JABBA: Just Another Bayesian Biomass Assessment for Indian Ocean swordfish

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Abstract

This working paper presents an application of the generalized Bayesian State-Space Surplus Production Model framework JABBA (Just Another Bayesian Biomass Assessment) to the 2017 IOTC assessment input data for Indian Ocean swordfish. JABBA has been previous applied and tested in assessments of South Atlantic blue shark, North Pacific blue shark, Mediterranean albacore tuna, North Atlantic shortfin mako shark, South Atlantic swordfish and Indian Ocean blue shark. Here, we focus on inbuilt JABBA features for evaluating, identifying and potentially improving poor fits that may arise from fitting of multiple standardized CPUE time series with conflicting trends to the available catch time series. For this purpose, we considered four alternative Scenarios, which increased in complexity by sequentially adding additional time series. However, taking trade-offs among goodness of the fits, precision and residual degrees of freedom as an indicator for predictive power into account, Scenario 3, fitted to standardized abundance indices from Japan, Portugal and South Africa was identified as the most plausible candidate base-case scenario.

1. Introduction

The stock assessment software 'Just Another Bayesian Biomass Assessment' JABBA was applied to explore four alternative data scenarios during the 2017 the swordfish (*Xiphias gladius*) stock assessment. JABBA is generalized Bayesian State-Space Surplus Production Model framework that has previously been applied and tested in the 2015 ICCAT South Atlantic blue shark, the 2017 Mediterranean albacore assessment, the 2017 North and South Atlantic shortfin mako shark assessments and the 2017 ICCAT South Atlantic swordfish assessment. JABBA is coded within a user-friendly R to JAGS interface to provide a means to generate reproducible stock status estimates and diagnostics. . Here, we focus on inbuilt JABBA features for evaluating, identifying and potentially improving poor fits to Indian Ocean swordfish stock assessment data that may arise from fitting of multiple standardized CPUE time series with conflicting trends to the available catch time series. To ensure reproducibility, JABBA will be distributed through the global open-source platform GitHub and will soon be accessible free at https://github.com/JABBA, pending formal publication of the full JABBA software documentation (Winker et al. in prep.).

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2. Material and Methods

2.1 Model formulation

JABBA is generalized in the sense that the production function can take on various forms, including conventional Fox and Schaefer production functions, which can be fit based on a range of alternative error assumptions. The surplus production function is formulated in the form of generalized three parameter by Pella and Tomlinson Surplus Production Model (SPM) (1969):

(1) $$SP_t = \frac{r}{m-1} B_{t-1}\left(1-\left(\frac{B_{t-1}}{K}\right)^{m-1}\right),$$

where r is the intrinsic rate of population increase at time t, K is the unfished biomass and m is a shape parameter that determines at which B/K ratio maximum surplus production is attained. If the shape parameter is m = 2, the model reduces to the Schafer form, with the surplus production (SP) attaining MSY at exactly K/2. If $0 < m < 2$, SP attains MSY at depletion levels smaller than K/2 and vice versa. The Pella-Tomlinson model reduces to a Fox model if m approaches one ($m=1$) resulting in maximum surplus production at ~ 0.37K, but there is no solution for the exact Fox SP with m = 1. The shape parameter m can be directly translated into B_{MSY}/K and thus determines the biomass depletion level where MSY is achieved, such that:

(2) $$\frac{B_{MSY}}{K} = m^{\left(-\frac{1}{m-1}\right)}.$$

It follows that B_{msy} is given by:

(3) $$B_{MSY} = Km^{\frac{-1}{m-1}},$$

and the corresponding harvest rate at MSY (H_{MSY}) is:

(4) $$F_{MSY} = \frac{r}{m-1}\left(1-\frac{1}{m}\right),$$

where the harvest rate H is defined here as the ratio of:

(5) $$F = \frac{C}{B}.$$

where C denotes the catch.

We formulated JABBA building on the Bayesian state-space estimation framework proposed by Meyer and Millar (1999). The biomass B_y in year y is expressed as proportion of K (i.e. $P_y = B_y / K$) to improve the efficiency of the estimation algorithm. The model is formulated to accommodate multiple CPUE series for fisheries f. The initial biomass in the first year of the time series was scaled by introducing model parameter to estimate the ratio of the biomass in the first year to K (Carvalho et al., 2014). The stochastic form of the process equation is given by:

$$(6) \quad P_y = \begin{cases} \varphi e^{\eta_y} & \text{for } y = 1 \\ \left(P_{y-1} + \frac{r}{(m-1)} P_{y-1}\left(1 - P_{y-1}{}^{m-1}\right) - \frac{\sum_f C_{f,y-1}}{K} \right) e^{\eta_y} & y = 2,3,\ldots,n \end{cases}$$

where η_y is the process error, with $\eta_y \sim N(0,\sigma_\eta^2)$, $C_{f,y-1}$ is the catch in year y by fishery f.

The corresponding biomass for year y is:

$$(7) \quad B_y = P_y K \,,$$

The observation equation is given by:

$$(8) \quad I_{i,y} = q_i B_y e^{\varepsilon_{y,i}} \qquad y = 1, 2,\ldots, n.$$

where, q_i is the estimable catchability coefficient associated with the abundance index i and $\varepsilon_{y,i}$ is the observation error, with $\varepsilon_{y,i} \sim N(0,\sigma^2_{\varepsilon,y,i})$,where $\sigma^2_{\varepsilon,y,i}$ is the observation variance in year y for index i.

2.2 *Prior formulations*

All priors were kept consistent across all the scenarios. A vaguely informative lognormal prior for K = 200,000 metric tons with a CV of 200%. For r, a lognormal prior (mean = log(0.42), CV = 0.4), which closely matched the priors used for the 2017 ICCAT North and South Atlantic stock assessment. The initial biomass depletion prior ($\varphi = B_{1950}/K$) was inputted in the form of a lognormal prior, assuming that the Indian Ocean stock was unexploited in 1950 with a CV = 0.25. All catchability parameters were formulated as uninformative uniform priors, while the process variance and observation variance priors were implemented by assuming the following inverse-gamma distributions:

$$(9) \quad \sigma_\eta^2 \sim \frac{1}{gamma(4,0.01)}$$

$$(11) \quad \sigma^2_{ADD,f} \sim \frac{1}{gamma(2,0.01) + 0.25^2}$$

The process variance prior corresponds to mean process error of σ_η = 0.056 (CV = 0.65). The prior for the estimable observation variance component assumes an uninformative inverse-gamma distribution with both gamma scaling parameters set to 0.001. Because most of the indices provided were considered over-precise with CV's < 0.1, a minimum observation standard error of 0.25 was added a priori to all time series (see Eq. 12). Adding a fixed observation error to the standard errors of the abundance indices may be warranted to account additional process errors associated with abundance indices, such as caused by year-to-year variation in catchability (Francis, 2011) or lack of independence in fisheries dependent data that may lead to overly precise standard errors from model-based abundance indices (Winker et al., 2013).

2.3 Scenarios

During the 2017 IOTC swordfish assessment, the evaluation of alternative scenarios specifically focused on identifying and improving poor fits to CPUE series that may arise from fitting of multiple standardized CPUE time series with conflicting trends to the available catch time series Fig. 1.

Following evaluations of initial assessment fits based on a variety of modelling frameworks, including fits from Stock Synthesis 3 (ss3) as well as deterministic (APSIC) and state-space Bayesian Surplus Production Models, the WPB considered the years 1994-1999 of the standardized CPUE series from Japan (JPN.II) and the EU-POR CPUE index for the period 2000-2015 as primary abundance indices as primary inputs for a potential base-case scenario.

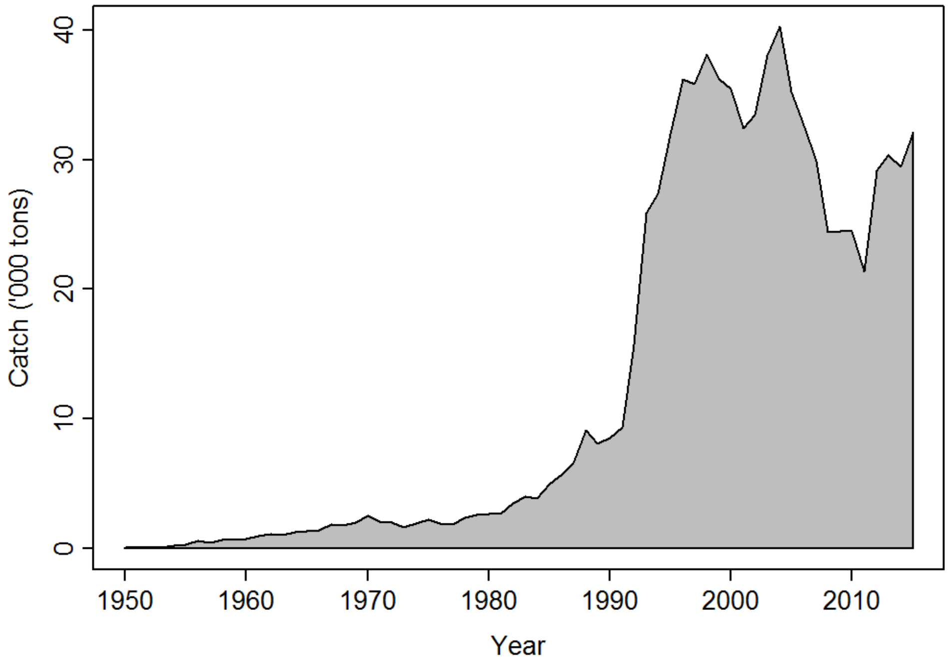

Fig.1 Total catch estimates for Indian Ocean swordfish for the period 1950-2015.

This report evaluates the effects of adding additional CPUE indices in terms of model fits, stock status and associated uncertainty. The additional CPUE indices were selected among the least likely to cause data conflicts with the two primary CPUE indices JPN.II3 and EU-POR. The additional CPUE indices identified were: (1) the extended Japanese CPUE series (1994-2015; JPN.II), (2) the South African CPUE series (2004-2015; ZAF) and (3) the second part of the Taiwanese CPUE series (1994-2015; TAI.II). According to the sequential addition of each CPUE index (Fig. 2), the following four scenarios were formulated:

Scenario 1: JPN.II3 (1994-1999) + EU-POR (2000-2015)

Scenario 2: JPN.II (1994-2015) + EU-POR (2000-2015)

Scenario 3: JPN.II (1994-2015) + EU-POR (2000-2015) + ZAF (2004-2015)

Scenario 4: JPN.II (1994-2015) + EU-POR (2000-2015) + ZAF (2004-2015) + TAI.II (1994-2015)

In addition, Scenario 4 was used as a reference case to conduct sensitivity runs by dropping one CPUE index at a time. Sensitivity was assessed with respect to the stock status estimates B/B_{MSY} and F/F_{MSY}.

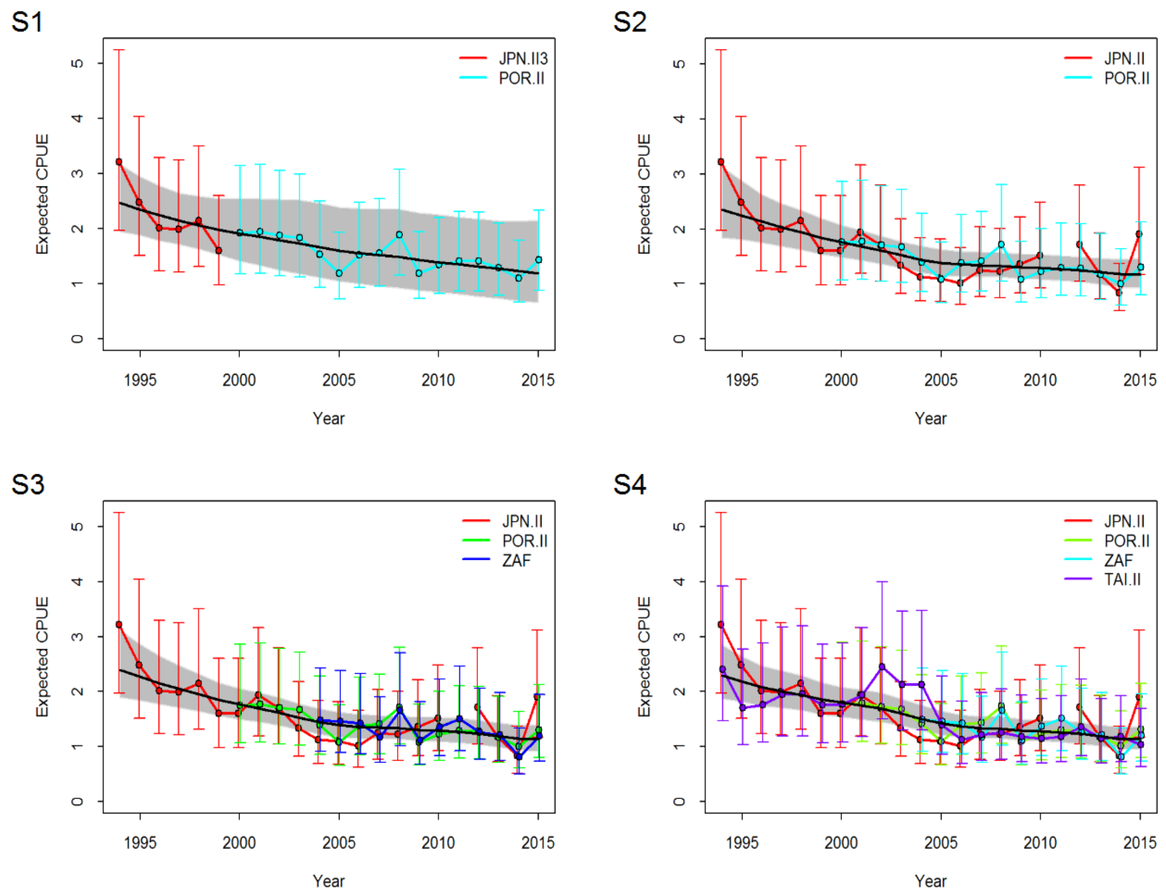

Fig. 2. Aligned CPUE indices according to Scenarios 1-4 (S1-S4) for Indian Ocean swordfish, which were produced using the state-space CPUE averaging tool implemented in JABBA. The underlying abundance trend is treated as an unobservable state variable that follows a log-linear Markovian process, so that 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.

3. Results and Discussion

3.1. Convergence

All runs but Scenario 4 showed robust convergence diagnostics. Although the Heidelberger and Welch test could not reject the hypothesis that the MCMC chains were stationary at the 95% confidence level for any of the estimable parameters for all scenarios, the swordfish Scenario 4 showed some severe distortion in the process error deviance (Fig. 1), which also resulted in implausible result outputs. Further evidence of model misspecification was that the process error estimate exceeded 0.2 (Thorson et al., 2014). By subsequently increasing the fixed variance component from 0.25^2 to 0.3^2 and thereby down-weighing the CPUE indices, it was possible to achieve a more stationary process error deviance that also resulted in interpretable assessment outputs for the swordfish Scenario 4.

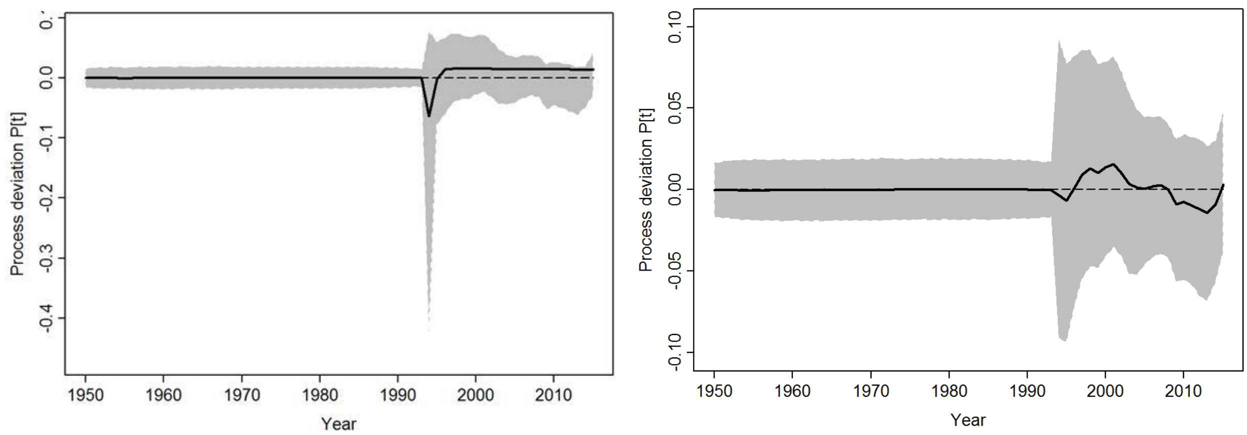

Fig. 3. Process error deviations trajectories for the swordfish Scenario 4, run with two different fixed observation variance components of 0.25^2 (left) and 0.3^2 (right)

3.2.2 Swordfish CPUE fits and sensitivity

A summary of the model fit statistics revealed that by adding the extended Japanese time series in Scenario 2 slightly increased the RSME (Table 2). Compared to Scenario 2, adding the ZAF CPUE improved the goodness of the fit again as judged by the RMSE, and also helped to substantially increase the residual degrees of freedom (Res.df).

Table 1: Summary of JABBA fit statistics for Indian Ocean swordfish. N_{obs}: Number CPUE observations, N_p: Number of model parameters, Res.df: Residual degree of freedom, Root-mean-squared-error (RSME), Deviance Information Criterion (DIC)

Statistic	Scenario 1	Scenario 2	Scenario 3	Scenario 4
N_{obs}	22	37	49	71
N_p	8	8	10	12
DF	14	29	39	59
RMSE (%)	18	18.7	18.4	18.7
DIC	-341	-336.9	-192.2	-208.4

Graphical JABBA residual diagnostics for all four scenarios are presented in Fig. 4. In particular, Scenarios 2-4 showed little evidence of a systematic residual pattern as indicated by a close to straight loess spline. By comparison, Scenario 1 indicated slight departures from zero, particular at both tails of the available CPUE time series. Scenario 2 and 3 appeared to improve the stationary stability in the residual pattern compared to Scenario 1. Including the TAI.II CPUE series slightly worsened the fit again, which points towards some arising data conflict. Comparisons of observed and predicted CPUE indices for individual time series are shown in Appendix I (Figs. A1-A4).

The sensitivity analysis based on the complete set of the four considered CPUE indices demonstrated that the stock status estimates for B/B_{MSY} and F/F_{MSY} were generally fairly insensitive to excluding any one CPUE series at the time (Fig. 5). Excluding the JPN.II index showed the only clearly discernable effect, but only for the period 2000-2010 and not for the final assessment year 2015. Excluding either JNP.II or TAI.II improved the fits, indicating again some extend data conflict between the two time series. Notably, excluding the ZAF index increased the RMSE, which can be interpreted as a stabilizing property of the ZAF CPUE (Fig. 5).

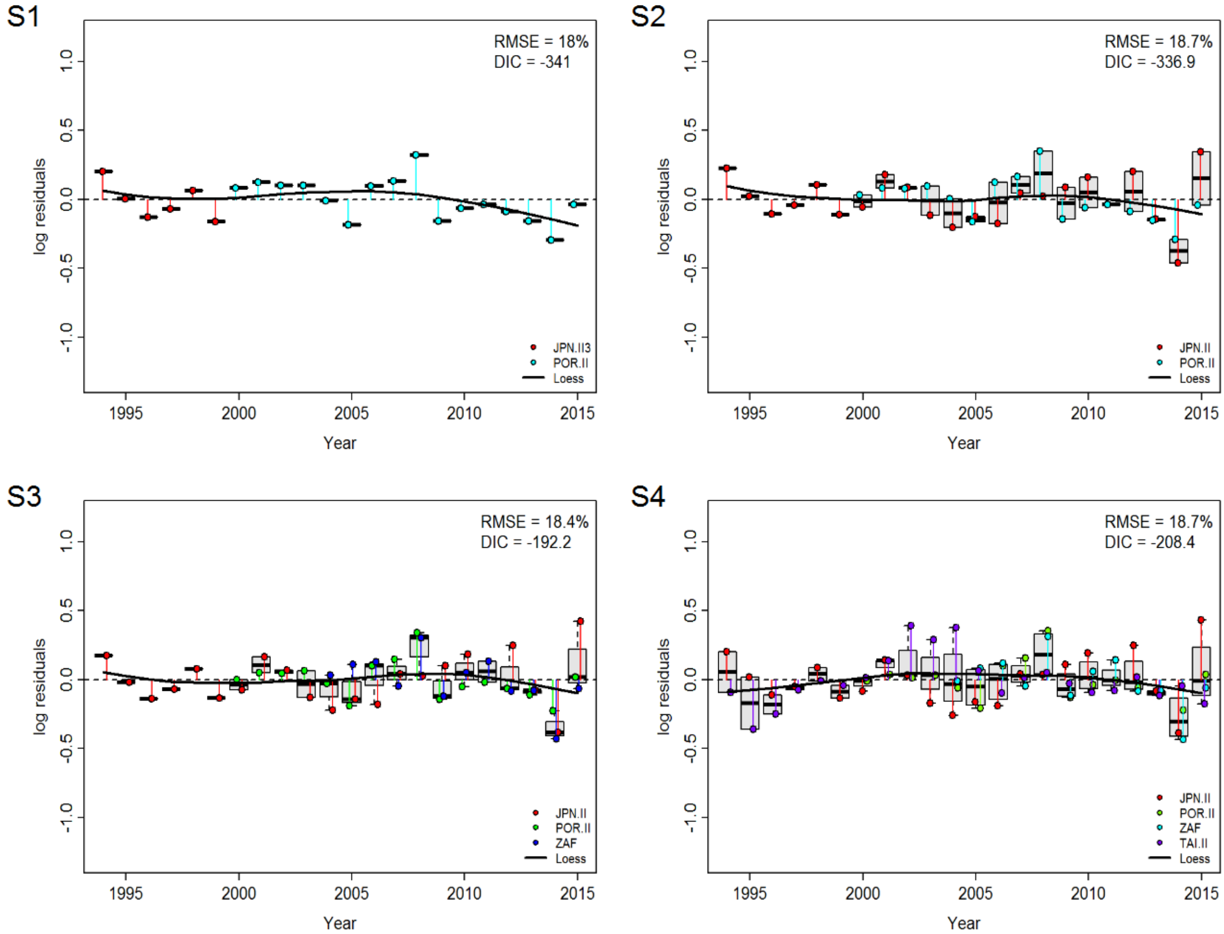

Fig. 4. JABBA Residual diagnostic plots for the for the Fox model scenarios (S1-S4) for Indian Ocean swordfish, showing the log- residuals for CPUE series, loess smothers fitted across all CPUE residuals and the width of the boxplots illustrating the relative extend of conflicts among CPUE residuals. The Residual-Mean-Error (RMSE%) is provided as good-of-the-fit metric together with the DIC.

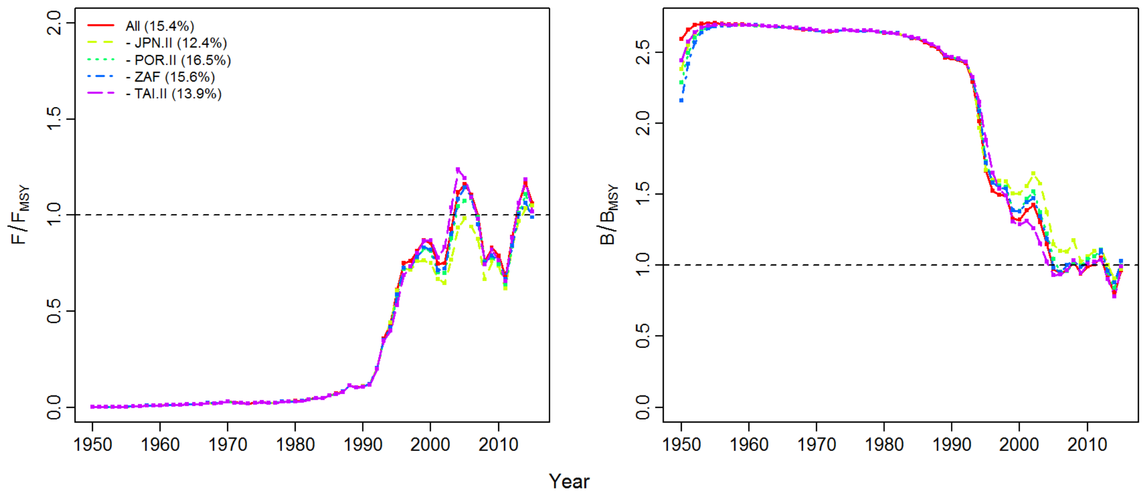

Fig. 5. Sensitivity analysis showing the effects of excluding one CPUE index at the time on the stock status estimates of F/F_{MSY} and B/B_{MSY} B_{MSY} for Indian Ocean swordfish, using Scenario 4 as a reference (All). Residual-mean-squared errors (RSME) as statistic for the goodness-of-fit are provided in brackets.

3.3.2 Reference points and stock status for swordfish

Model parameter, stock depletion (B/K) and current status estimates (B/B_{MSY} and F/F_{MSY}) for Indian Ocean swordfish are provided for the four Fox models scenarios in Table 2. For the final assessment year 2015, all runs produced results suggesting that biomass depletion and current fishing mortality were close to B_{MSY} and F_{MSY}, respectively. Scenario 3 and 4 are marginally more pessimistic, with medians current fishing mortality just a few decimal points over F_{MSY}.

All F/F_{MSY} trajectories predicted that sustainable fishing mortality had been exceeded at around 2005 and that biomass levels had approached (Scenario 1) or dropped just below B_{MSY} (Scenarios 2-4) between 2006 and 2007 (Fig. 6). The subsequent decrease in F towards 2010 appeared to have promoted a slight recovery in biomass. The shapes of F/F_{MSY} and B/B_{MSY} trajectories were similar across Scenarios 1-4.

The simultaneous development of the B/B_{MSY} and F/F_{MSY} is further illustrated in the form of Kobe phase plots for all four scenarios (Fig. 7). The probability of the stock being in the sustainable target area ranged from 35.8% (Scenario 4) to 65.3% (Scenario 2) and risk of the stock being over-fished ranged from 20.0% (Scenario 2) to 44.6% (Scenario 4). Scenario 3 and 4 produced slightly more pessimistic estimates about the stock status but no Scenario predicted more than 50% probability of an overfished state. Comparisons of the stock status posteriors highlight the increased uncertainty associated with Scenario 1, which results in an increased risk of overfishing compared to Scenario despite very similar point estimates of B/B_{MSY} and F/F_{MSY}.

Table 2. Summary of posterior estimates (medians) and 95% Bayesian Credibility Intervals (C.I.s) of parameters from the four JABBA scenario fits to Indian Ocean swordfish catch and CPUE series, assuming a Fox production function.

	Scenario 1			Scenario 2		
Estimates	Median	2.50%	97.50%	Median	2.50%	97.50%
K	264585.2	137432.1	507121.7	273653.2	181151.1	446504.7
r	0.343	0.190	1.019	0.307	0.187	0.479
ψ (*psi*)	0.875	0.598	1.084	0.89	0.581	1.051
σ	0.06	0.032	0.089	0.055	0.032	0.089
F_{MSY}	0.343	0.189	1.018	0.306	0.186	0.478
B_{MSY}	97384.1	50583.7	186652.9	100721.7	66675.1	164342.0
MSY	31476.4	25731.7	81952.1	30389.9	26246.5	41238.6
B_{1950}/K	0.875	0.598	1.082	0.89	0.581	1.05
B_{2015}/K	0.467	0.229	0.866	0.431	0.301	0.653
$B_{2015}/B_{\mathrm{MSY}}$	1.270	0.622	2.352	1.172	0.819	1.774
$F_{2015}/F_{\mathrm{MSY}}$	0.809	0.169	1.851	0.911	0.452	1.414
	Scenario 3			Scenario 4		
Estimates	Median	2.50%	97.50%	Median	2.50%	97.50%
K	272164.9	185400.1	423862.5	255764.8	169530.1	392495.7
r	0.294	0.176	0.464	0.313	0.190	0.493
ψ (*psi*)	0.825	0.54	1.038	0.855	0.617	1.047
σ	0.06	0.032	0.095	0.055	0.032	0.095
F_{MSY}	0.294	0.176	0.463	0.313	0.19	0.493
B_{MSY}	100173.9	68239.0	156008.2	94137.6	62397.8	144463.3
MSY	29282.2	25005.6	35493.1	29380.3	25436.4	34652.8
B_{1950}/K	0.825	0.54	1.037	0.856	0.617	1.046
B_{2015}/K	0.377	0.264	0.549	0.377	0.265	0.523
$B_{2015}/B_{\mathrm{MSY}}$	1.023	0.717	1.492	1.024	0.720	1.420
$F_{2015}/F_{\mathrm{MSY}}$	1.080	0.625	1.650	1.078	0.678	1.611

All four scenarios predicted that swordfish catches mostly remained under the surplus production since 2010 (Fig. 8), but for the most recent years the results suggest that the catch has already exceeded the stock's current surplus production levels. Median estimates of MSY were similar and ranged from 29282 to 31476 metric tons. However, by adding additional abundance information to Scenario 1, the uncertainty around the MSY estimates could be substantially decreased for Scenarios 2-4 (Table 4; Fig. 8).

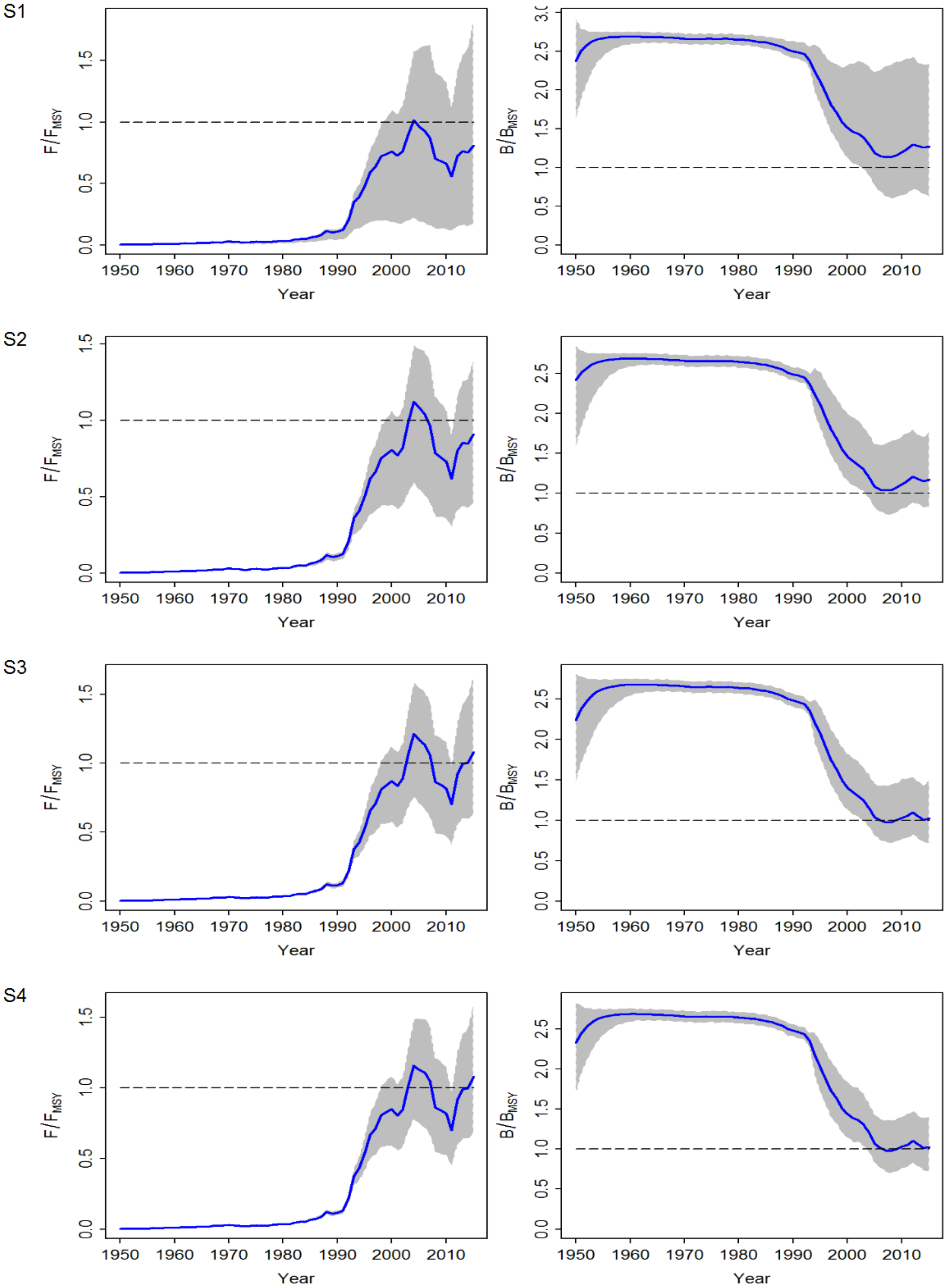

Fig. 6. Trajectories of F/F_{MSY} and B/B_{MSY} for Indian Ocean swordfish (1950-2015) for the four scenarios (S1-S4). Grey shading indicates 95% credibility intervals.

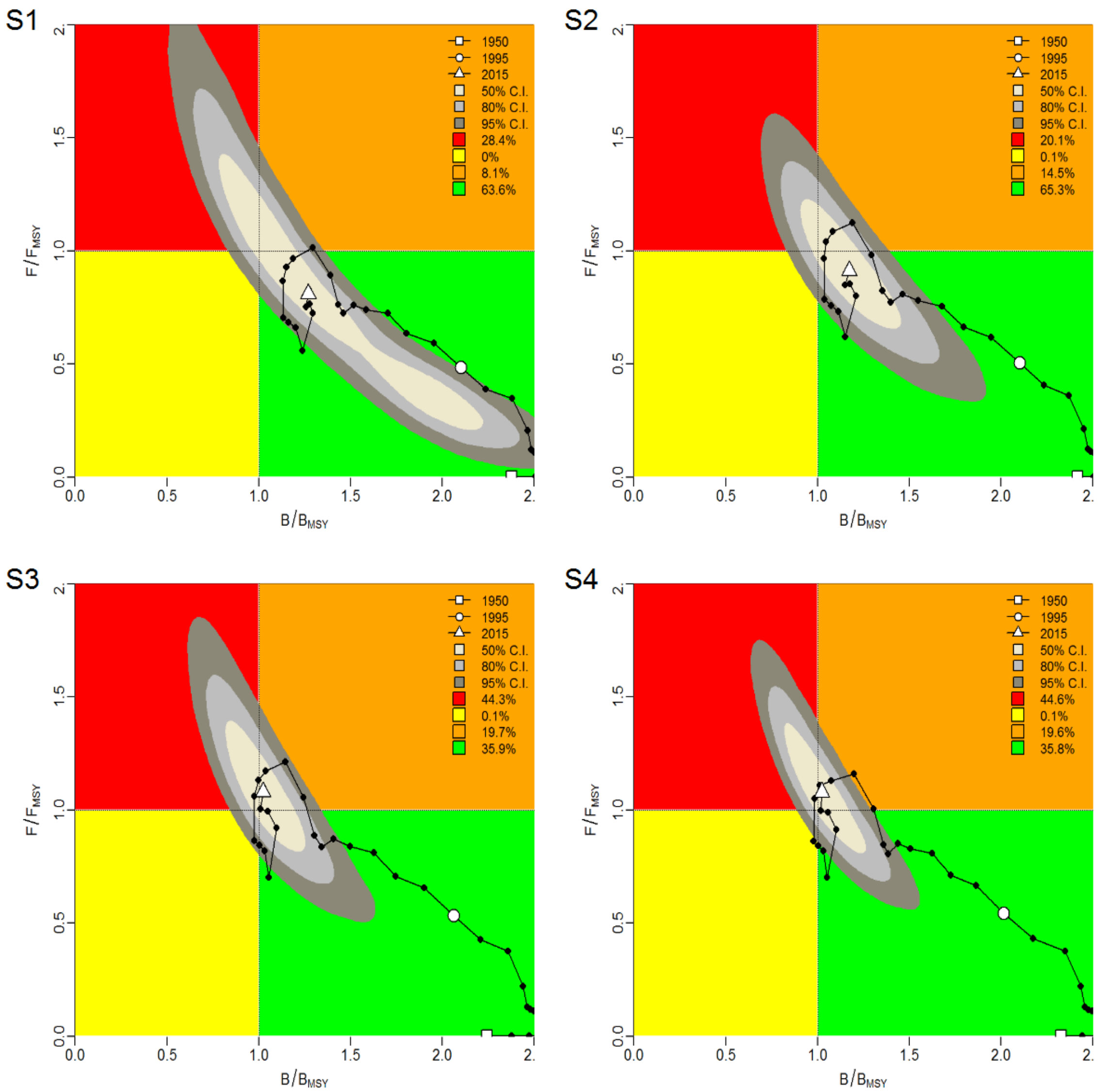

Fig. 7. Kobe plots for the for JABBA scenarios (S1-S4), showing the estimated trajectories (1950-2015) of B/B_{MSY} and F/F_{MSY} considered for the Indian Ocean swordfish stock assessment. Different grey shaded areas denote the 50%, 80% and 95% credibility interval for the final assessment years. The proportion of points falling within each quadrant is indicated in the figure legend.

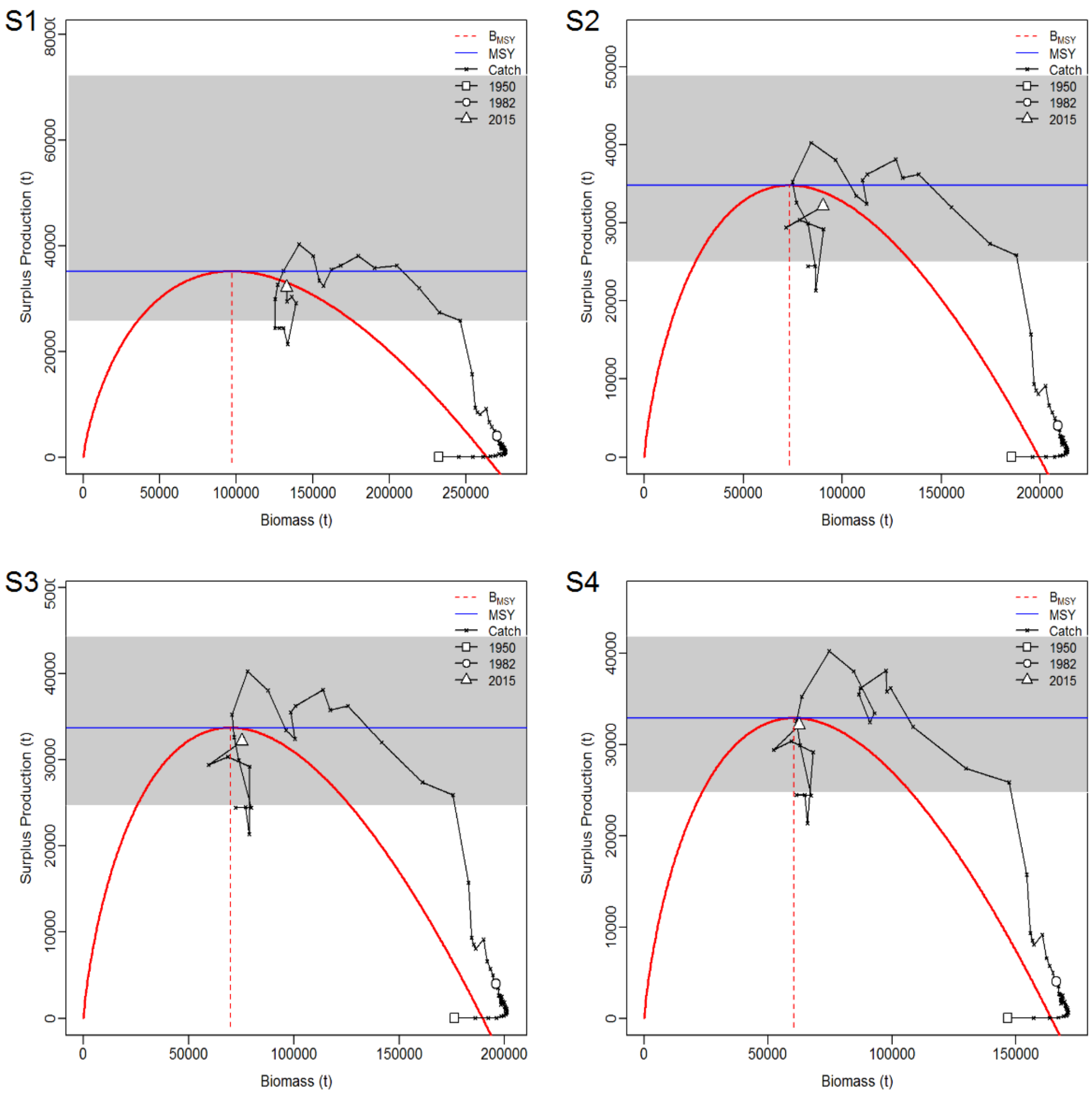

Figure 8. Showing estimated surplus production curves and catch trajectories as a function of biomass shown for Fox model scenarios 1-4 (S1-S4) over the period 1950-2015 for the Indian Ocean swordfish. The inflection point at MSY is highlighted together with the blue shaded area denoting its 95% credibility region.

Overall, the mean stock status estimates are comparable across all 4 scenarios. However, considering only the short JPN.II3 (94-99) and the EU-POR (2000-2015) CPUE series for Scenario1 resulted in very high uncertainty about the stock status. Adding alone the extended JPN.II time series (1994-2015) in Scenario 2 reduced the uncertainty about the stock status substantially, without introducing apparent data conflict. Including the ZAF CPUE in Scenario 3 generally corroborated the trends and produced satisfying fitting diagnostics. Finally, adding the recent TAI.II (1994-2015) further corroborates the stock status in general, but appears to introduce some degree of data conflict with the JPN.II data. Taking trade-offs among goodness of the fits, precision and residual degrees of freedom as an indicator for predictive power into account, Scenario 3 appears the most plausible candidate base-case scenario, closely followed by Scenario 2. According to projections based on Scenario 3 total catch levels should be kept at least below 28000 t to maintain sustainable biomass levels into the future (Fig .9). The corresponding Kobe-posterior of the 2015 final assessment year for Scenario 3 is illustrated in Fig. 10.

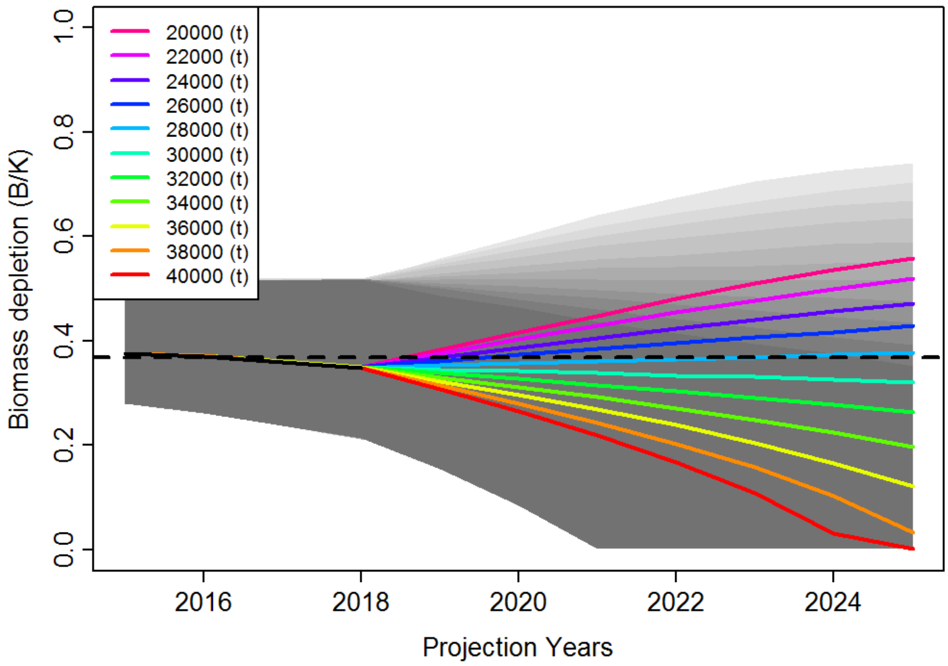

Fig. 7. Projections of biomass depletion based on the Fox model candidate base case (Scenario 3) for Indian Ocean swordfish for various levels of future catch. The dashed line denotes B_{MSY} and grey shaded areas depict the confidence regions.

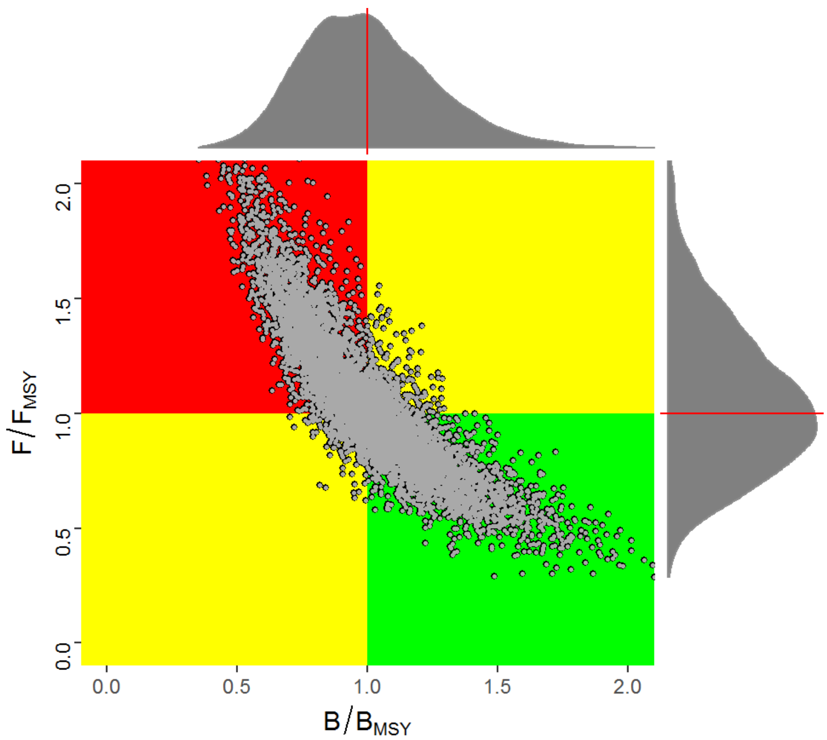

Fig. 8 Kobe phase plot for the base-case candidate Scenario 3 of the JABBA Indian Ocean swordfish assessment, showing the joint posteriors of B/B_{MSY} and F/F_{MSY} based 8000 samples of the MCMC.

4. References

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Appendix A

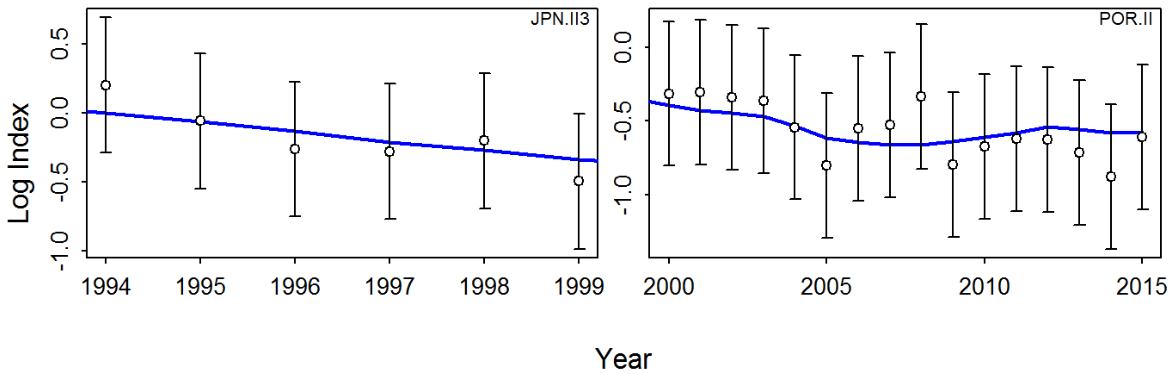

Fig. A1. Observed and predicted CPUE based on the fit for Scenario 1.

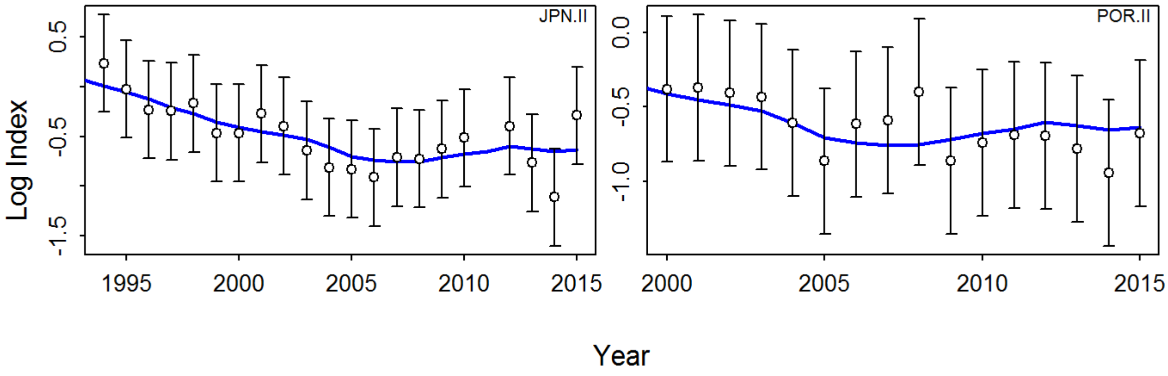

Fig. A2. Observed and predicted CPUE based on the fit for Scenario 2.

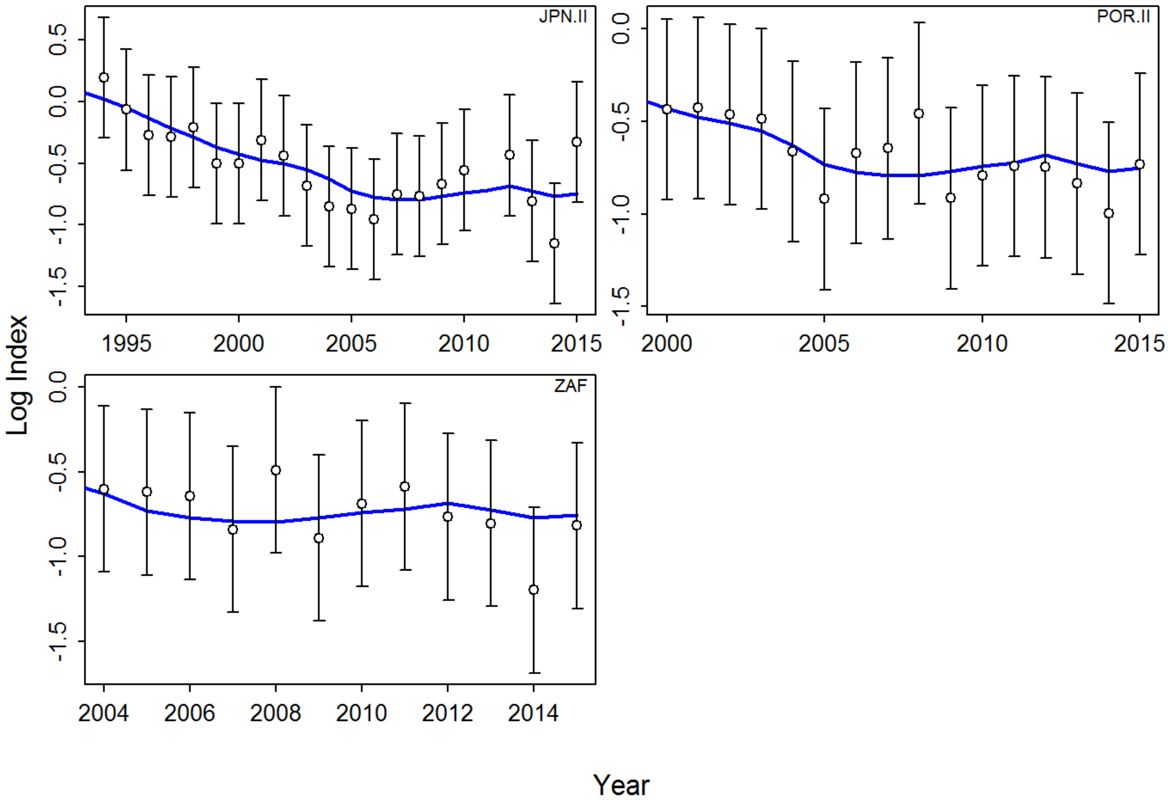

Fig. A3. Observed and predicted CPUE based on the fit for Scenario 3.

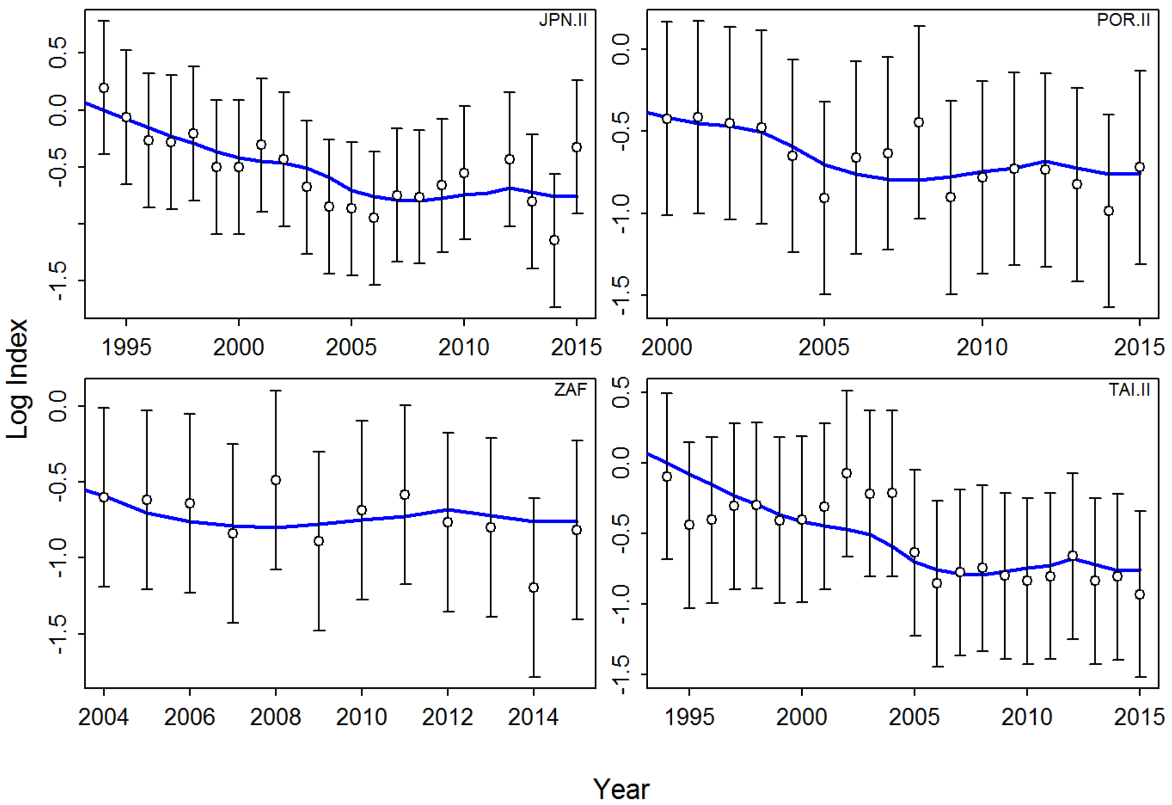

Fig. A4. Observed and predicted CPUE based on the fit for Scenario 4.