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 stock status became to be pessimistic because of the substantial increase in catches in recent years but the stock assessment results were obviously influenced by the adoption of CPUE series. The assessment results obtained from Schaefer models were much pessimistic than those from Fox models. Based on the comparison of AIC values obtained in this study and the comments on the Schaefer model from previous studies, this study would recommend that the assessment results obtained from Fox models would be more appropriate to be considered evaluating the stock status of swordfish in the Indian Ocean. 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.

1. INTRODUCTION

In 2017, the stock assessment of swordfish in the Indian Ocean was conducted using Stock Synthesis (SS), A Stock-Production Model Incorporating Covariates (ASPIC), Statistical catch at age (SCAA), Bayesian Surplus Production Model (IOTC, 2017). 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_{2015}/FMSY< 1; SB_{2015}/SBMSY> 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 grouped into seven fisheries from 1950 to 2018 were provided by IOTC secretariat (Table 1 and Fig. 1) and the aggregated total catch of all fleets was used in the assessment. The standardized CPUE series were available from Taiwanese (TWN by 4 areas, 1979-2019; Wang, 2020), and Japanese (JPN by 4 areas,1979-2018; Taki et al., 2020), Portuguese (POR, 2000-2018; Coelho and Rosa, 2020), Spainish (ESP, 2001-2018; Ramos-Cartelle et al., 2020), South African (ZAF, 2004-2019; Parker, 2020) and Indonesian (IDN, 2006-2019; Setyadji et al., 2020) 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 IOTC WPB, the time period of the assessment started in 1950 when the stock would have been very close to unfished biomass (IOTC, 2017). 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 (1994-current year) were adopted for conducting the assessment (IOTC, 2017). Therefore, Japanese and Taiwanese CPUE series from 1994 to 2018 were also used in this study. The CPUE series of JPN (excluded SW area) and POR were adopted for the base-case as the previous assessment of SS (IOTC, 2017), and CPUE series of ESP was also considered as an alternative index instead of POR used in base-case. Prager (2016) indicated that a fundamental assumption of ASPIC is that all indices represent the abundance of the stock and it is not recommended to use abundance indices that are uncorrelated or negatively correlated with one another unless their overlap is short. Since the CPUE series of ZAF and IDN revealed highly negative correlations with many other CPUE series (Table 2), those CPUE series were not used in this study.

Based on the preliminary runs of ASPIC, problematic estimations were found when performing the generalized production function (Pella-Tomlinson model). Thus Schaefer and Fox models were adopted to conduct the stock assessment for each scenario. The scenarios conducted in this study were listed in Table 3.

3. RESULTS AND DISCUSSIONS

Although a few of CPUE series selected for conducting the assessment were still uncorrelated or negatively correlated with some other CPUE series, the model can reach the normal convergence for all scenarios. The model fits to 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. Although different CPUE series were used for each scenario, however, the values of root-mean-square error (RMSE) indicated that the scenarios with Taiwanese CPUE series likely provided relatively worse model performances than other scenarios (Table 4).

The estimated biomass and fishing mortality revealed obvious difference since they derived from quite 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 became to be pessimistic because of substantial increase in catches in recent years (Figs. 1 and 4). The results obtained from Fox models generally provided relatively optimistic results than those from Schaefer models. Under the same assumption of production function (Schaefer or Fox), the scenarios using CPUE series without negative correlations (SJrP, STP, FJrP and STP) resulted in more pessimistic stock status than other scenarios when POR CPUE series was used and this may be because the decreasing trend in abundance was not be flatted by the series with conflict trends; while the most optimistic stock status was obtained when ESP CPUE series was used instead of POR (SJrE and FJrE) because ESP CPUE series remained stable but POR CPUE series revealed a decreasing trend in recent years. Kobe plot with the estimates of 2018 is shown in Fig. 5. The assessment results obtained from Schaefer models were much pessimistic than those from Fox models. Although the results from most of the scenarios indicated the current status of swordfish in the Indian Ocean may be not overfished and not subject to overfishing but there was a high risk of being overfishing or overfished.

The estimates of key quantities and model performance statistics are shown in Table 4. 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, estimates related to the absolute quantities shown in Fig. 2 and Table 5 were listed here for reference only.

Comparing the values of Akaike information criterion (AIC) from Schaefer and Fox models under the same data sets, AIC values obtained from Fox models were generally lower than those from Schaefer models although the differences in AIC values were indistinct between Schaefer and Fox models (Table 4). 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) and Wang et al. (2014) also supported to discard the Schaefer model from the stock assessment due to the production function is sensitivity to biological processes and selectivity. Therefore, this study would recommend that the assessment results obtained from Fox models would be more appropriate to be considered evaluating the stock status of swordfish in the Indian Ocean. Kobe plot with the results obtained from Fox models is shown in Fig. 6 and all scenarios indicated that the current status of swordfish in the Indian Ocean may be not overfished and not subject to overfishing.

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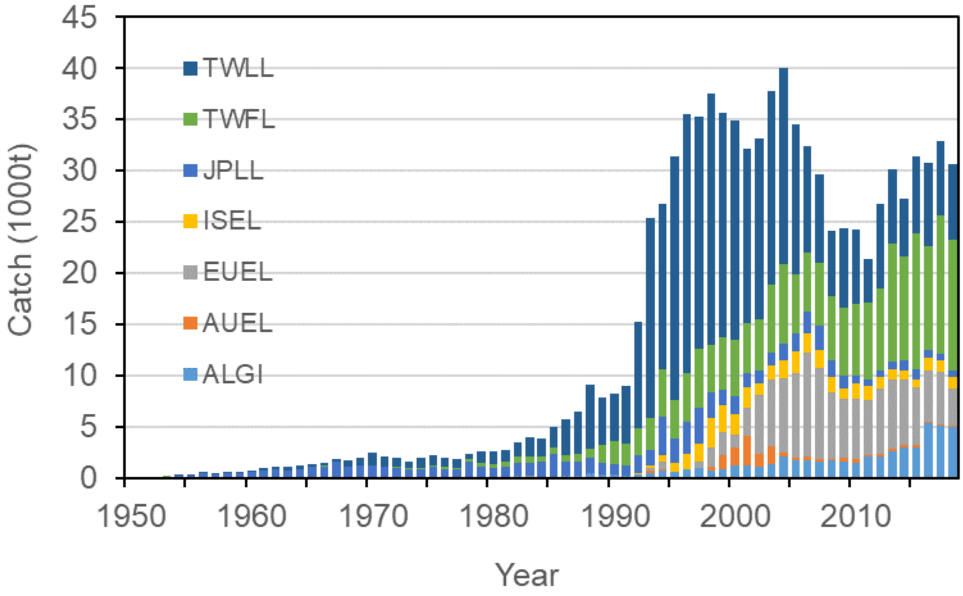

Fig. 1. Nominal catches of swordfish in the Indian Ocean from 1950 to 2015.

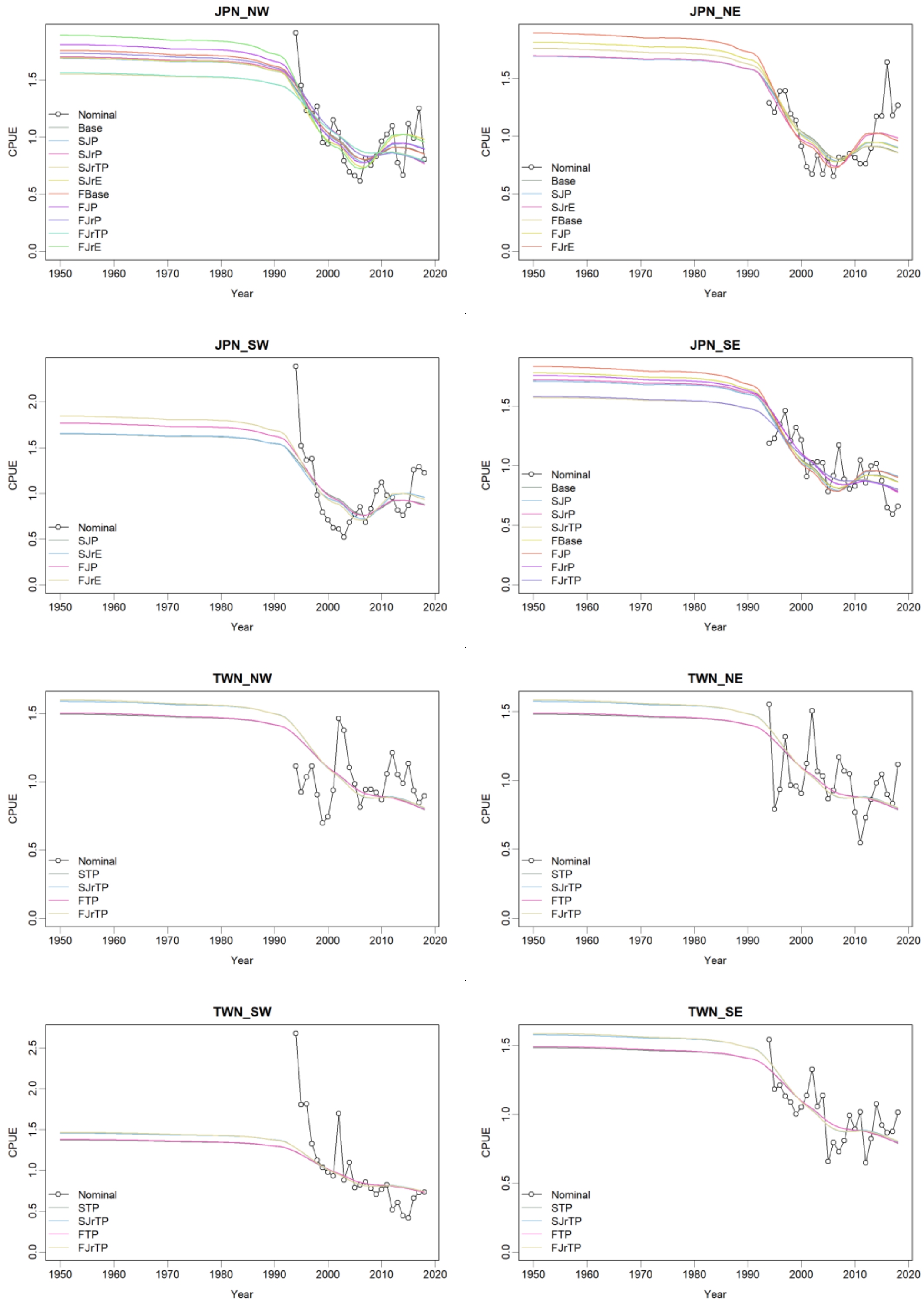

Fig. 2. Observed (standardized) and model-estimated CPUE series of swordfish in the Indian Ocean.

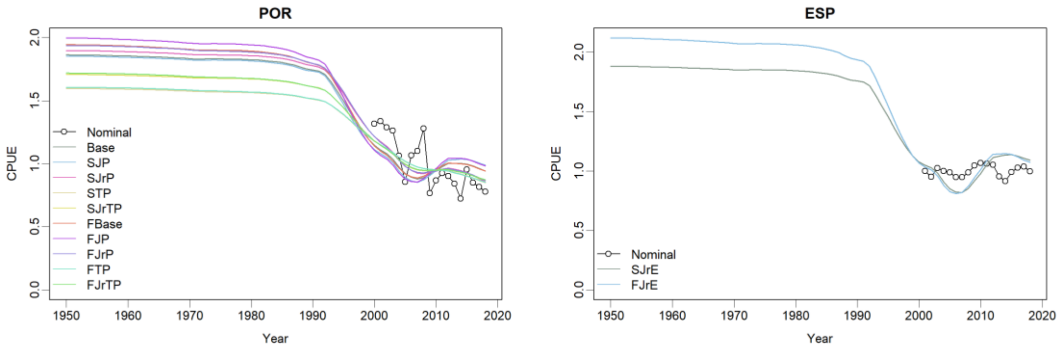

Fig. 2. (Continued).

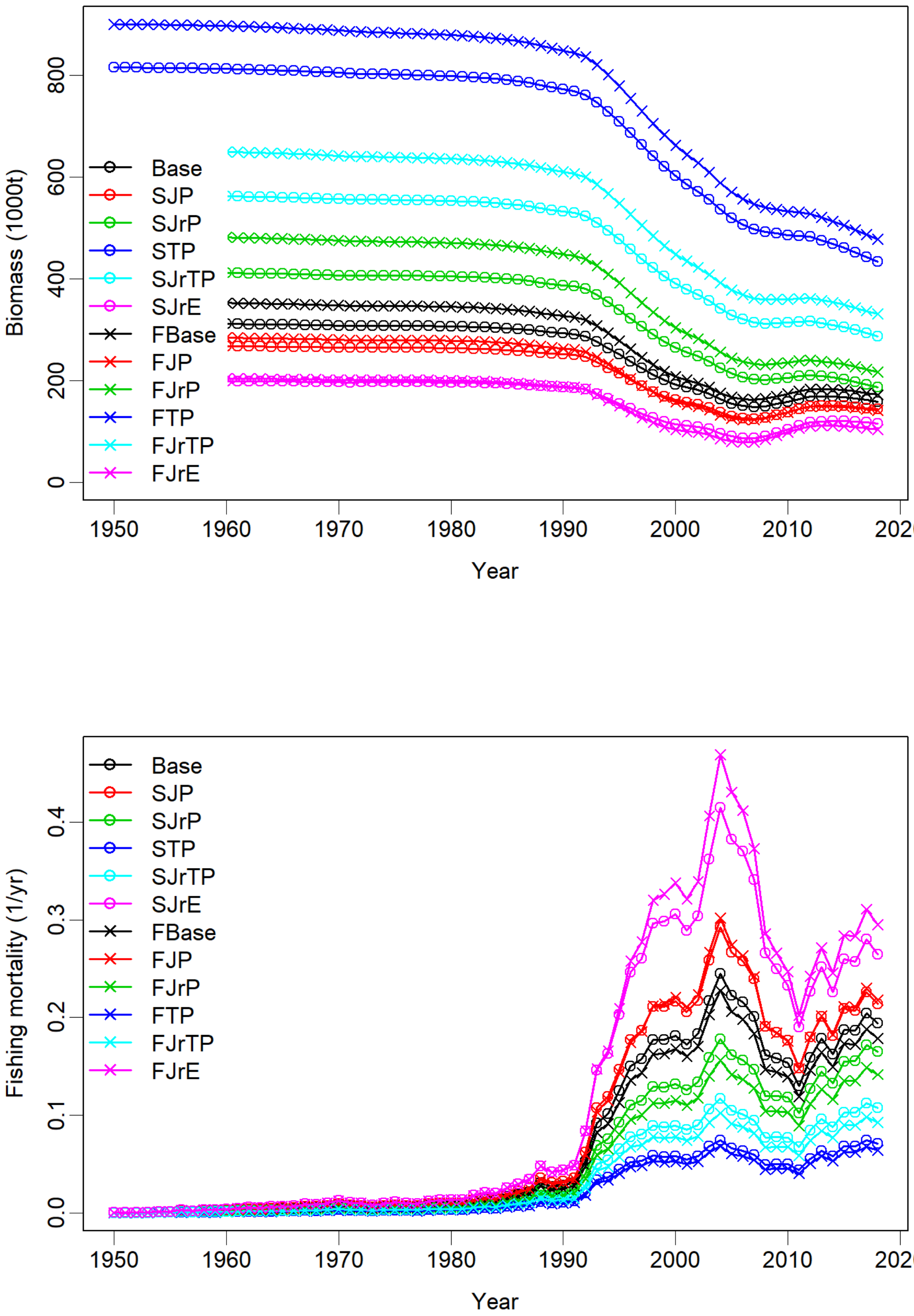

Fig. 3. The trajectories of the estimated biomass and fishing mortality for swordfish in the Indian Ocean.

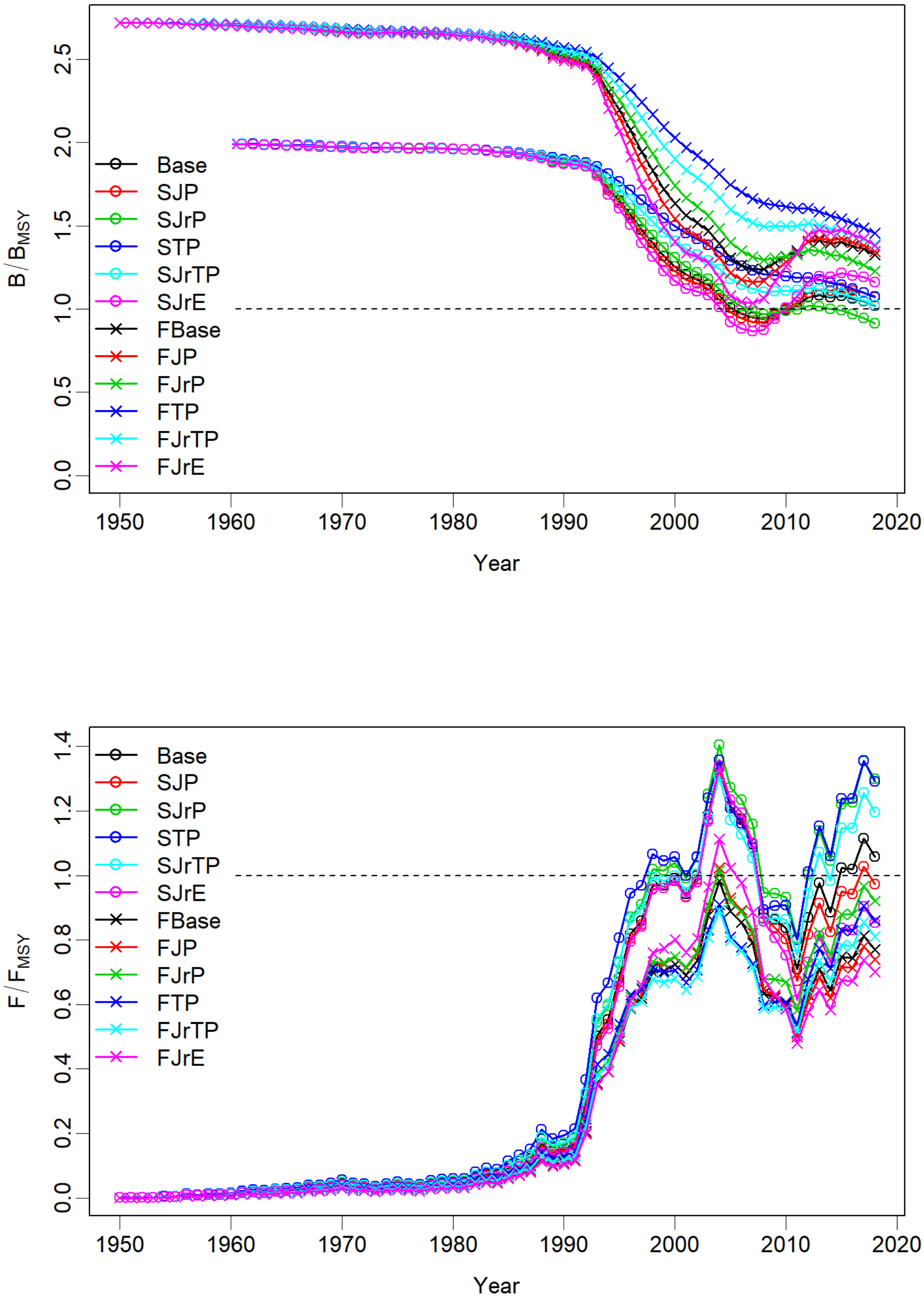

Fig. 4. The trajectories of the estimated relative biomass and fishing mortality to the MSY level for swordfish in the Indian Ocean.

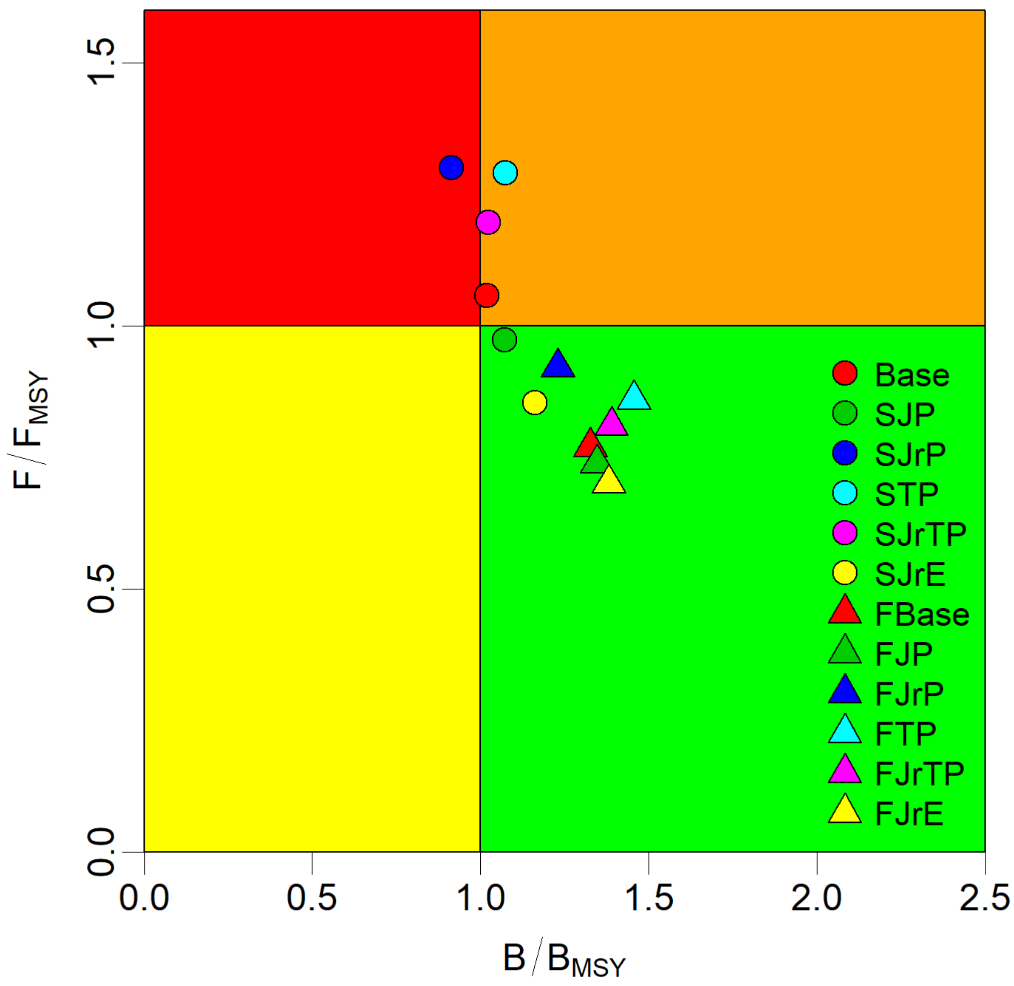

Fig. 5. Kobe plot based on the estimated relative biomass and fishing mortality in 2018 for swordfish in the Indian Ocean obtained from Schaefer and Fox models.

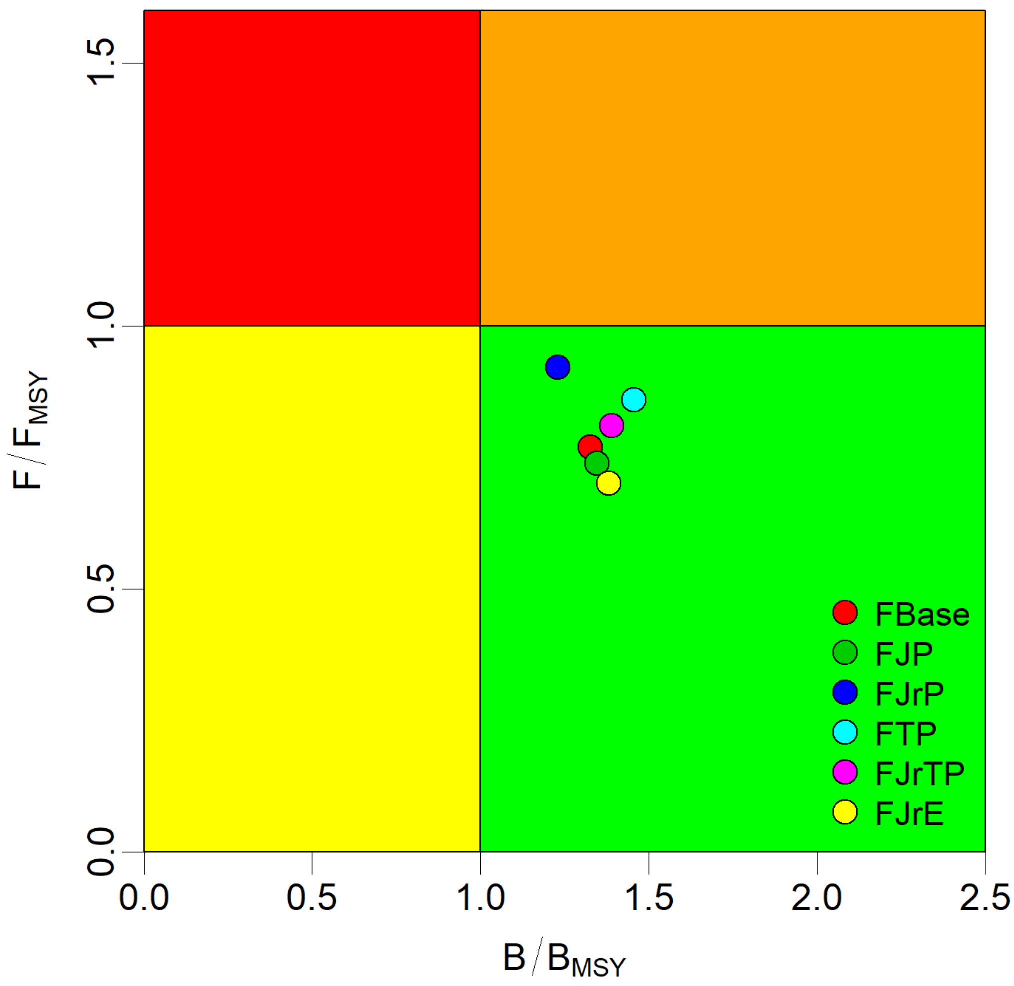

Fig. 6. Kobe plot based on the estimated relative biomass and fishing mortality in 2018 for swordfish in the Indian Ocean obtained from Fox models.

Table 1. Fisheries used for the assessment of swordfish in the Indian Ocean.

Fishery	Description
ALGI	Contains data for gillnet, trolling and other minor artisanal fisheries. The catches for several fisheries under this category were revised between 2010-13 with catches of swordfish added to some fisheries that had not reported this species in the past.
AUEL	Contains data for the longline fishery of Australia (target is SWO)
EUEL	Contains data for EU longliners (from EU.Spain, EU.Portugal and the EU.UK) targetting SWO plus other longliners assimilated to EU longliners (generally owned by Spanish nationals)
ISEL	Contains data for the semi-industrial longline fleets operating in Reunion(EU.France), Mayotte(EU.France), Madagascar, Mauritius and the Seychelles, which also target SWO
JPLL	Contains data for the longline fishery of Japan plus other fleets assimilated to the Japanese fleet (e.g. South Korea, Thailand, Oman)
TWFL	Contains data for the fresh-tuna longline fleets of Taiwan and Indonesia, plus other fresh-tuna longline fleets assimilated to those and all sport fisheries and fleets operating hand lines. This fishery also includes the catches of swordfish by the component of the gillnet and longline combination fishery of Sri Lanka that was caught using longlines. Note that all those catches had been previously assigned as gillnet (this is why catches under this category have increased markedly as compare to data for previous years).
TWLL	Contains data for the large scale tuna longline fleet of Taiwan,China, plus other longline fleets assimilated to the Taiwanese fleet (a component of those fleets may target SWO)

Table 2. Pearson correlation coefficients of CPUE series between fleets.

	TWN_NW	TWN_NE	TWN_SW	TWN_SE	JPN_NW	JPN_NE	JPN_SW	JPN_SE	POR	ZAF	ESP	IDN
TWN_NW	1.00											
TWN_NE	0.40	1.00										
TWN_SW	0.22	0.54	1.00									
TWN_SE	0.28	0.57	0.80	1.00								
JPN_NW	0.11	0.28	0.72	0.61	1.00							
JPN_NE	**-0.18**	0.11	0.24	0.28	0.48	1.00						
JPN_SW	**-0.08**	0.21	0.64	0.46	0.78	0.62	1.00					
JPN_SE	0.06	0.25	0.57	0.49	0.33	0.15	0.13	1.00				
POR	0.24	0.46	0.63	0.35	0.08	**-0.49**	**-0.69**	0.55	1.00			
ZAF	0.13	**-0.19**	0.55	**-0.22**	**-0.26**	**-0.67**	**-0.34**	0.27	0.72	1.00		
ESP	**-0.06**	**-0.54**	**-0.13**	**-0.10**	0.50	0.05	0.52	**-0.43**	**-0.18**	0.21	1.00	
IDN	**-0.51**	0.55	**-0.19**	0.30	**-0.06**	0.51	0.32	**-0.50**	**-0.48**	**-0.77**	**-0.30**	1.00

* Values in light yellow and yellow background represent the correlations significant and highly significant from 0.

Table 3. Scenarios used for the stock assessment of swordfish in the Indian Ocean.

Case	Model	CPUE series
Base	Schaefer	JPN (1994-2018, excluded SW), POR (2000-2018)
SJP	Schaefer	JPN (1994-2018), POR (2000-2018)
SJrP	Schaefer	JPN (1994-2018, excluded NE & SW), POR (2000-2018)
STP	Schaefer	TWN (1994-2018), POR (2000-2018)
SJrTP	Schaefer	JPN (1994-2018, excluded NE & SW), TWN (1994-2018), POR (2000-2018)
SJrE	Schaefer	JPN (1994-2018, excluded SE), ESP (2001-2018)
FBase	Fox	PN (1994-2018, excluded SW), POR (2000-2018)
FJP	Fox	JPN (1994-2018), POR (2000-2018)
FJrP	Fox	JPN (1994-2018, excluded NE & SW), POR (2000-2018)
FTP	Fox	TWN (1994-2018), POR (2000-2018)
FJrTP	Fox	JPN (1994-2018, excluded NE & SW), TWN (1994-2018), POR (2000-2018)
FJrE	Fox	JPN (1994-2018, excluded SE), ESP (2001-2018)

Table 4. 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	AIC*
Base	312,609	28,637	0.183	156,304	1.006	1.058	0.196	-292.1
SJP	268,757	29,579	0.220	134,379	1.071	0.973	0.218	-343.7
SJrP	413,231	26,202	0.127	206,616	0.913	1.300	0.173	-230.1
STP	814,669	22,376	0.055	407,334	1.073	1.290	0.229	-335.3
SJrTP	564,374	25,297	0.090	282,187	1.024	1.197	0.216	-497.8
SJrE	199,849	30,987	0.310	99,924	1.162	0.854	0.198	-287.5
FBase	354,239	30,207	0.232	130,317	1.312	0.770	0.196	-292.6
FJP	285,794	30,996	0.295	105,138	1.346	0.739	0.215	-346.5
FJrP	483,444	27,364	0.154	177,849	1.229	0.921	0.173	-230.0
FTP	899,355	24,732	0.075	330,854	1.455	0.860	0.228	-335.5
FJrTP	651,757	27,461	0.115	239,768	1.389	0.811	0.216	-497.8
FJrE	205,436	31,845	0.421	75,576	1.381	0.701	0.192	-293.2

* Values are only comparable for the models based on the same data sets (the same color).