Stock assessment of swordfish (*Xiphias gladius*) in the Indian Ocean using A Stock-Production Model Incorporating Covariates (ASPIC)

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ABSTRACT

A Stock-Production Model Incorporating Covariates (ASPIC) was used to conduct the stock assessment for swordfish in the Indian Ocean. The results indicated that the stock status became to be optimistic, and this may result from the obvious decline in catches in recent years, while the CPUE series revealed fluctuation with increasing or relatively flat trends. All scenarios of Fox models 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, ASPIC was also used to conduct the stock assessments of swordfish in the Indian Ocean by incorporating the standardized CPUE series from various fleets.

2. MATERIALS AND METHODS

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.

The stock assessment analysis was conducted by fitting the catch data and standardized CPUE series to ASPIC (version 7.05; Prager, 1994; Prager, 2016). 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). In addition, the results of preliminary runs of ASPIC indicated that the estimate of initial biomass (B1), which derived from the estimate of ratio of the initial biomass to carrying capacity (B1/K) was very unstable and sensitive to the initial values of estimated parameters. Therefore, B1/K was fixed 1 rather than estimating it in this study although this is not clear that that approach is appropriate for every stock (Punt, 1990).

This study conducted various scenarios for exploring the assessment results by fitting the model to different combinations of CPUE series. Wang et al. (2015) indicated that assuming time-blocks for both catchabilities may be appropriate to reflect the changes in fishing operations of Japanese and Taiwanese longline fleets, especially for Japanese data series. However, Japanese and Taiwanese CPUE series in the early period were considered non-informative to the abundance and thus only the late CPUE series were adopted for conducting the assessment (IOTC, 2017). Therefore, Japanese CPUE series from 1994 to 2021 and Taiwanese CPUE series from 2005 to 2021 were used in this study. Wang (2018) indicated that the pessimistic results when including the TWN indices are largely driven by the substantial decrease in CPUE in the southwest Indian Ocean. Since the CPUE fits indicate the ASPIC model is unable to describe the full extent of the observed decline in the TWN southwest index, this CPUE series were not used in this study. As the recommendation in the previous assessment models (IOTC, 2020), the CPUE series of JPN (excluded SW area) and POR were adopted for the base-case in this study. Since TWN CPUE data before 2005 have been excluded, the CPUE series of TWN in all areas as well as IND CPUE were included for exploring the influence of the inclusion of other CPUE series on the stock assessment results even though relatively higher negative correlations existed between some of CPUE series

(Table 1). In addition, JPN CPUE data in SW area from 1994 to 1999, which might represent the depletion of this stock, were also included to make consistency in the use of CPUE data with other assessment approaches used for swordfish in the Indian Ocean. The scenarios conducted in this study were listed in Table 2.

In the previous ASPIC assessment (Wang, 2020), the values of the Akaike information criterion (AIC) were used to compare the model fits obtained from Schaefer and Fox models under the same data sets, and AIC values obtained from Fox models were generally lower than those from Schaefer models. In addition, the Schaefer model has been considered an inappropriate assumption because contemporary stock assessment models, which explicitly model the individual population processes, suggest that for most teleost species maximum sustainable yield (MSY) is obtained at biomass levels substantially less than 50% under the assumption that the only density dependence is represented by Beverton–Holt recruitment (Maunder, 2003; Wang et al., 2014). Maunder (2003) also supported to discard the Schaefer model from the stock assessment due to the production function is sensitivity to biological processes and selectivity. Therefore, Fox model was only used to conduct the stock assessment of swordfish in the Indian Ocean in this study. The confidence intervals of the quantities of the model were calculated based on the bootstrap estimation with 500 iterations.

3. RESULTS AND DISCUSSIONS

Although a few of the CPUE series selected for conducting the assessment were still negatively correlated with some other CPUE series, the model can reach the normal convergence for all scenarios. The model fits of the CPUE series are shown in Fig. 2. The results indicated that the model estimated CPUE series generally fitted to trends of standardized CPUE series, except for extremely high or low values in some years. The different CPUE series were used for each scenario, and the values of root-mean-square error (RMSE) indicated that the scenarios with the Taiwanese CPUE series likely provided relatively better model performances than other scenarios (Table 2).

The estimated biomass and fishing mortality revealed obvious differences when TWN and JPN CPUE series in SW area used because they derived from different levels of estimated initial biomass (Fig. 3). The trajectories of the relative biomass and fishing mortality to the MSY level indicated that the stock status appears to be more optimistic than previous assessment, especially for JPT and JPIT case. This may result from the obvious decline in catches in recent years, while the TWN CPUE series in southern areas revealed increasing trends. In addition, relatively optimistic results were also obtained when including the TWN CPUE series in the northern areas even though TWN CPUE series in SW and/or SE areas were excluded. However, incorporating JPN CPUE data in SW area lead to relatively pessimistic stock status due to substantial decline of this CPUE series (Table 3 and Figs. 2-4).

The key quantities are shown in Table2. Prager (2017) indicated that "*Among the quantities more precisely estimated are maximum sustainable yield (MSY), optimum effort (f_{MSY}), and relative levels of stock biomass and fishing mortality rate. In contrast, absolute levels of stock biomass and related quantities, which include uncertainty in the estimate of catchability, are usually estimated much less precisely. One cannot place nearly as much credence in the absolute estimates of stock size, fishing mortality, or any quantities that depend upon them. Absolute estimates of biomass (B) and fishing mortality (F) from ASPIC are provided for the modeler's information and are not intended for use as management guidelines*". Therefore, the absolute estimates of F_{MSY} and B_{MSY} are listed here for reference only.

Kobe plot with the estimates of the relative biomass and fishing mortality in 2021 to the MSY level obtained from various scenarios is shown in Fig. 5. The point estimates obtained from all scenarios are located in the green quadrant. In addition, little difference in the estimates of relative biomass and fishing mortality resulted from the various combinations of incorporating CPUE series into the ASPIC.

Kobe plot with 50%、80% and 95% bootstrap confidence surfaces around 2021 based on the case "Base_rev" is shown in Fig. 6. 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 bootstrap confidence surfaces. The key assessment quantities obtained from the bootstrap estimations for the case "Base_rev" of ASPIC are shown in Table 4. The results of ASPIC indicate that the current status of swordfish in the Indian Ocean may be not overfished and not subject to overfishing.

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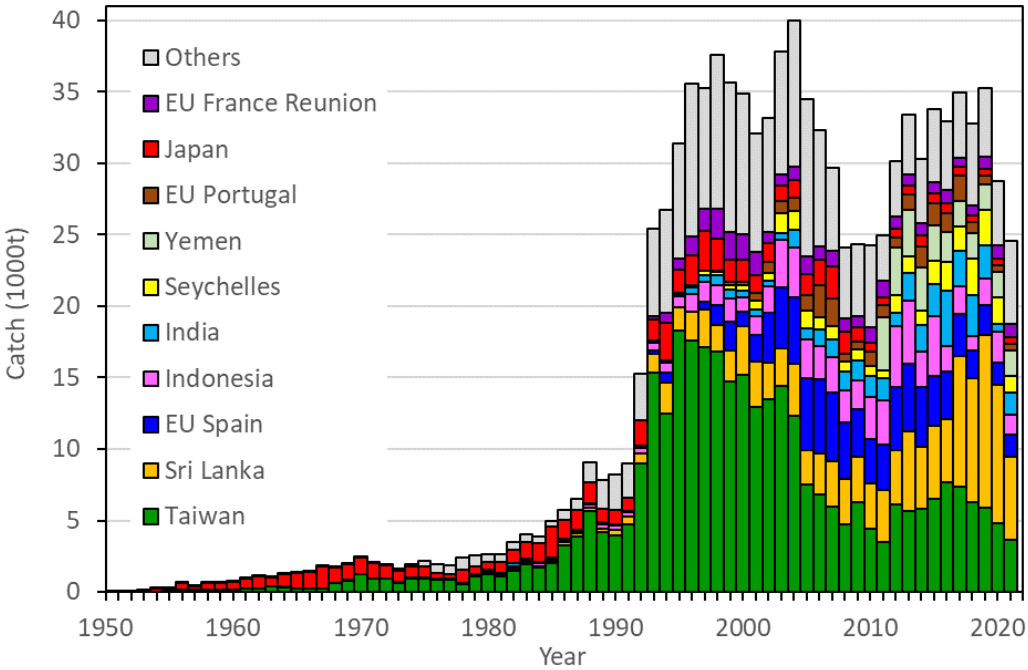


Fig. 1. Annual catches by fleets swordfish in the Indian Ocean during 1950–2021.

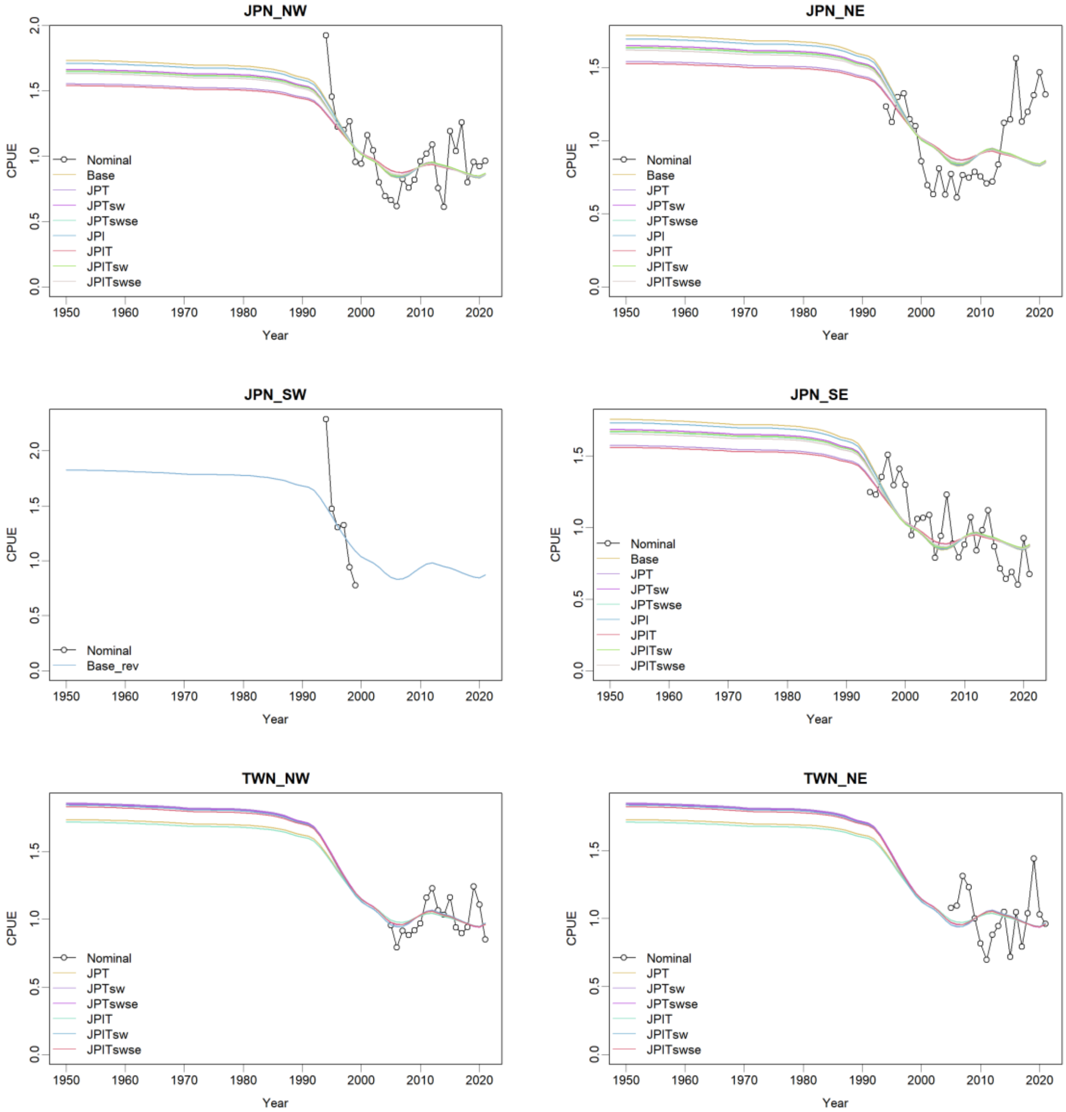
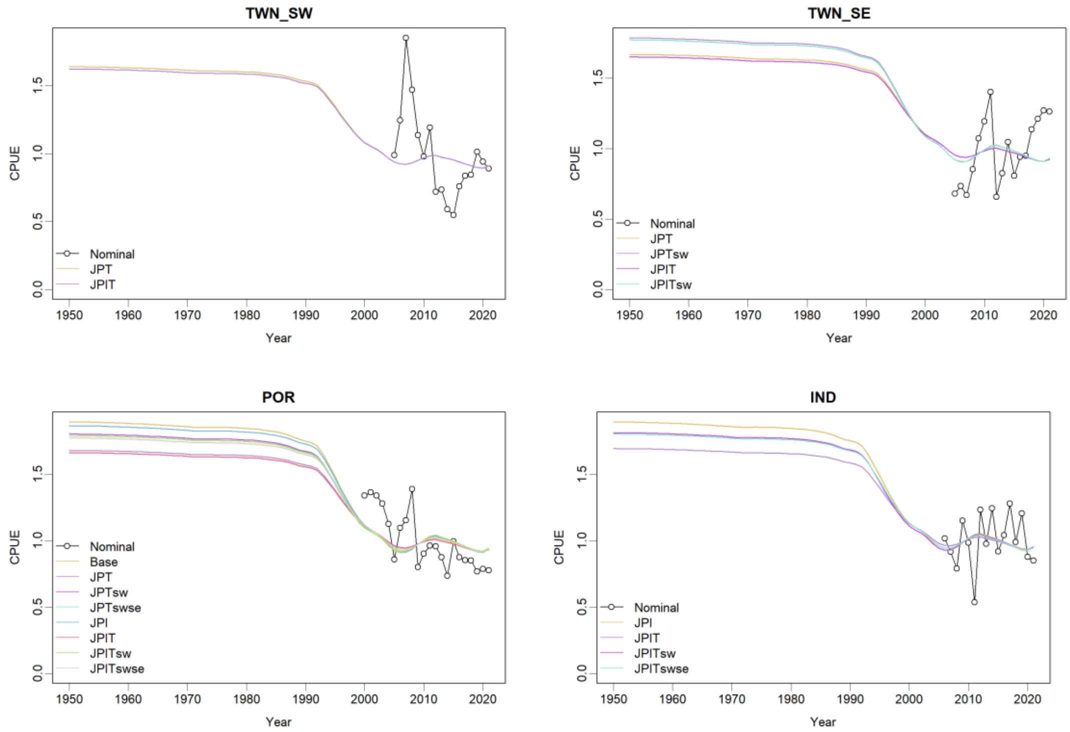


Fig. 2. Observed (standardized) and model-estimated CPUE series of swordfish in the Indian Ocean.



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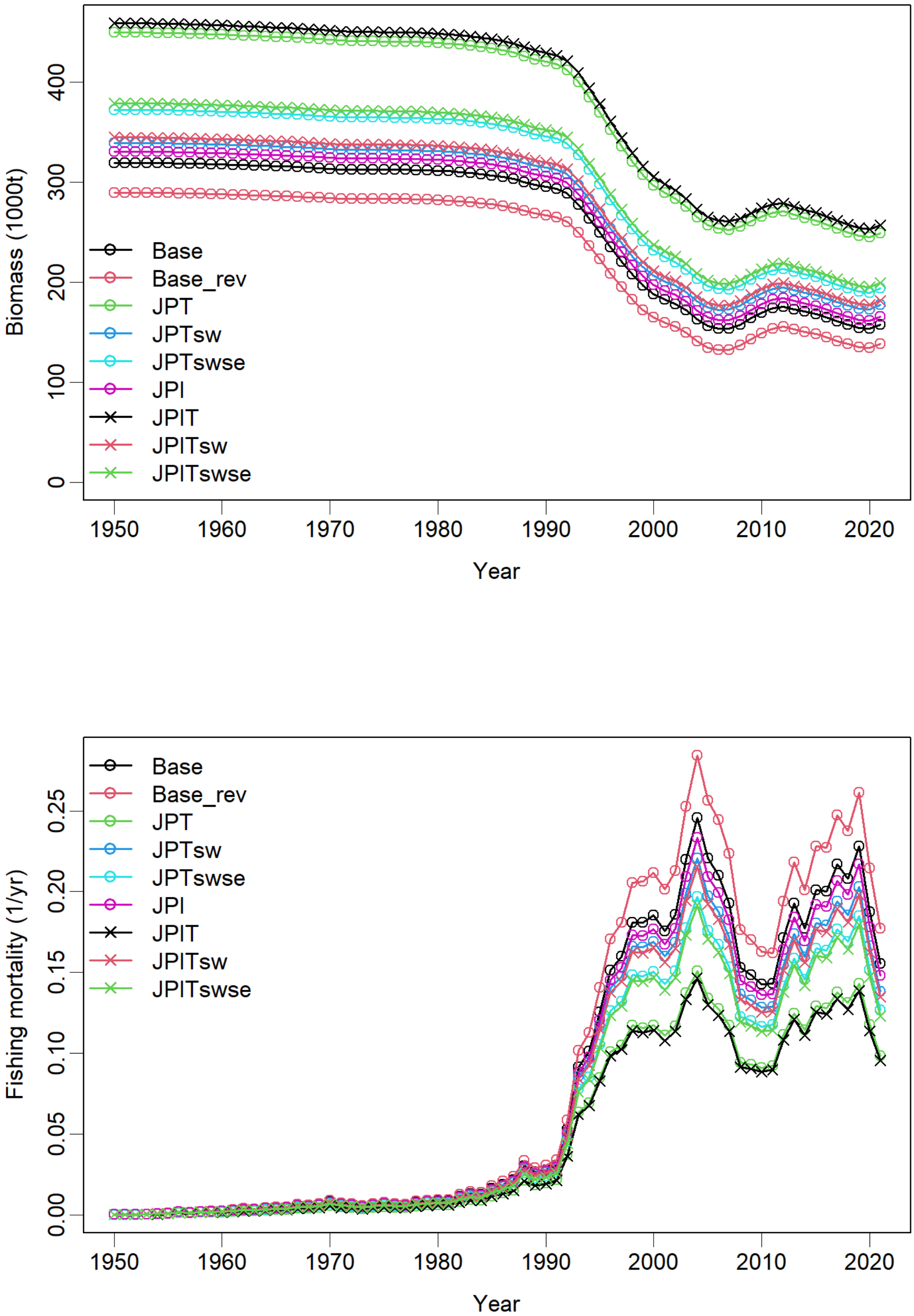

Fig. 3. The trajectories of the estimated biomass and fishing mortality for swordfish in the Indian Ocean.

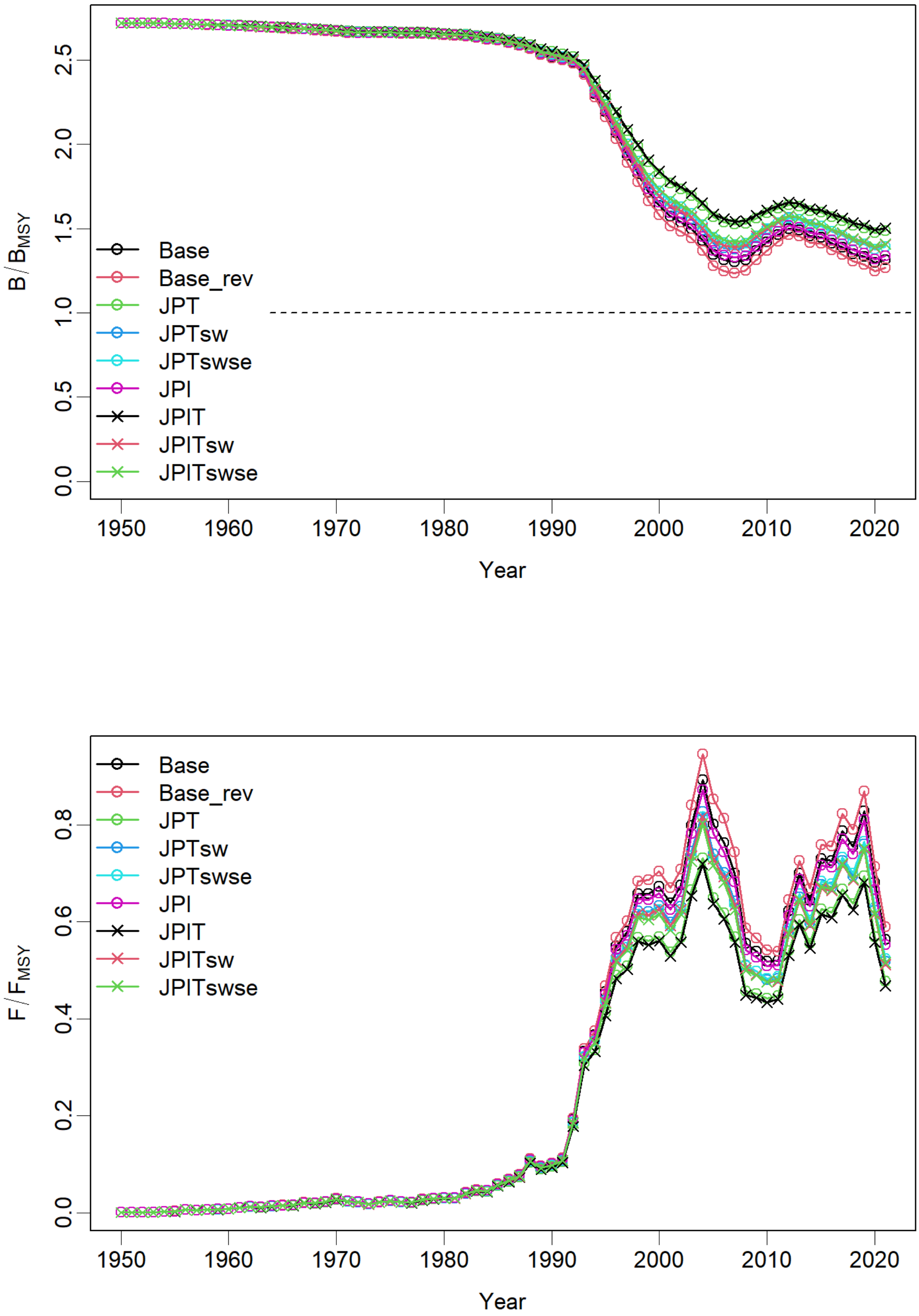

Fig. 4. The trajectories of the estimated relative biomass and fishing mortality to the MSY level for swordfish in the Indian Ocean.

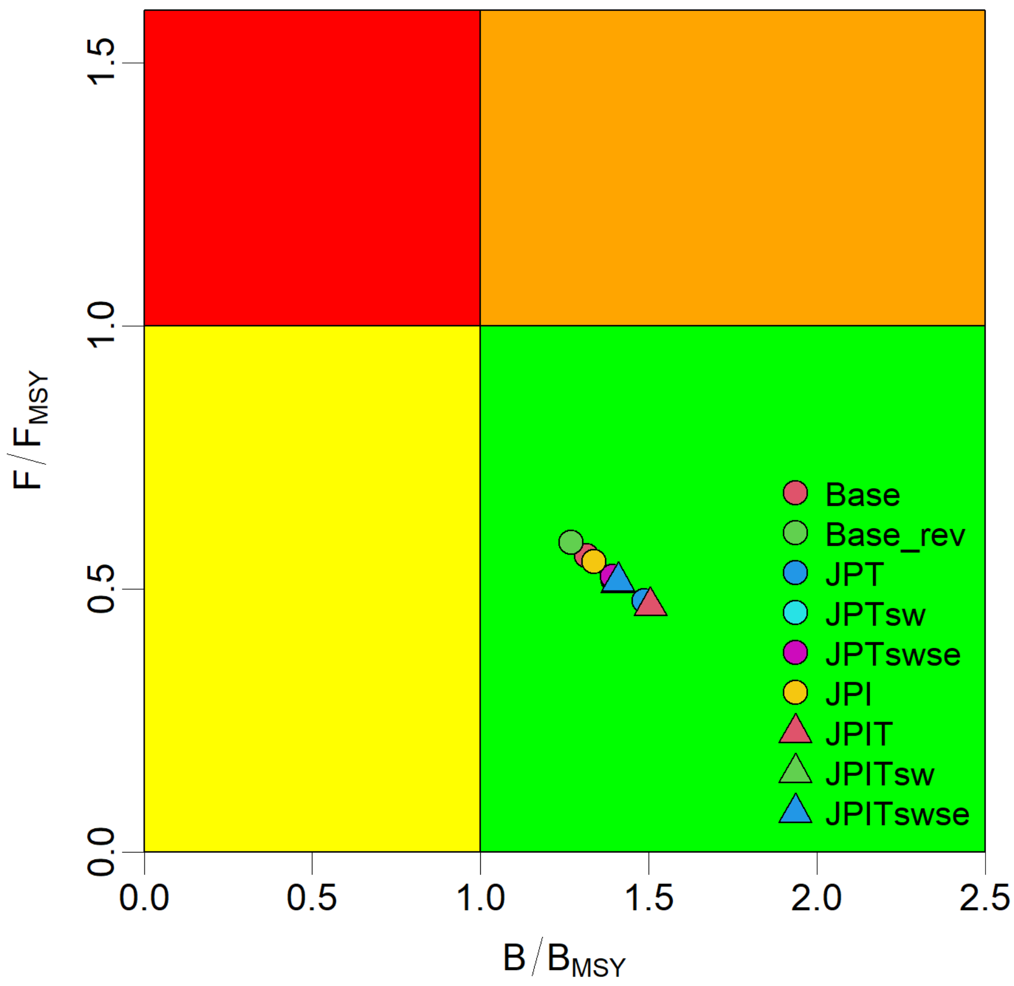

Fig. 5. Kobe plot based on the point estimates of the relative biomass and fishing mortality in 2021 for swordfish in the Indian Ocean obtained from various scenarios of ASPIC.

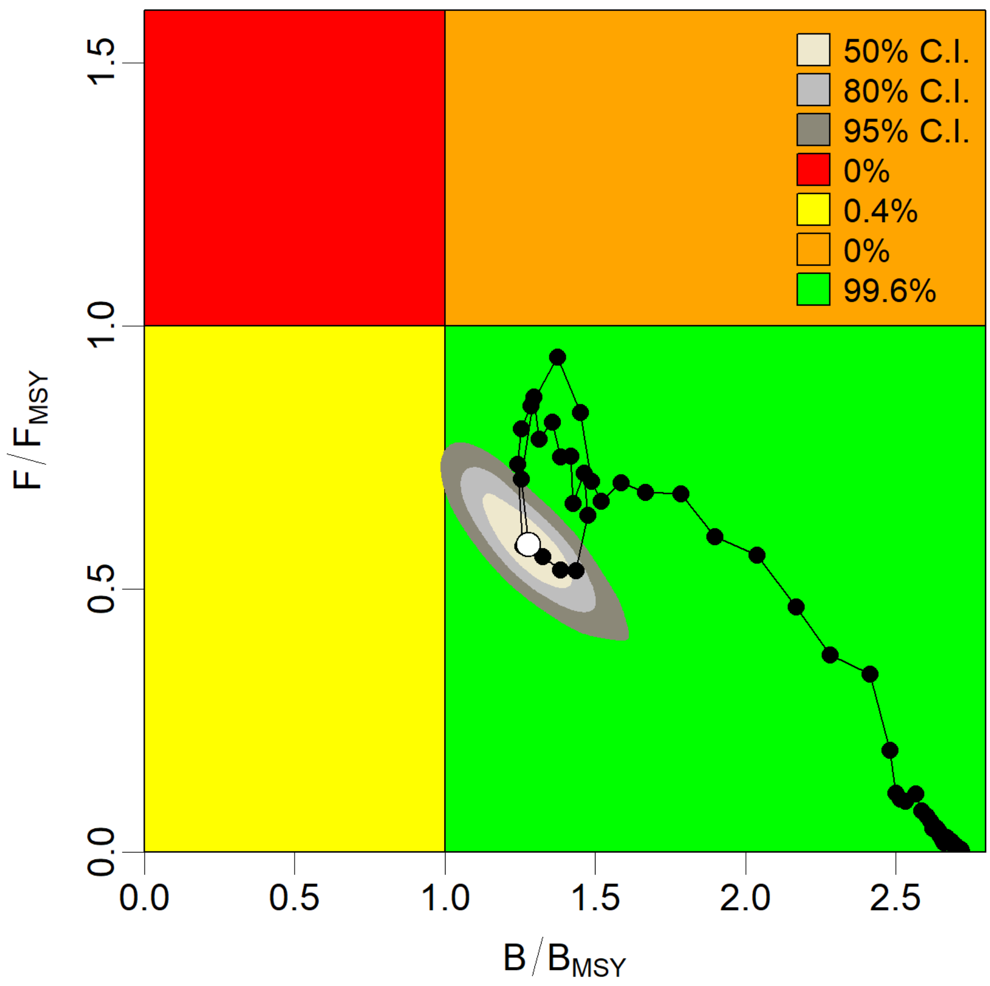

Fig. 6. Kobe plot with bootstrap confidence surfaces around 2021 estimates for swordfish in the Indian Ocean obtained from case “Base_rev” of ASPIC. The black line trace with points shows the median estimates of the trajectory.

Table 1. Pearson correlation coefficients of CPUE series between fleets.

	POR	JPN_NW	JPN_NE	JPN_SW	JPN_SE	IND	TWN_NW	TWN_NE	TWN_SW	TWN_SE
POR	1.000									
JPN_NW	0.056	1.000								
JPN_NE	-0.600	0.397	1.000							
JPN_SW		0.947	0.379	1.000						
JPN_SE	0.572	0.290	-0.020	-0.451	1.000					
IND	-0.416	0.041	0.164		-0.356	1.000				
TWN_NW	-0.266	0.376	0.141		0.046	0.043	1.000			
TWN_NE	0.180	-0.510	0.106		-0.018	0.191	-0.144	1.000		
TWN_SW	0.638	-0.303	-0.466		0.388	-0.389	-0.385	0.506	1.000	
TWN_SE	-0.483	0.185	0.417		-0.204	-0.327	0.178	-0.171	-0.132	1.000

* Values in red and in yellow background represent the higher positive and negative correlations, respectively.

Table 2. Scenarios used for the stock assessment of swordfish in the Indian Ocean.

Case	Model	CPUE series
Base	Fox	JPN (1994-2021, excluded SW), POR (2000-2021)
Base_rev	Fox	JPN (1994-1999 for SW and 1994-2021 for other areas), POR (2000-2021)
JPT	Fox	JPN (1994-2021, excluded SW), POR (2000-2021), TWN(2005-2020)
JPTsw	Fox	JPN (1994-2021, excluded SW), POR (2000-2021), TWN(2005-2021, excluded SW)
JPTswse	Fox	JPN (1994-2021, excluded SW), POR (2000-2021), TWN(2005-2021, excluded SW and SE)
JPI	Fox	JPN (1994-2021, excluded SW), POR (2000-2021), IND(2006-2021)
JPIT	Fox	JPN (1994-2021, excluded SW), POR (2000-2021), IND(2006-2021), TWN(2005-2020)
JPITsw	Fox	JPN (1994-2021, excluded SW), POR (2000-2021), IND(2006-2021), TWN(2005-2021, excluded SW)
JPITswse	Fox	JPN (1994-2021, excluded SW), POR (2000-2021), IND(2006-2021), TWN(2005-2021, excluded SW and SE)

Table 3. The estimates of key quantities for swordfish in the Indian Ocean.

Case	K	MSY	F_{MSY}	B_{MSY}	B/B_{MSY}	F/F_{SMY}	RMSE
Base	319,566	32,394	0.276	117,562	1.368	0.564	0.220
Base_rev	289,699	32,052	0.301	106,574	1.327	0.589	0.222
JPT	449,648	34,148	0.206	165,416	1.522	0.477	2.295
JPTsw	339,440	33,354	0.267	124,873	1.444	0.518	0.216
JPTswse	372,442	33,079	0.241	137,014	1.436	0.524	0.212
JPI	330,662	32,592	0.268	121,644	1.387	0.552	0.221
JPIT	459,005	34,428	0.204	168,858	1.539	0.468	2.289
JPITsw	344,919	33,495	0.264	126,889	1.455	0.512	0.217
JPITswse	379,045	33,290	0.239	139,443	1.452	0.515	0.213

Table 4. Stock status summary table for the swordfish assessment (ASPIC) obtained from the bootstrap estimations of the case “Base_rev” (CI = 80% confidence interval).

Catch (1,000 t) in 2021	24.528
Average catch (1,000 t) 2017–2021	31.259
MSY (1,000 t)	32.101 (30.875, 33.755)
F_{MSY}	0.3 (0.23, 0.39)
B_0(1,000 t)	292.077 (224.64, 386.638)
B_{2021} (1,000 t)	136.249 (96.725, 197.66)
B_{MSY}	107.449 (82.641, 142.24)
B_{2021}/B_0	0.47 (0.42, 0.52)
B_{2021} / B_{MSY}	1.34 (1.19, 1.47)
F_{2021} / F_{MSY}	0.58 (0.5, 0.68)