Updated stock assessment of swordfish (*Xiphias gladius*) in the Indian Ocean using the Bayesian state-space surplus production model (JABBA)

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ABSTRACT

Bayesian Surplus Production Model (JABBA) was used to conduct the stock assessment for swordfish in the Indian Ocean. This study was an updated analysis based on the Reference Model and model specifications of Parker (2020). The results indicated that the current status of swordfish in the Indian Ocean may be not overfished and not subject to overfishing, and only a negligible risk of being overfished may occur.

1. INTRODUCTION

In 2020, the stock assessment of swordfish in the Indian Ocean was conducted using Stock Synthesis (SS), A Stock-Production Model Incorporating Covariates (ASPIC) and Bayesian Surplus Production Model (JABBA) (IOTC, 2020). The results of SS were adopted for stock status advice and indicated that MSY-based reference points were not exceeded for the Indian Ocean population as a whole ($F_{2018}/F_{MSY} < 1$; $SB_{2018}/SB_{MSY} > 1$). Most other models applied to swordfish also indicated that the stock was above a biomass level that would produce MSY. Although there are some uncertainties in the catch estimates from the Indonesian fresh tuna longline, the stock is determined to be not overfished and not subject to overfishing.

As a comparison purpose, JABBA was also used to conduct the stock assessments of swordfish in the Indian Ocean by incorporating the standardized CPUE series from various fleets. This study was an updated analysis based on the Reference Model and model specifications of Parker (2020) as well as the descriptions.

2. MATERIALS AND METHODS

2.1 Assessment model

The stock assessment analysis was conducted by fitting the catch data and standardized

CPUE series 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 2021 were provided by IOTC secretariat and the aggregated total catch of all fleets was used in the assessment (Fig. 1).

The standardized CPUE series were available from Taiwanese (TWN by 4 areas, 2005-2021; Lin, 2023), and Japanese (JPN by 4 areas, 1975-1993 and 1994-2021, Matsumoto et al., 2023), Portuguese (POR, 2000-2021; Coelho et al., 2023) and Indonesian (IND, 2006-2021, Setyadji et al., 2023) longline fleets. In this study, the CPUE data were used based on the Reference Model of Parker (2020): JP_NE (1994-2021), JP_NW (1994-2021), JPN-SE (1994-2021), JPN-SW (1994-1999) and POR (2000-2021).

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, 2020).

Based on the study of Parker (2020), Pella-Tomlinson production function was used for the assessment analysis. The initial depletion (φ= B1950/K) was set a lognormal prior with mean = 1 and CV of 10%. The unfished equilibrium biomass (K) was set an informative lognormal prior with a large CV of 100% and a central value that corresponds to eight times the maximum total catch. The intrinsic grow rate (r) was set as a lognormal prior with mean = 0.42 and CV=0.4. The shape of the production function of Pella-Tomlinson production function was fixed at B_{MSY}/K = 0.4. The process error of log(By) was estimated "freely" by the model using an uninformative inverse-gamma distribution with both scaling parameters setting at 0.001.

In this study, JABBA was first run by setting φ as a lognormal prior with mean = 1 and CV of 20%, K as an uniform prior with a range from 100,000 to 500,000 and r as an uniform prior with a range from 0.1 to 0.7. Then JABBA was run based on the model specifications and the inputs of the central values of φ, K and r were obtained from the medians of previous model run.

3. RESULTS AND DISCUSSIONS

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 with respect to K. The extensive prior/posterior overlap, as well as both PPMR and PPVR values close to 1, indicate that the posterior for initial depletion (φ) was largely informed by the prior (Figs. 2 and 3).

The model appeared to fit CPUE data well, and run tests conducted on the log-residuals indicated that the POR JP_NE indices possibly violated the hypothesis of randomly distributed residual patterns (Figs. 4 and 5). Generally, the goodness-of-fit was adequate value of root-mean-square error (RMSE = 22.8%) with inflated residual patterns but there were no notable deviations on the process error (Fig. 6).

The estimated biomass and fishing mortality were shown in Fig. 7. The trajectory of biomass showed a sharp decrease from 1990 to the mid-2000s, before stabilizing at a level above B/B_{MSY} = 1. The increase in fishing mortality from 1950 to 1990 was negligible, but fishing mortality increased rapidly thereafter to reach a peak in 2004. A decrease in F/F_{MSY} was observed from 2005 – 2011 and in recent years.

The surplus production phase and Kobe plots were shown in Fig. 8. The stock was likely being approaching to overfishing for a very brief period of 2003-2006, however catches returned to below the surplus production curve relatively quickly. Accordingly, the Kobe plot indicated that the median of F/F_{MSY} was less than 1 and the median of B/B_{MSY} was higher than 1. In addition, there is a very high probability that the current status of swordfish may be not overfished and not be overfishing. Only a negligible risk of being overfished may occur based on the confidence surfaces. The key assessment quantities obtained from the bootstrap estimations of JABBA are shown in Table 1. The results of JABBA indicate that the current status of swordfish in the Indian Ocean may be not overfished and not subject to overfishing.

Based on the hindcasting cross-validation, Results for the JP_NW index suggests 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 reality of model-based scientific advice (Fig. 9). Projections with future catch at constant levels from 40% to 160% indicated that the stock status of swordfish in the Indian Ocean may be not overfished and not subject to overfishing when fishing exploitation can be maintained at current catch level (Fig.10).

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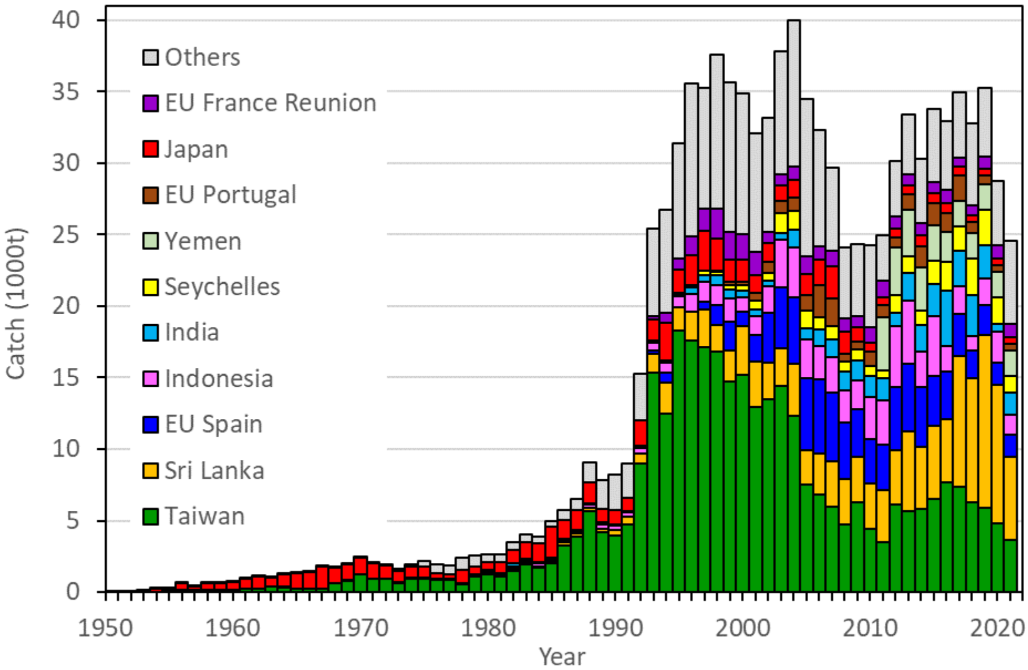

Fig. 1. Annual catches by fleets swordfish in the Indian Ocean during 1950–2021.

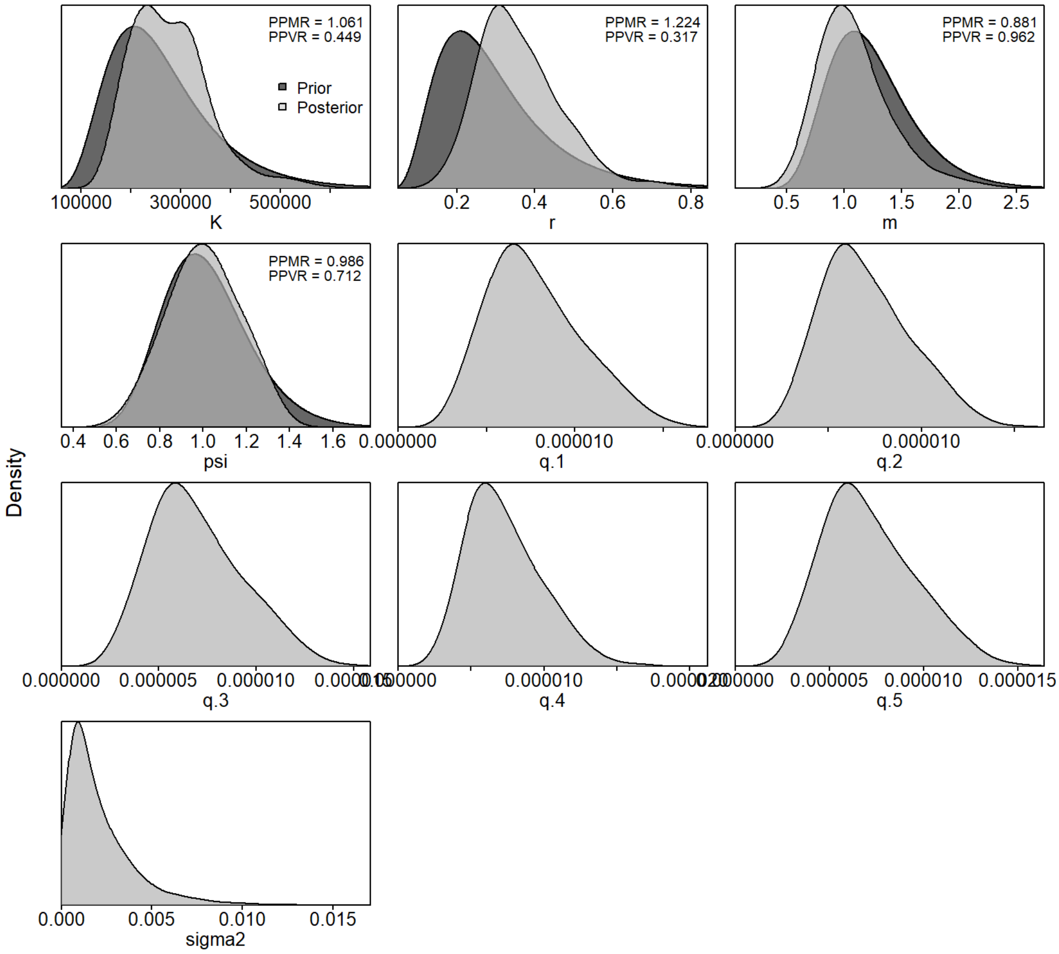

Fig. 2. Prior and posterior distributions for the first run of JABBA with uniform distributions for *r* and *K* for swordfish in the Indian Ocean. PPRM: Posterior to Prior Ratio of Means; PPRV: Posterior to Prior Ratio of Variances..

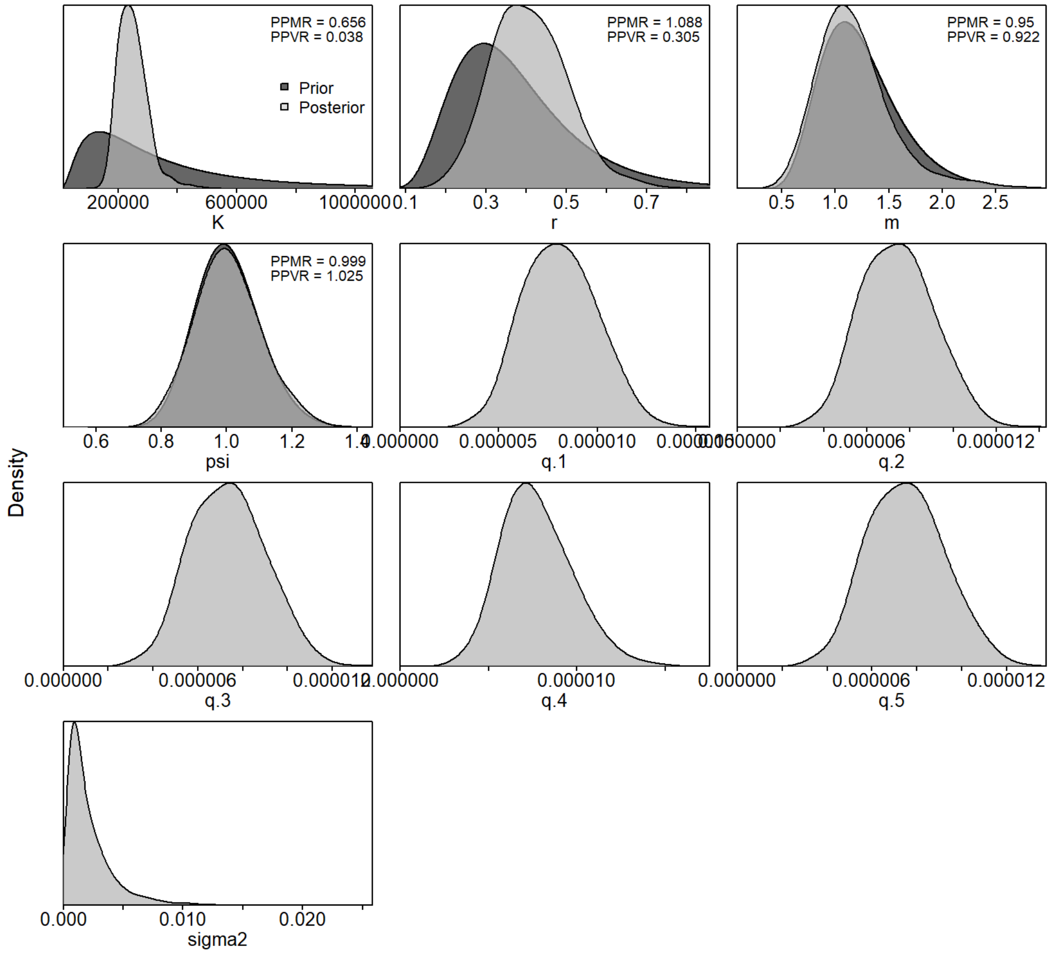

Fig. 3. Prior and posterior distributions for the final run of JABBA with lognormal distributions for *r* and *K* for swordfish in the Indian Ocean. PPRM: Posterior to Prior Ratio of Means; PPRV: Posterior to Prior Ratio of Variances..

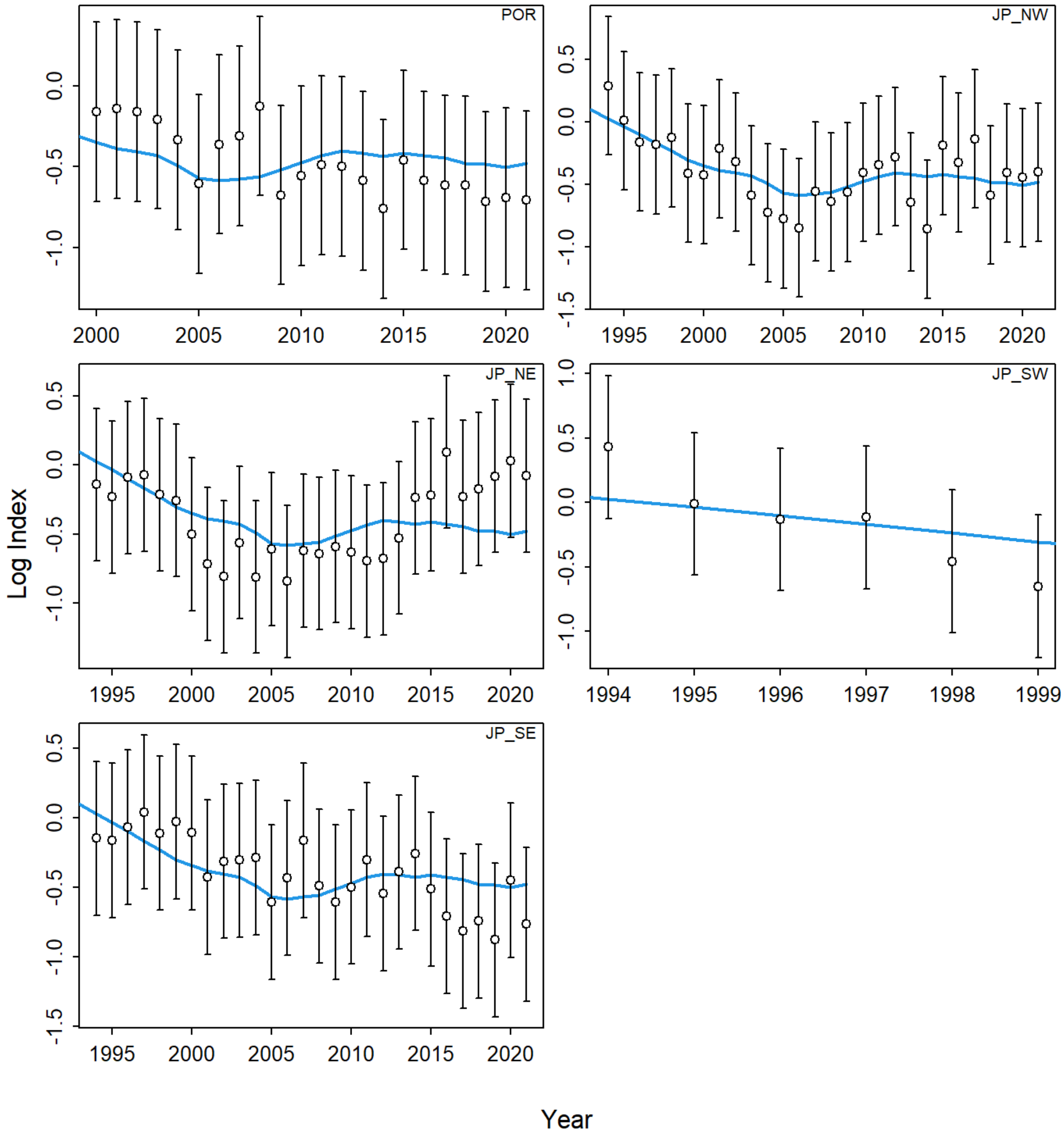

Fig. 4. Time-series of observed (circle) with 95% confidence intervals (error bars) and predicted (solid line) CPUE of JABBA for swordfish in the Indian Ocean.

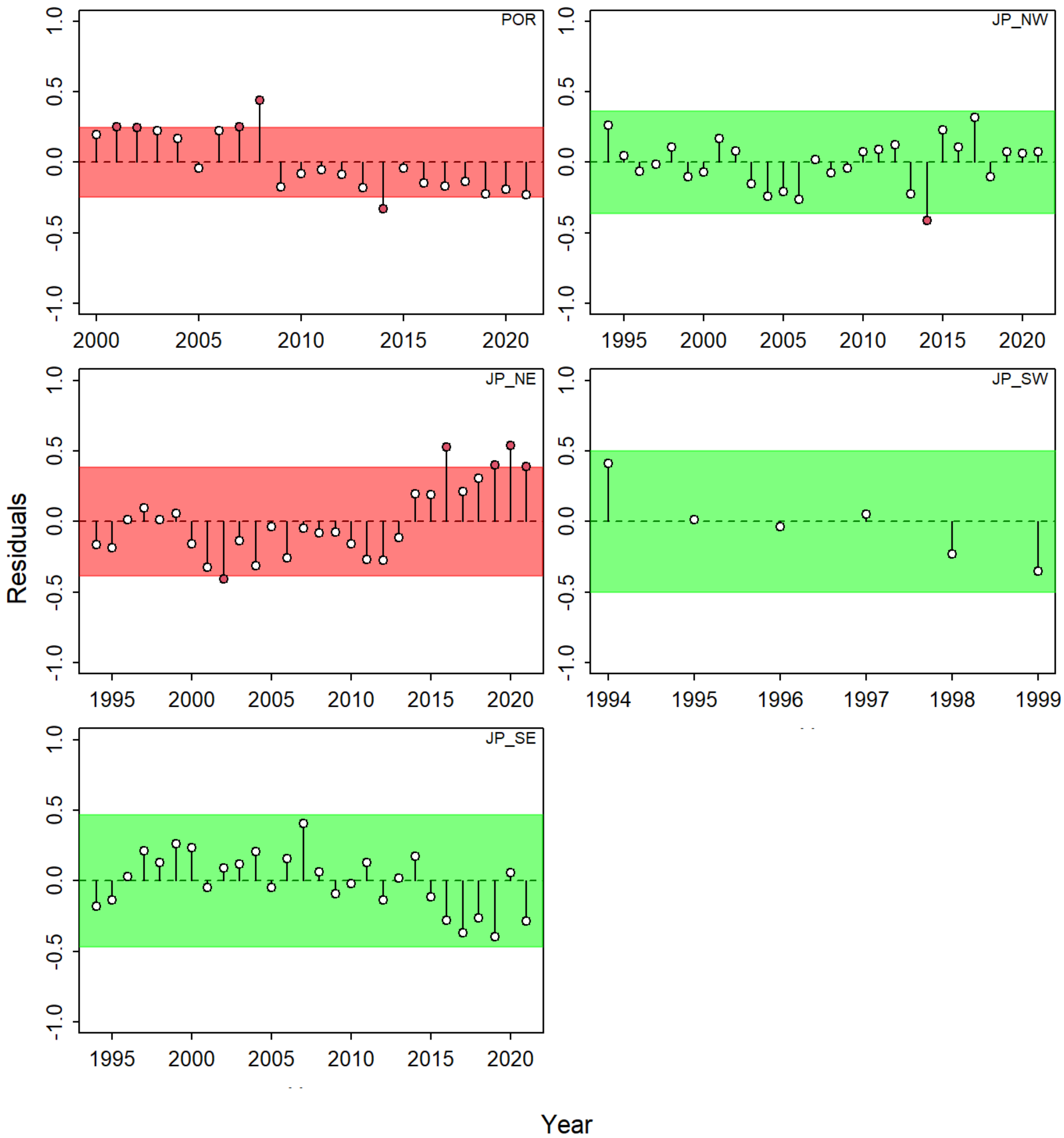

Fig. 5. Runs tests of JABBA for the randomness of the time series of CPUE residuals by fleet for swordfish in the Indian Ocean. Green panels indicate no evidence of lack of randomness of time series residuals (p>0.05) while red panels indicate the opposite. The inner shaded area shows three standard errors from the overall mean and red circles identify a specific year with residuals greater than this threshold value (3x sigma rule).

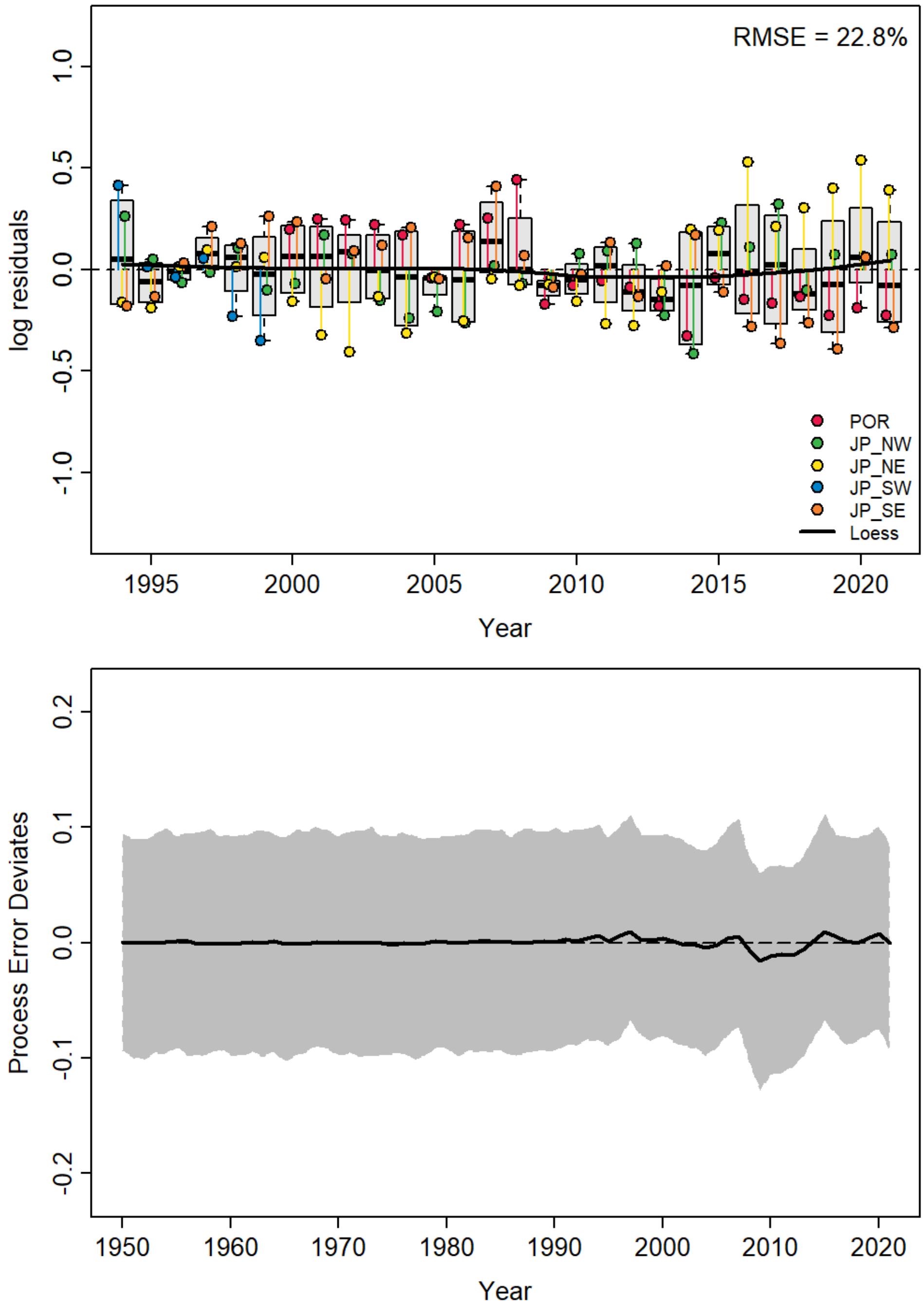

Fig. 6. Residual diagnostic plots of JABBA for CPUE indices for swordfish in the Indian Ocean. Top panel: Boxplots indicating the median and quantiles of all residuals available for any given year, and solid black lines indicate a loess smoother through all residuals. Bottom panel: Process error deviates (median: solid line) with shaded grey area indicating 95% credibility intervals.

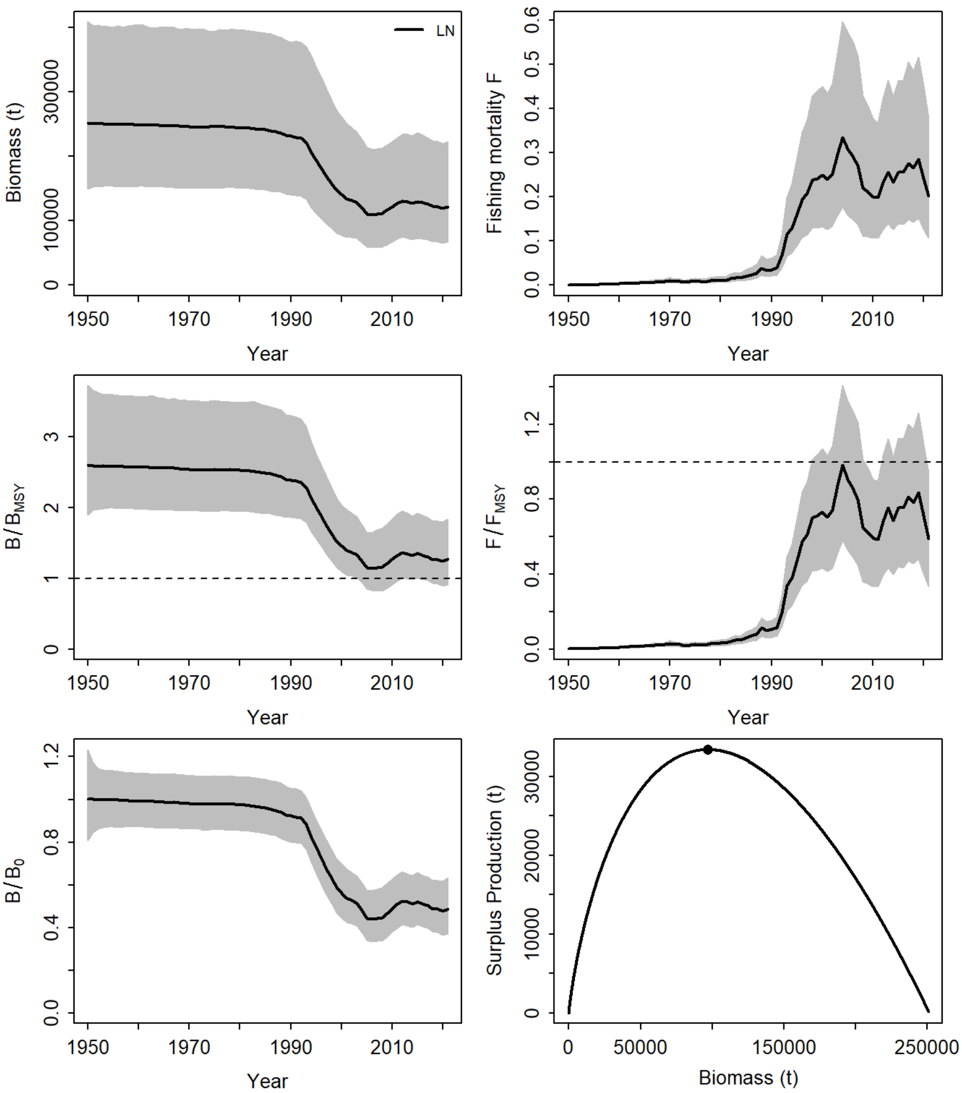

Fig. 7. The trajectories of the estimated biomass and fishing mortality with 95% confidence intervals obtained from JABBA for swordfish in the Indian Ocean.

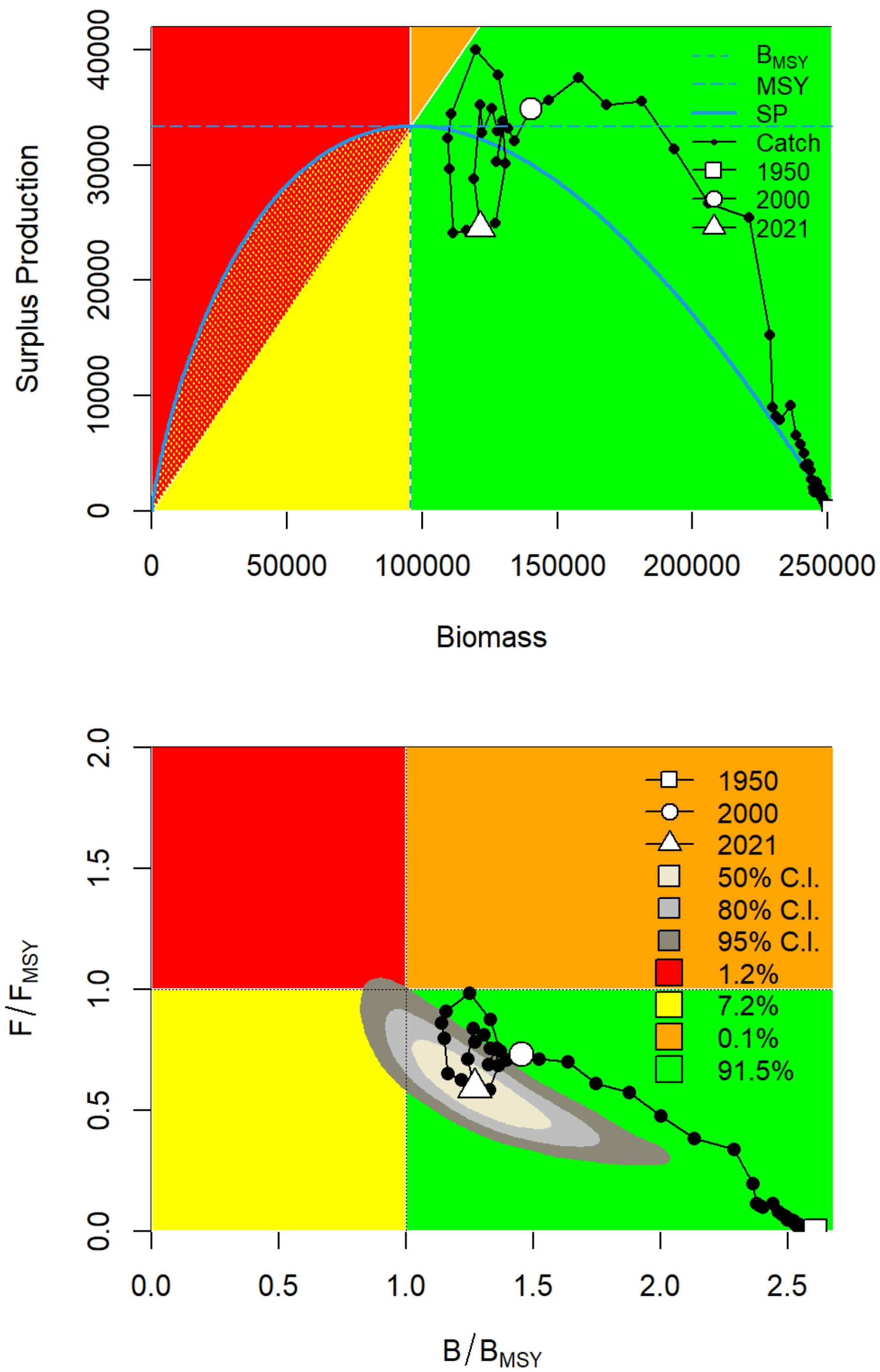

Fig. 8. Surplus production phase plot (top panel) and Kobe plot (bottom panel) with bootstrap confidence surfaces around 2021 estimates for swordfish in the Indian Ocean obtained from JABBA.

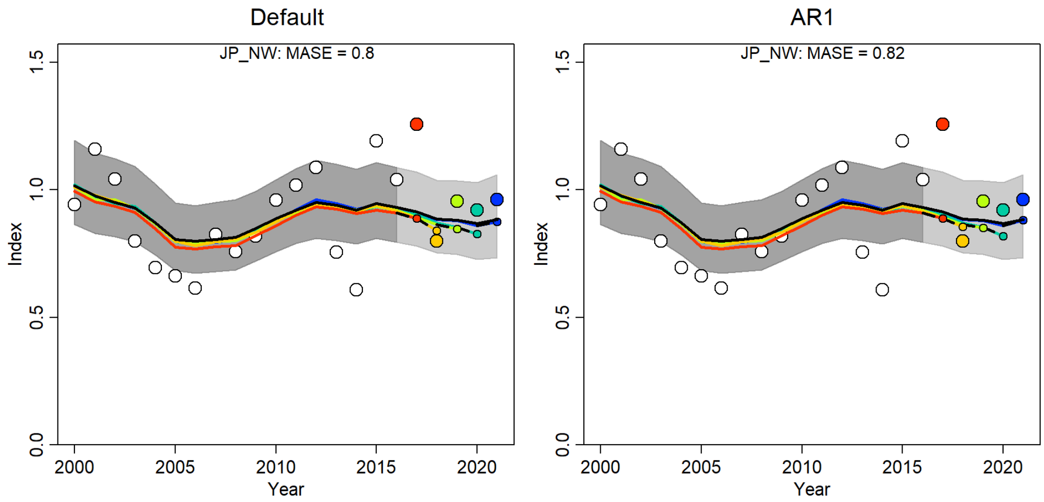

Fig. 9. Hindcasting cross-validation of JABBA (HCxval) for swordfish in the Indian Ocean swordfish, showing one-year-ahead forecasts of CPUE values (2010-2021), performed with eight hindcast model runs relative to the expected CPUE. The CPUE observations, used for cross-validation, are highlighted as 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).

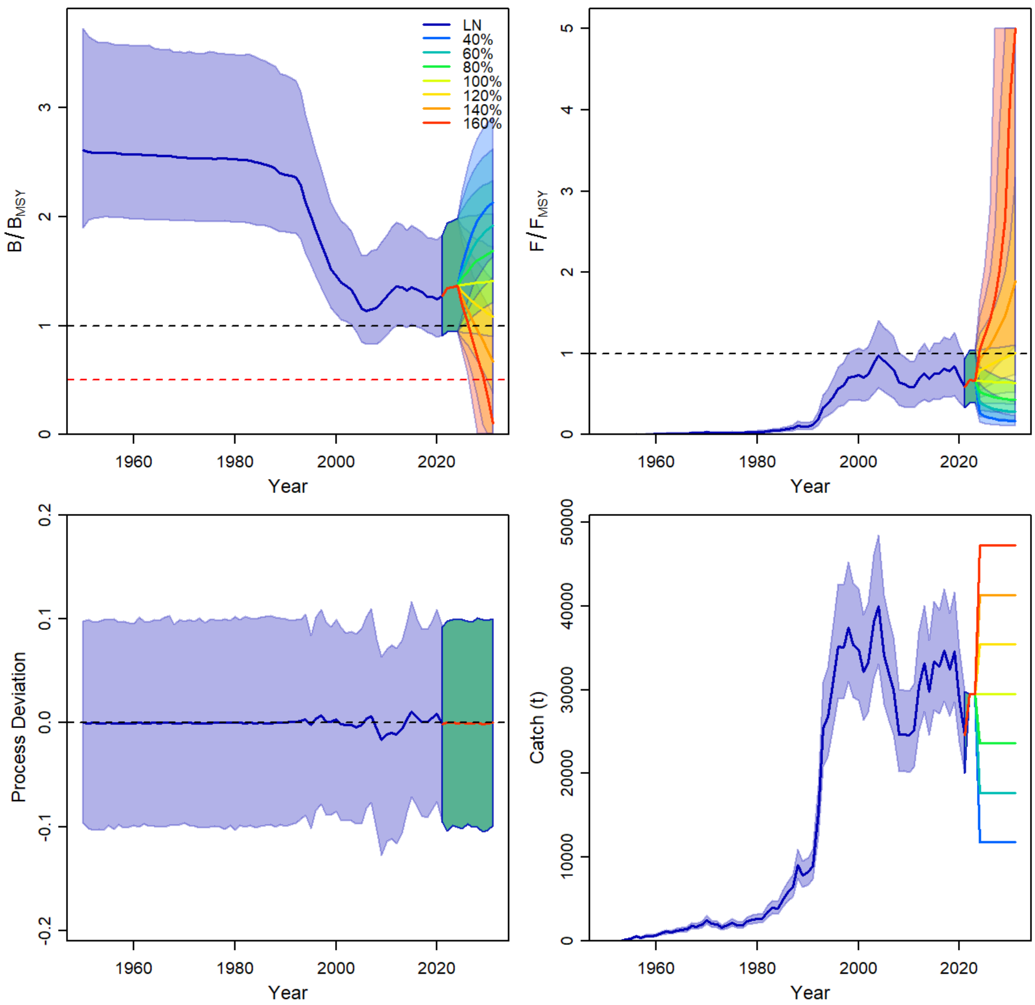

Fig. 10. Projections with 95% confidence intervals of JABBA based on the future catch set at constant levels from 40% to 160% for swordfish in the Indian Ocean.

Table 1. Stock status summary table for the swordfish assessment (JABBA). (CI = 80% confidence intervals).

Catch (1,000 t) in 2021	24.528
Average catch (1,000 t) 2017–2021	31.259
MSY (1,000 t)	32.695 (30.207, 36.643)
F_{MSY}	0.35 (0.24, 0.51)
B_0(1,000 t)	251.097 (184.38, 335.252)
B_{2021} (1,000 t)	122.284 (75.596, 194.111)
B_{MSY}	95.678 (67.482, 136.036)
B_{2021}/B_0	0.49 (0.41, 0.58)
B_{2021} / B_{MSY}	1.27 (1.01, 1.61)
F_{2021} / F_{MSY}	0.59 (0.41, 0.81)