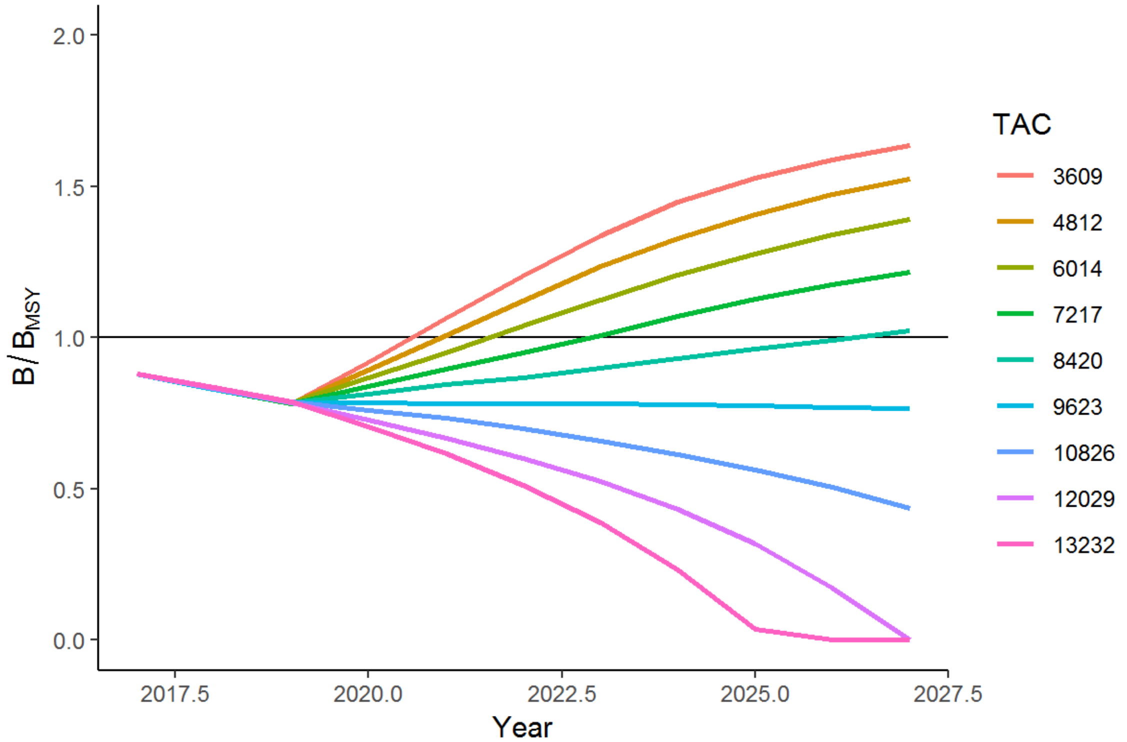

Figure 10. Projections based on the JABBA *Base case* scenario for blue marlin in the Indian Ocean for various levels of future catch. The dashed line denotes B_{MSY}.