Stock assessment of Striped marlin (*Tetrapturus audax*) in the Indian Ocean using the Stock Synthesis

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ABSTRACT

In this study, Stock Synthesis (SS) was used to conduct the stock assessment for striped marlin in the Indian Ocean by incorporating historical catch, CPUE and length-frequency data. The influences of CPUE series, time-varying catchability and selectivity assumption and life-history parameters on the assessment results were examined by various scenarios. The results of most scenarios indicated that the current stock status of striped marlin in the Indian may be overfished and overfishing already, except for the scenario of incorporating CPUE series of Iran and Pakistan.

1. INTRODUCTION

Striped marlin are largely considered to be a non-target species of industrial fisheries. Longlines account for around 69% of total catches in the Indian Ocean, followed by gillnets (24%), with remaining catches recorded under troll and handlines. The catches were mainly made by Indonesia (drifting longline and coastal longline, 36%), Taiwan (drifting longline, 24%) I.R. Iran (gillnet, 14%), and Pakistan (gillnet, 8%). Catch trends are variable, ranging from 2000 t to 8000 t per year, which may reflect the level of reporting and the status of striped marlin as a non-target species (IOTC, 2016).

The stock status of striped marlin in the Indian Ocean has been evaluated using a non-equilibrium production model (A Stock-Production Model Incorporating Covariates, ASPIC), Bayesian production model, age-structured integrated analysis and stock reduction analysis and the stock status was determined to be overfished and subject to overfishing (IOTC, 2013; 2015).

Since historical length-frequency data and parts of auxiliary information, such as life-history parameters, were available for striped marlin in the Indian Ocean, the integrated stock assessment approach can be applied to evaluate the stock status. Therefore, this study attempt to conduct the stock assessment for striped marlin in the

Indian Ocean using Stock Synthesis (Methot, 2012; Methot and Wetzel, 2013).

2. MATERIALS AND METHODS

2.1 Fishery definition

Striped marlin was mainly exploited by longline fleets (Taiwan and Indonesia) and gillnet fleets (Iran and Pakistan). The catch data were available for all of fleets and CPUE series were also available for these fleets. Except for Taiwan and Japan however, the length-frequency data were very sparse for other fleets. Therefore, the fleets operated in the Indian Ocean were simply aggregated into the five fleets (TWN: Taiwanese longline; JPN: Japanese longline; IRN: Iran; PAK: Pakistan; OTH: Other fleets).

2.2 Data used

The historical catches in weight and length-frequency data were provided by Indian Ocean Tuna Commission (IOTC). Fig. 1 shows the trends of catches for five fleets. The total catch roughly revealed an increasing before the late 1980s, substantially decreased during 1990-1992, and then gradually decreased until the late 2000s. In recent years, the catches obviously increased and mainly contributed from OTH fleet.

The standardized CPUE series were available from Taiwan, Japanese, Iran and Pakistan (Wang 2017; Ijima, 2017). According to the fishery definition, area-specific CPUE series of Taiwanese and Japanese fleets were aggregated into single series for each fleet based on approach (Wang, 2017). The trends of CPUE series by fleets are shown in Fig. 2.

The length data of striped marlin in the Indian Ocean were mainly collected by Japanese and Taiwanese longline fleets. Although the data also collected by other fleets, the sample sizes were very sparse and the time series of data were generally short or incomplete. All of the length-frequency data were converted into the measurement of lower jaw fork length (LJFL) and aggregated into 3 cm length interval (Fig. 3).

Fig. 4 shows the data presence by year for each fleet used in the stock assessment of striped marlin in the Indian Ocean, including catch, length-frequency and CPUE data.

2.3. Life-history parameters

Biological and life history parameters, including the length-weight relationship, growth, maturity and etc., are not available for striped marlin in the Indian Ocean. The study referred to the life history parameters used in stock assessment for striped marlin in the Western and Central North Pacific Ocean (see ISC, 2015 for details, Table 1). The natural mortality (*M*) was assumed to 0.45 year^{-1}. The standard Beverton-Holt stock-recruitment relationship was used in this study. The parameter of the stock-recruitment relationship (steepness, *h*), which represented the productivity of the fish, was assumed to be 0.86.

2.4 Model structure and assumption

Stock Synthesis (SS) version 3.24f (Methot, 2012) was used in this study. Equal weightings were assigned to all data components. Based on ISC (2015), the growth of striped marlin seems not to be sexually dimorphic (Fig. 5). Therefore, one growth pattern was adopted to conduct the SS analysis. SS provides three growth models as options, including von Bertalanffy growth curve, Schnute's generalized growth curve (aka Richards curve) and von Bertalanffy growth curve with age-specific deviations for growth coefficient (K). In this study, the standard von Bertalanffy growth curve was used and it was parameterized as:

$$L_2 = L_\infty + (L_1 - L_\infty)e^{-K(A_2 - A_1)}$$

where L_1 and L_2 are the sizes associated with ages near the youngest A_1 and oldest A_2 ages in the data, K is the growth coefficient, and L_∞ is the theoretical maximum length which can be solved based on the values other three parameters.

The population structure was sex-specific although sex specific data were not available but the model population age structure can be differentiated by sex to estimate the spawning stock biomass and its related quantities. The maximum age used in the model was 40 years. The time period of assessment model was from 1950 to 2015 along with 10-years projection. Sex ratio of female was assumed to be 0.5.

Recruitment was estimated as deviates from the Beverton-Holt stock recruitment relationship and was assumed to follow a lognormal distributed deviates with zero mean and standard deviation. In this study, the standard deviation was assumed to be 0.4, which was commonly adopted in previous stock assessment for tunas and billfishes. Due to lack of abundance index and length-frequency data before 1970s, recruitment deviations were assigned and estimated for 1970-2014 in the model and deviates for other years were fixed at zero.

Selectivity curves were length-based and modeled using double normal functions for TWN and JPN fleets and set to be 1 for IRN, PAK and OTH because of lack of length-frequency data.

Catchability was estimated assuming that survey indices are proportional to vulnerable biomass with a scaling factor of catchability. As Methot (2012) recommended, fishing mortality (F) was modelled using continuous F as full parameters. Basically, it was assumed that catchability was constant over time for all indices.

2.5 Sensitivity analysis

An obvious gap was observed for the Japanese CPUE series before and after 1994. Wang et al. (2015) also indicated that assuming time-blocks for both catchability may be appropriate to reflect the changes in fishing operations. Therefore, this study assumed two time periods for Japanese fishery (JPN1: 1950-1993; JPN2: 1994-2015). The relative abundance indices adopted in this study were mainly based on the standardized CPUE of Taiwanese and Japanese longline fleets. The standardized CPUE series from Iran and Pakistan were also used as a comparison of incorporating additional indices into the model.

Firstly, this study conducted serval basic scenarios to examine the influence of usage of CPUE series and time-varying assumption of catchability and selectivity on the assessment results. The growth parameters were estimated by SS or fixed as the values of ISC (2015). The description of scenarios listed in Table 2.

Secondly, sensitivity analysis was conducted to explore the influence of assumed values of steepness and natural mortality on the assessment results based the model above with better performance. Two values of steepness (h) were adopted to examine model estimations under the assumptions of higher (h=0.95, “hhigh”) and lower (h=0.75, “hlow”) productivity. Natural mortality (M) was increased to 0.55 year^{-1} for the high M assumption (“Mhigh”) and decreased to 0.35 year^{-1} for low M assumption (“Mlow).

3. RESULTS AND DISCUSSIONS

3.1 Basic scenarios

Poor convergence of model estimation occurred and unreasonable estimates were obtained when incorporating IRN and PAK CPUE series and assuming the time-varying catchability and selectivity of JPN. Therefore, the results of this scenario was not adopted in this study.

Fig. 6 shows the estimated selectivity obtained from the model of incorporating time-varying catchability and selectivity (TJ2) as an example. TWN tended to select fishes with wider range of body length than JPN. The patterns of JPN selectivity did not obviously change for the two time periods and thus the gap of JPN CPUE series might be mainly resulted from the change in the catchability.

Generally, the catch data were well fitted by the model (Fig. 1 and Table 3). Fig. 7 shows the model fits to CPUE series. The model roughly fitted to the trend of TWN CPUE series except for high values in early years. The model fits to JPN series obviously improved when time-varying catchability were assumed although some data points cannot be fitted well (Fig. 7 and Table 3). However, the assumption of time-varying catchability led to worse model fits to length-frequency data. Incorporating IRN and PAK CPUE series substantially deteriorated the model fits to both of TWN CPUE series because of the conflicting trends among these CPUE series in recent years. In addition, the model fits to length-frequency data of TWN and JPN were also substantially deteriorated when IRN and PAK CPUE series were used (e.g. scenarios TJ1 and TJ1IP, Fig. 8 and Table 3).

The model estimated growth curves were different with those of ISC (2015) especially for the estimates obtained when incorporating IRN and PAK CPUE series (Fig. 5). Fixing the growth parameters by the values of ISC (2015) can improve the model fits to TWN and JPN CPUE series but slightly influenced the model fits to length-frequency data (Table 3).

Time trajectories of the relative fishing mortality and relative spawning biomass are shown in Fig. 9. Time-vary catchability led to higher levels of spawning biomass during the late 1970s to the late 1990s than those obtained from other scenarios. Except for the scenario of incorporating IRN and PAK CPUE series, the results of most scenarios indicated that the spawning biomass was much lower than its MSY level and were only about 10% of its unfished level since 2000. The fishing mortality also exceed the MSY level since about the late 1990s. The estimates of key quantities of management interests were not substantially different among most of scenarios, especially for relative quantities (Table 4).

The scenario of time-varying catchability and fixing growth parameters was adopted to the sensitivity to examine the influence of assumed values of the natural mortality and steepness of stock-recruitment relationship on the model estimations because this scenario provided better fits to CPUE series that may represent the pattern of the abundance. As the most of previous stock assessment studies, the results indicated that the model estimates were sensitive to the assumptions of natural mortality and steepness of stock-recruitment relationship (Table 4). The stock status slightly changed in positive direction when assuming higher values of natural mortality and steepness, while lower natural mortality and steepness led to relatively pessimistic stock status, especially in fishing exploitation. Kobe plot consistently indicated that current stock status was overfished and overfishing based on the results from most of scenarios, except for IRN and PAK CPUE series were used (Fig. 10).

3.2 Scenarios suggested by the WPB

Based on the discussion during the WPB meeting, two additional scenarios modified based on scenario TJ2GF were used for conducting the stock assessment of striped marlin in the Indian Ocean. Except area-aggregated CPUE of Japanese fleet, Japanese CPUE in the area NW was adopted for conducting assessment (Fig. 11). For Japanese fleet, time varying catchability was used for Japanese CPUE but selectivity was assumed to be constant over time. OTH fleet was assumed to share the same selectivity of Taiwanese fleet, which was estimated based on Taiwanese data. In addition, the effective sample size for length-frequency data was decreased from 200 to 20. The description of the scenarios suggested by WPB was also listed in Table 2.

Fig. 7 shows the model fits to CPUE series and indicated that the model can fit to the both of Taiwanese and Japanese CPUE data very well for two additional scenarios, especially the improvement for high CPUE values in early years. The model estimated selectivity obtained from two scenarios were very similar (Fig. 12). The model can also fit to the length-frequency data well for both fleets although the model fits to Taiwanese length-frequency data slightly deteriorated when using Japanese CPUE in NW (Figs. 13 and 14).

The trajectories of the relative fishing mortality and spawning biomass were shown in Fig. 9. The estimates of relative biomass and fishing mortality were similar for recent decade although the estimates show obviously different patterns in 1970s and 1980s. The value of negative log-likelihood function for each data component and the model estimates of key quantities are listed in Table 3 and 4, but it should be noted that the likelihood values for some of data components are not comparable with those of other scenarios due to the usage of different CPUE data or effective sample size. Kobe plot based on the additional scenarios are shown in Fig. 10 and the results obtained from the scenarios suggested by WPB also indicated that the stock status of striped marlin in the Indian Ocean was overfished and overfishing.

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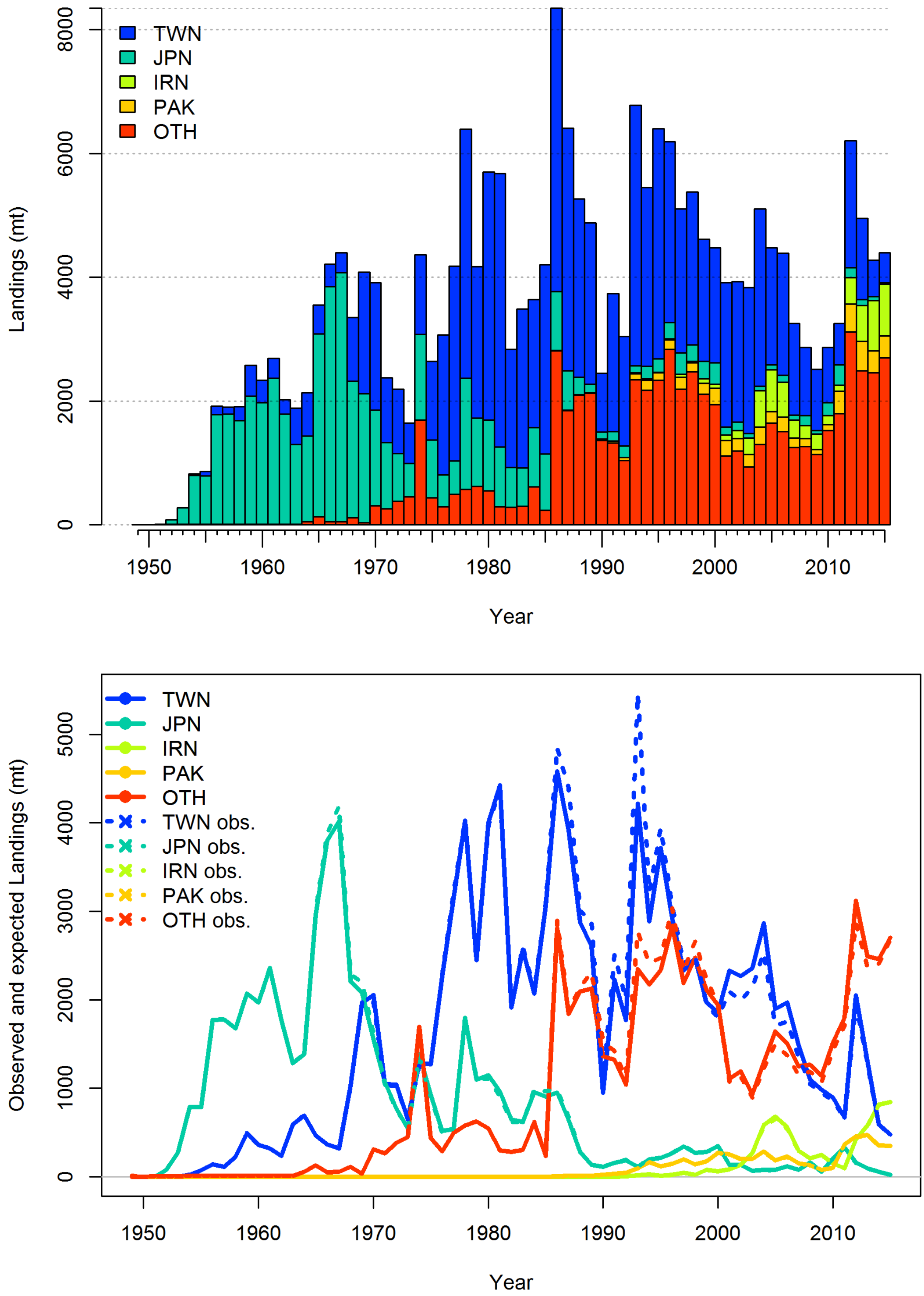


Fig. 1. Annual catches of striped marlin in the Indian Ocean. The dashed lines in lower panel are observed catches and solid lines are the model estimated catches.

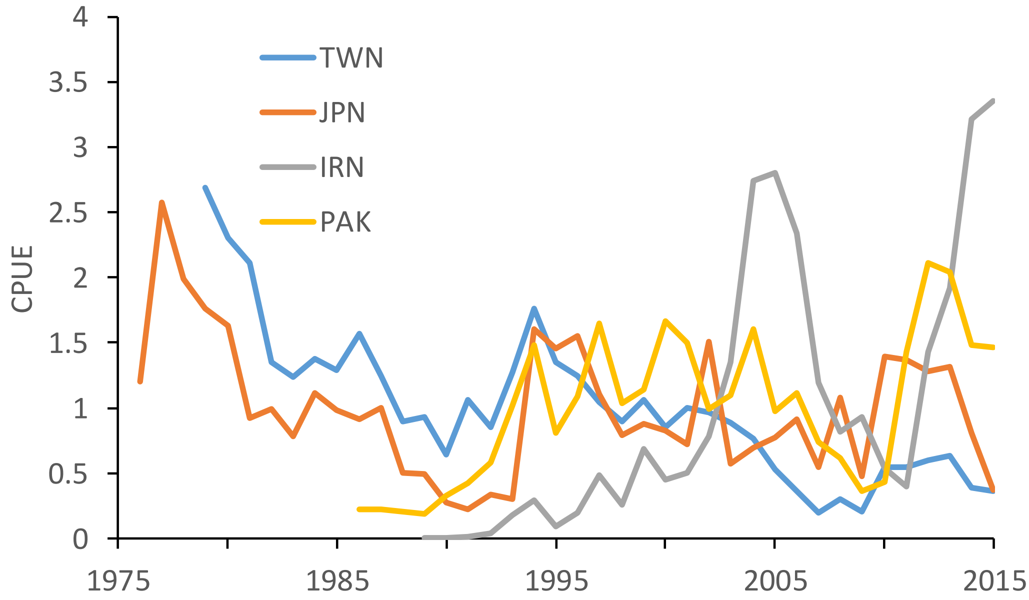


Fig. 2. Standardized CPUE series of striped marlin in the Indian Ocean.

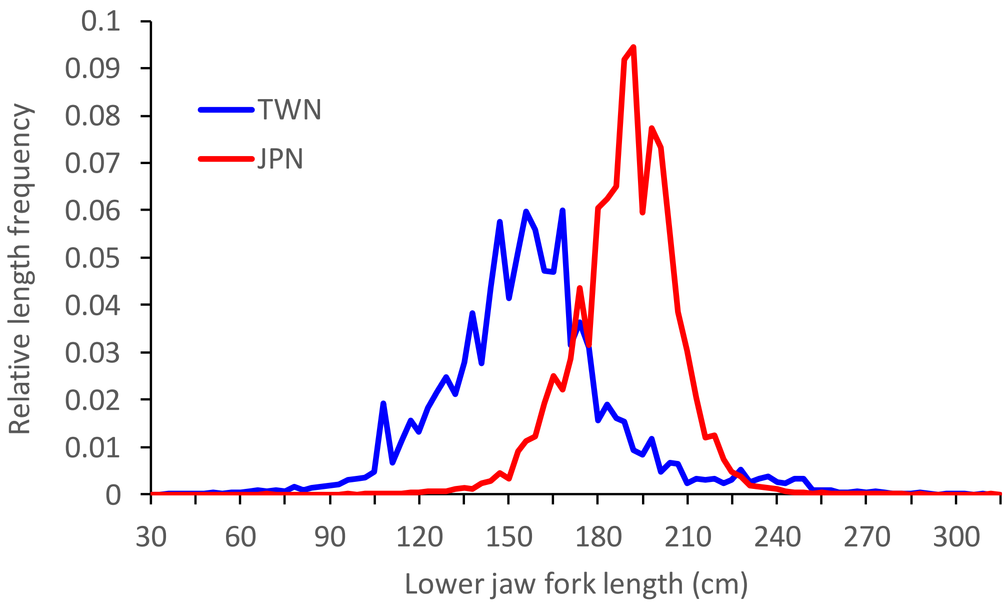


Fig. 3. Relative length-frequency of striped marlin in the Indian Ocean shown by the data aggregated across years.

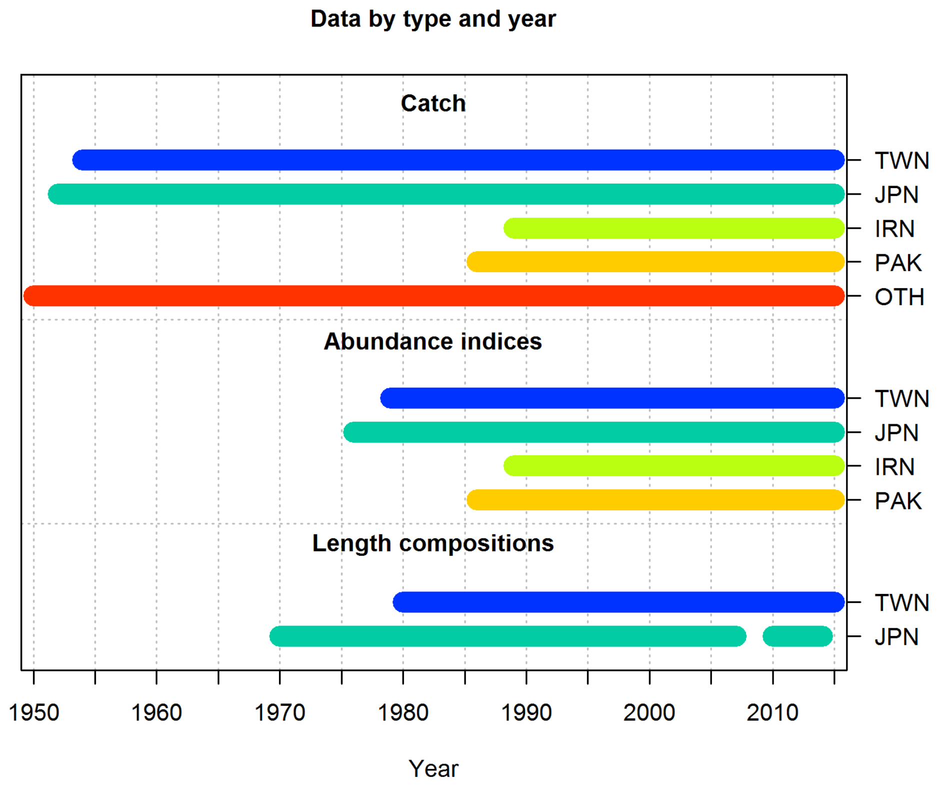


Fig. 4. Data presence by year for each fleet used in the stock assessment of striped marlin in the Indian Ocean.

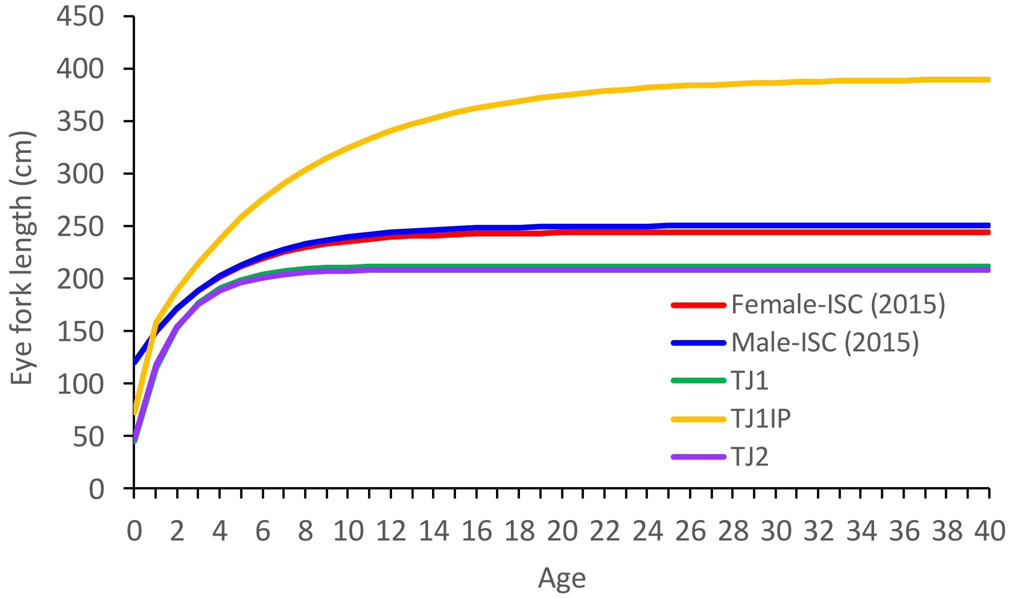


Fig. 5. Growth curves of striped marlin in the Indian Ocean obtained from ISC (2015) and estimated in this study.

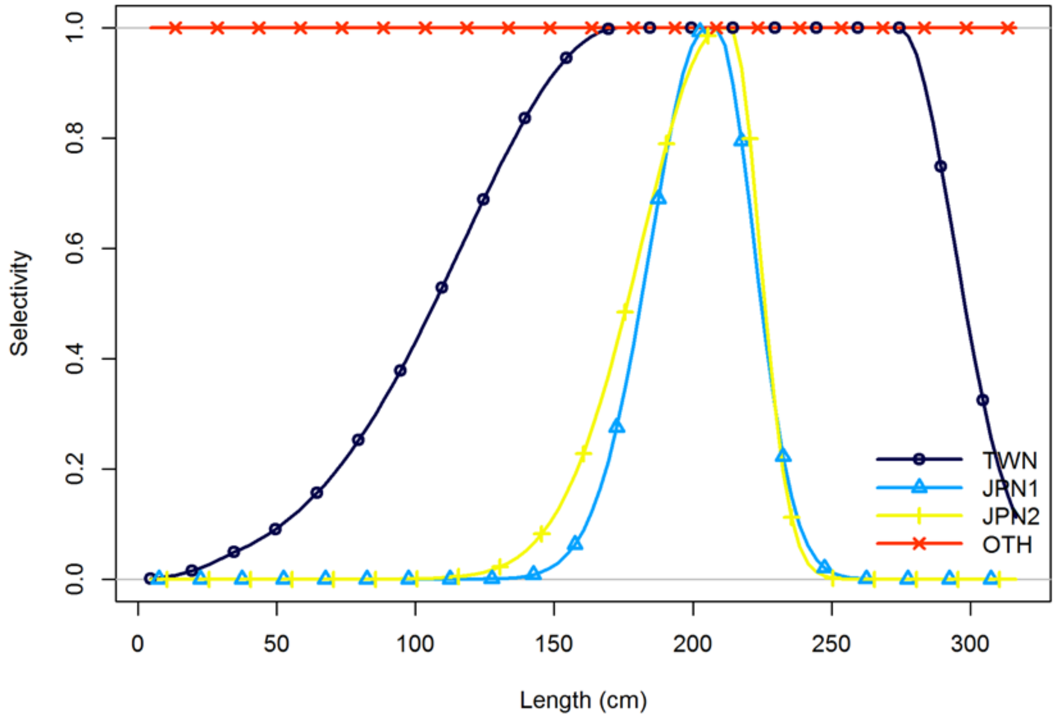


Fig. 6. Selectivity for striped marlin in the Indian Ocean estimated based on the scenario of assuming time-varying catchability and selectivity (TJ2).

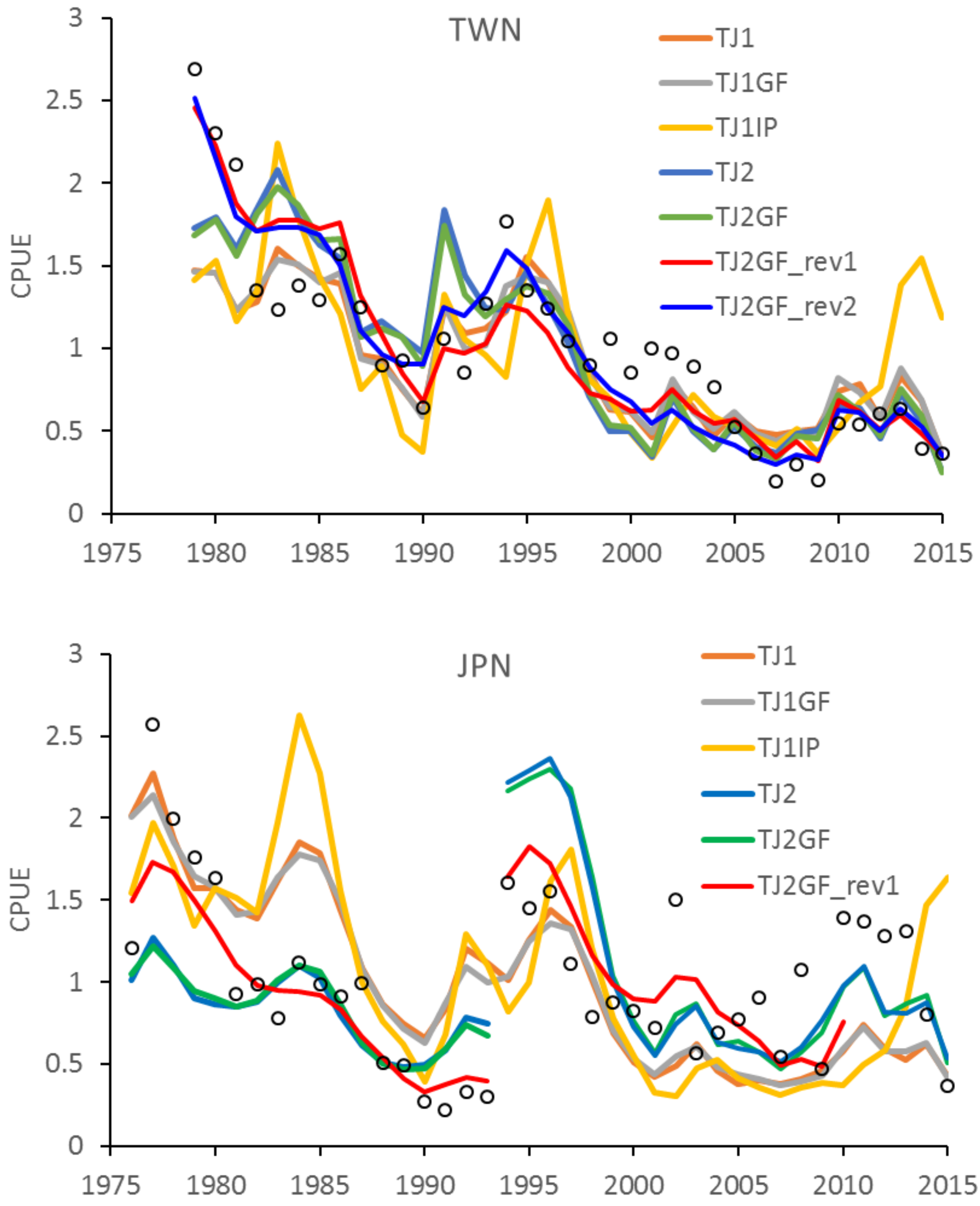
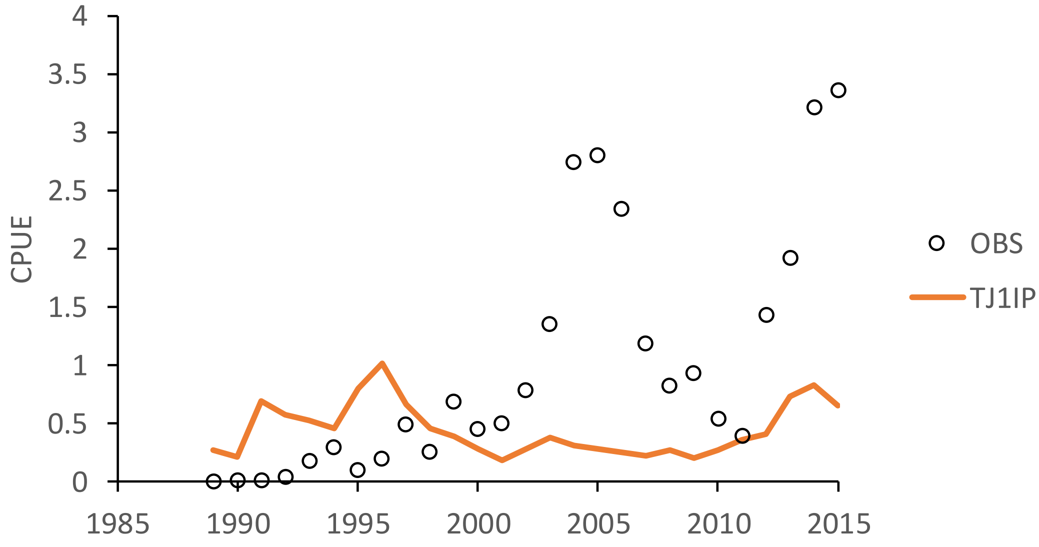


Fig. 7. Observed CPUE (dots) and model-estimated CPUE (lines) of striped marlin in the Indian Ocean.

IRN



PAK

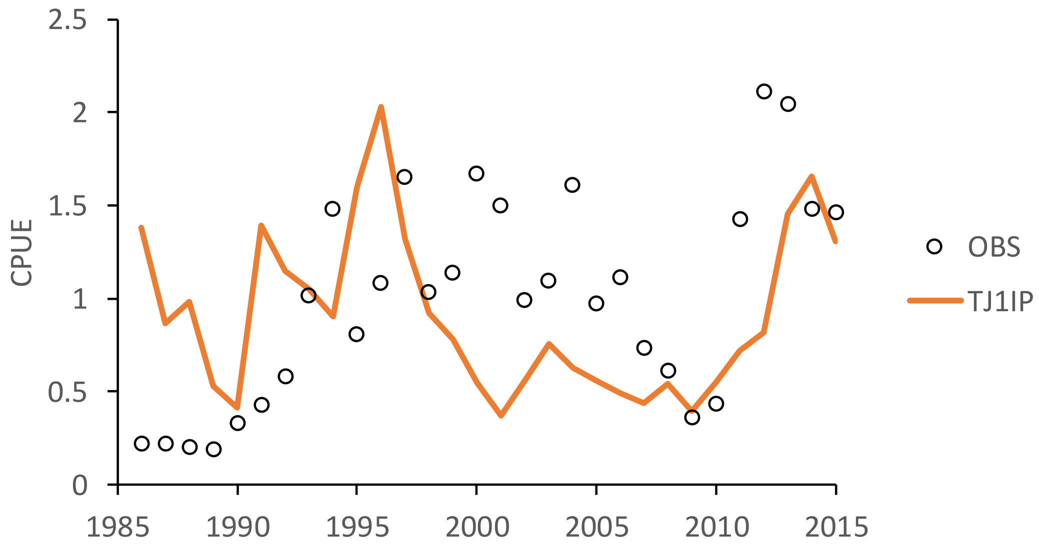


Fig. 7. (Continued).

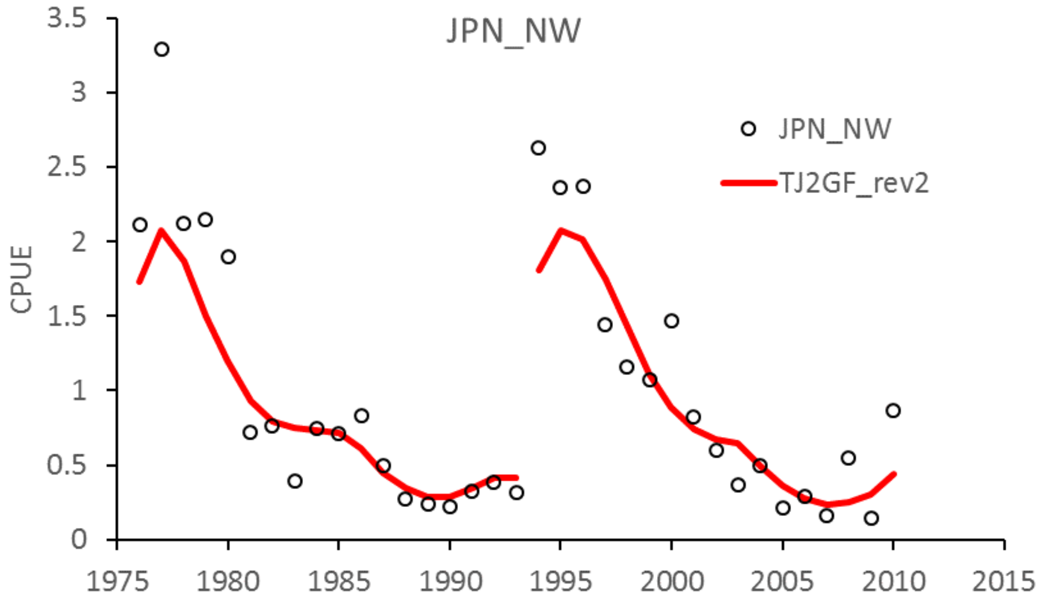
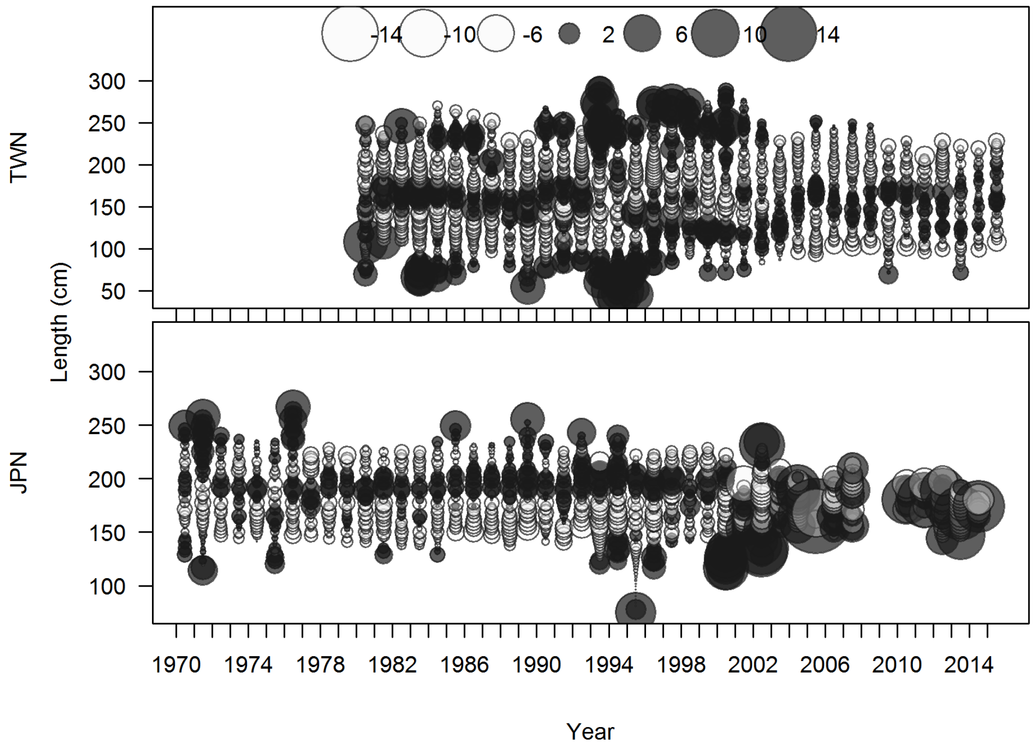


Fig. 7. (Continued).

Scenarios TJ1



Scenarios TJ1IP

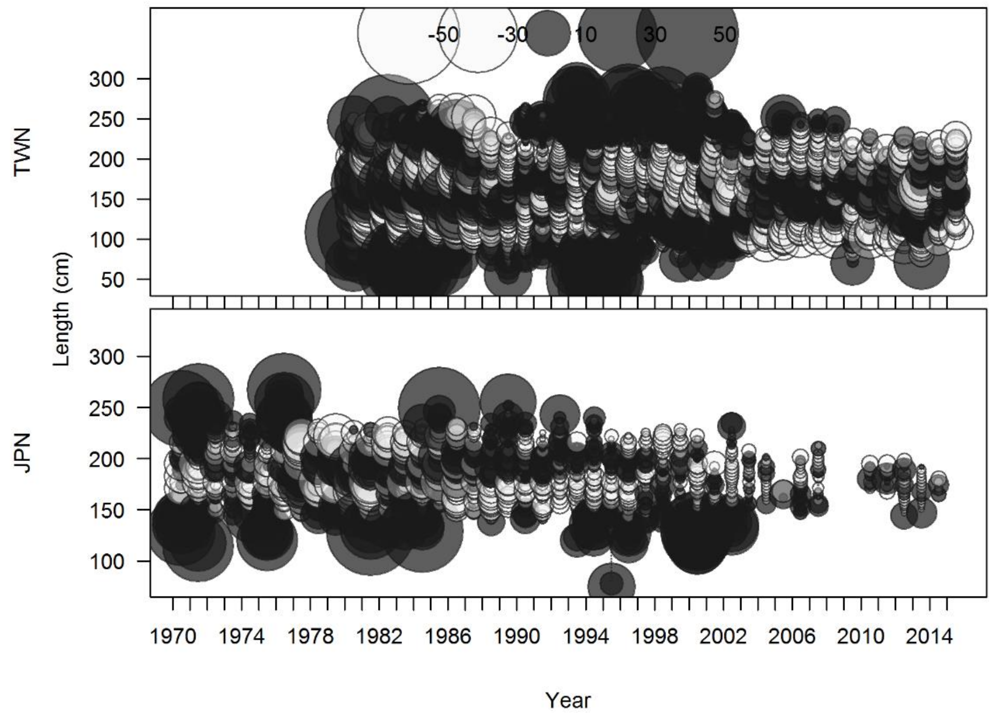


Fig. 8. Pearson residuals of the model fits to length-frequency data of striped marlin in the Indian Ocean based on the basic scenarios. Closed bubbles are positive residuals (observed > expected) and open bubbles are negative residuals (observed < expected).

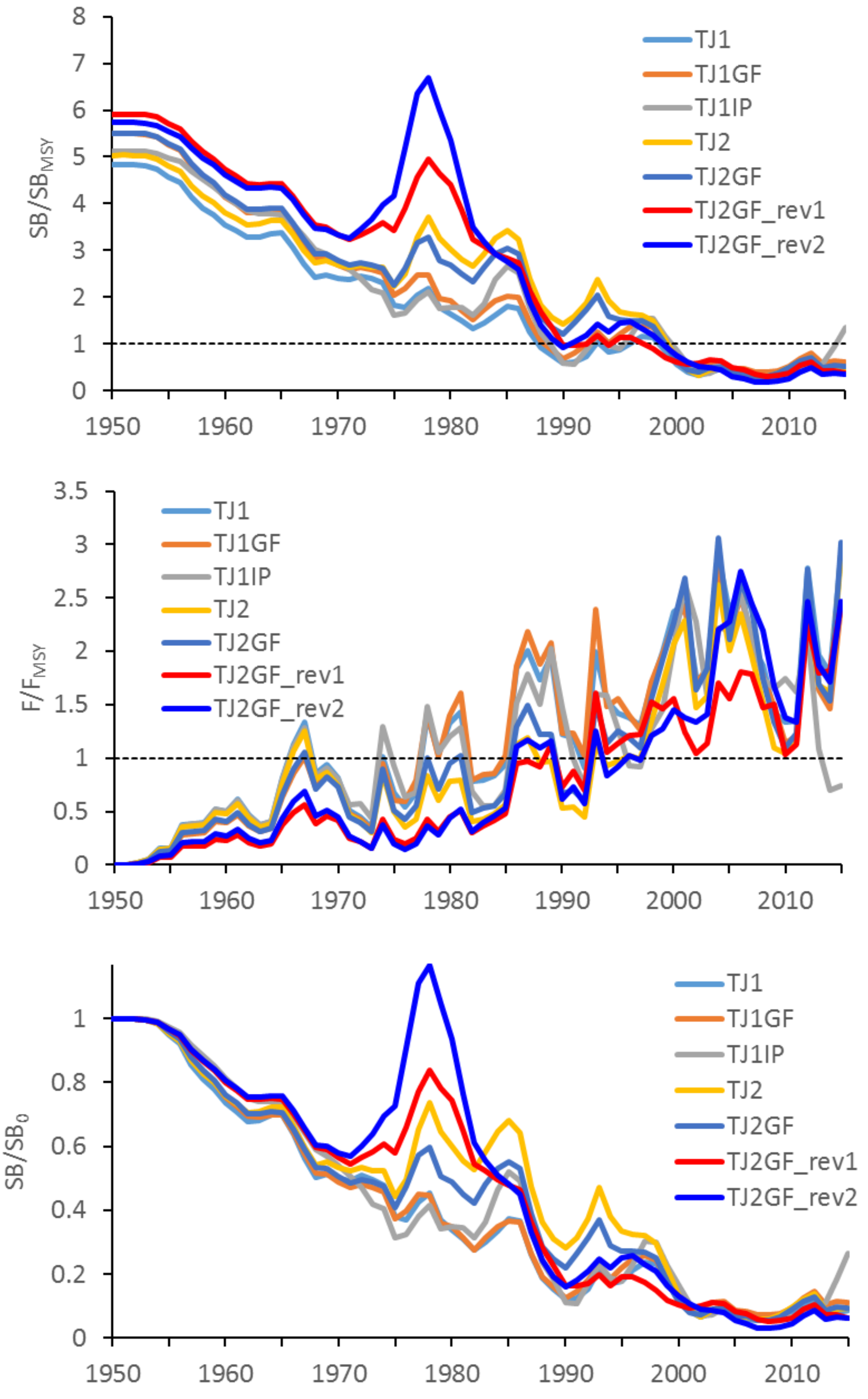


Fig. 9. Time trajectory of the relative fishing mortality and spawning biomass of striped marlin in the Indian Ocean.

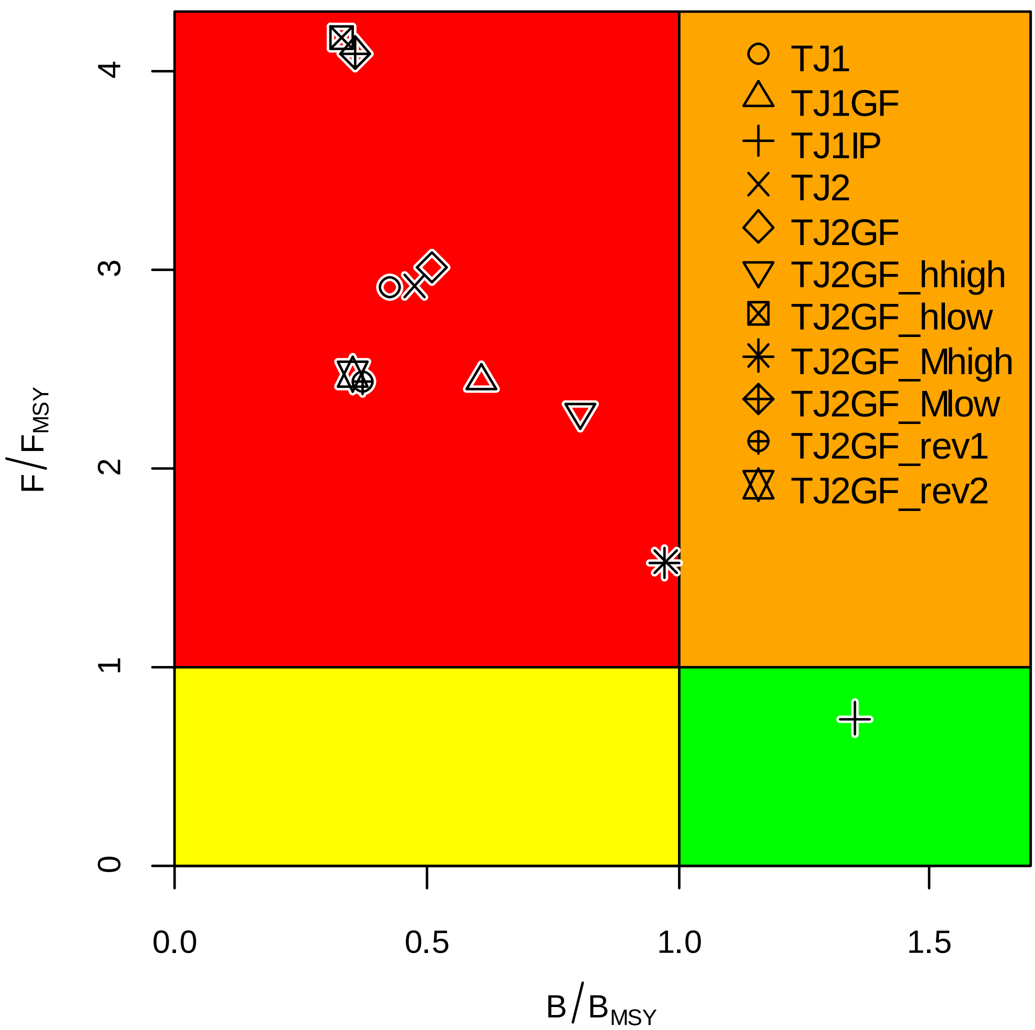


Fig. 10. Kobe plot for striped marlin in the Indian Ocean based on the estimates for 2015.

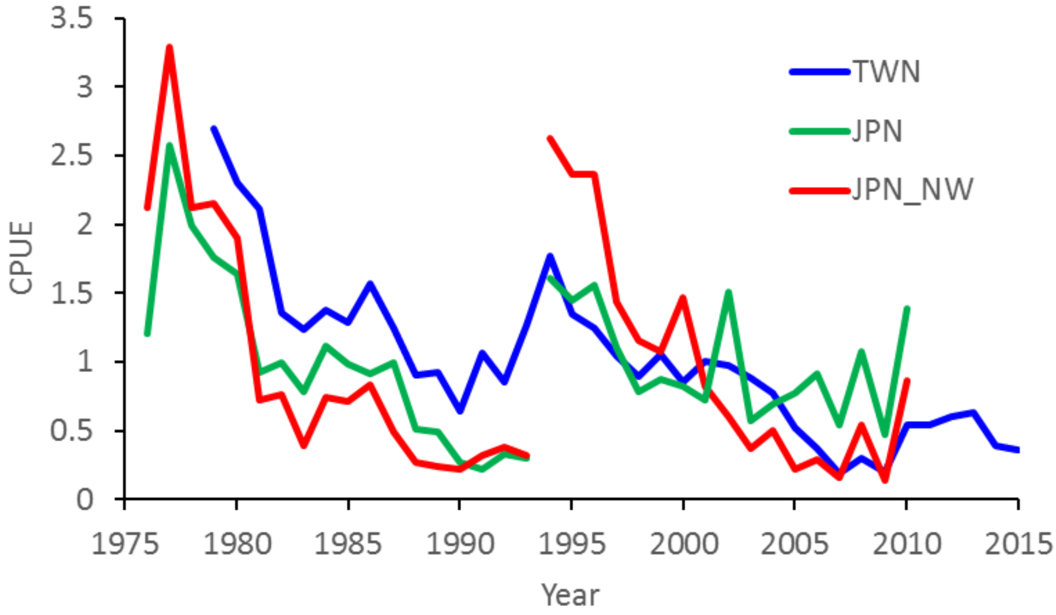
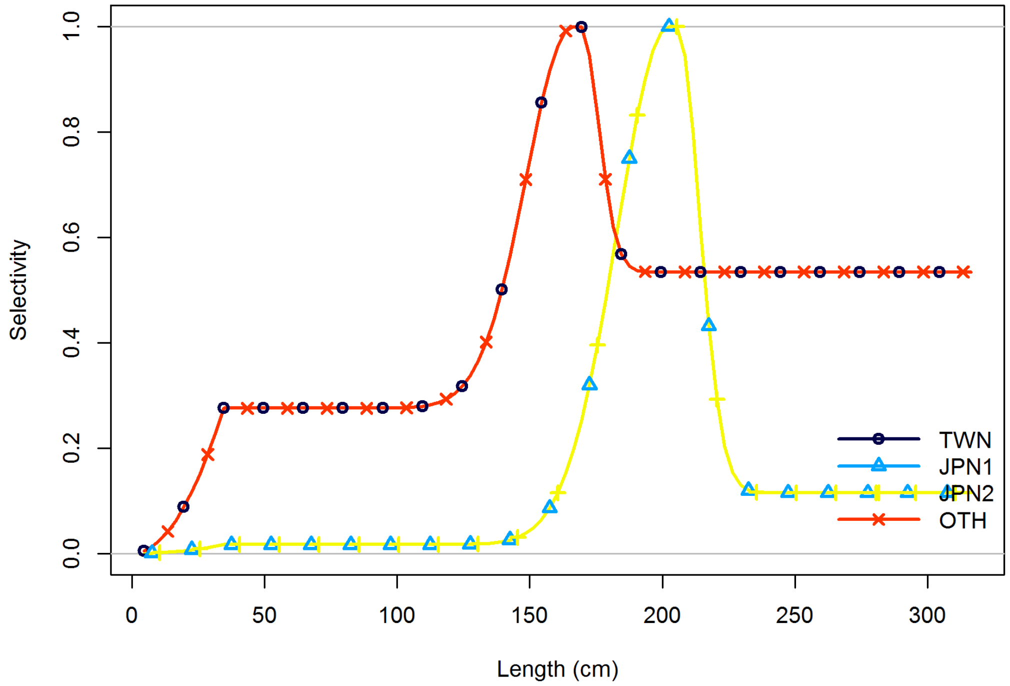


Fig. 11. CPUE series of Taiwanese and Japanese fleets used in the the scenarios suggested by WPB.

Scenario TJ2PGF_rev1



Scenario TJ2PGF_rev2

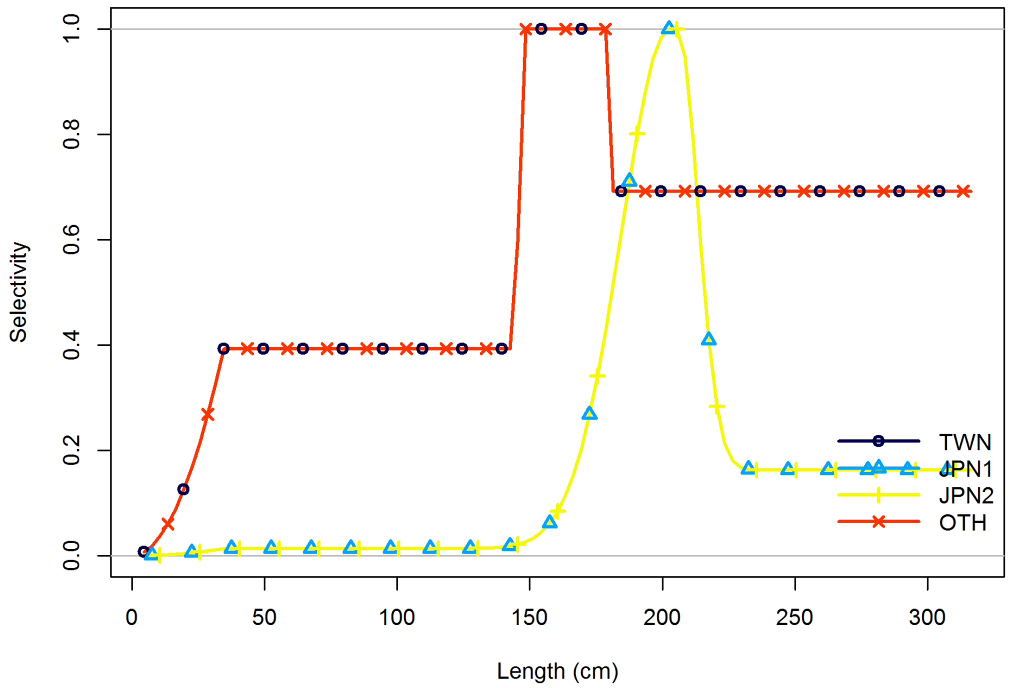
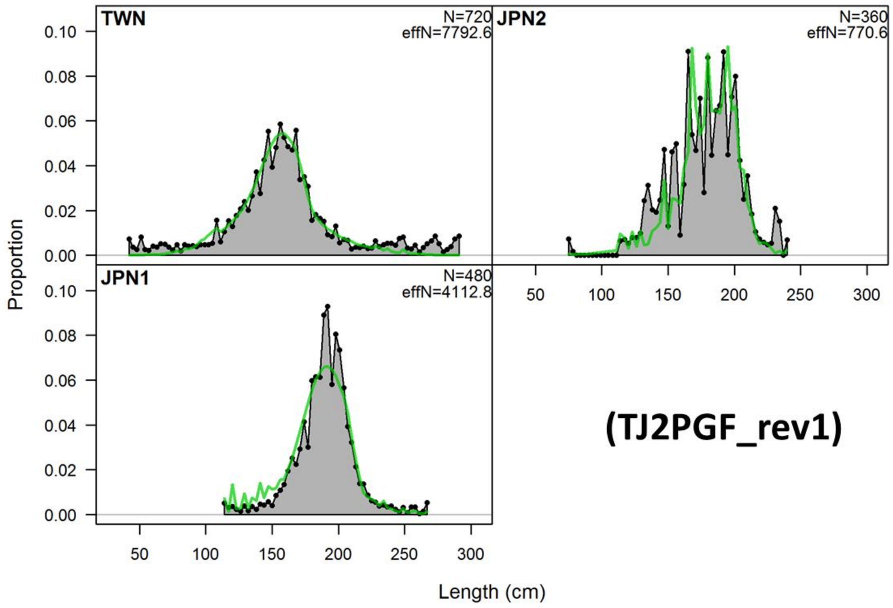


Fig. 12. Model estimated selectivity for Taiwanese and Japanese fleets based on the scenarios suggested by WPB.



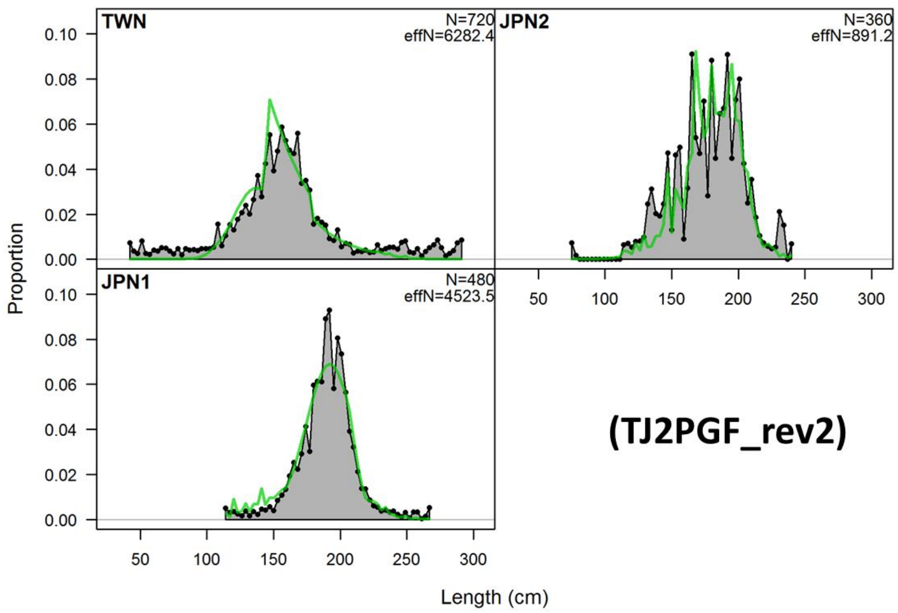


Fig. 13. Model fits to length-frequency data of Taiwanese and Japanese fleets based on the scenarios suggested by WPB.

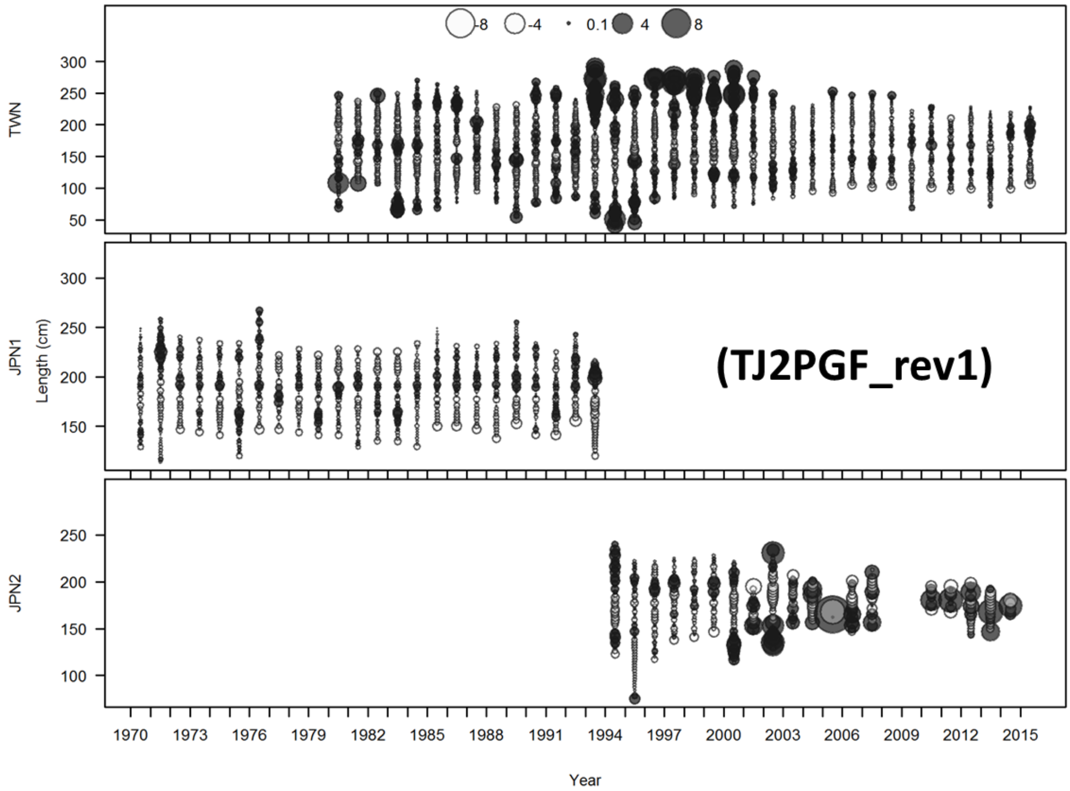


Fig. 14. Pearson residuals of the model fits to length-frequency data of striped marlin in the Indian Ocean based on the scenarios suggested by WPB. Closed bubbles are positive residuals (observed > expected) and open bubbles are negative residuals (observed < expected).

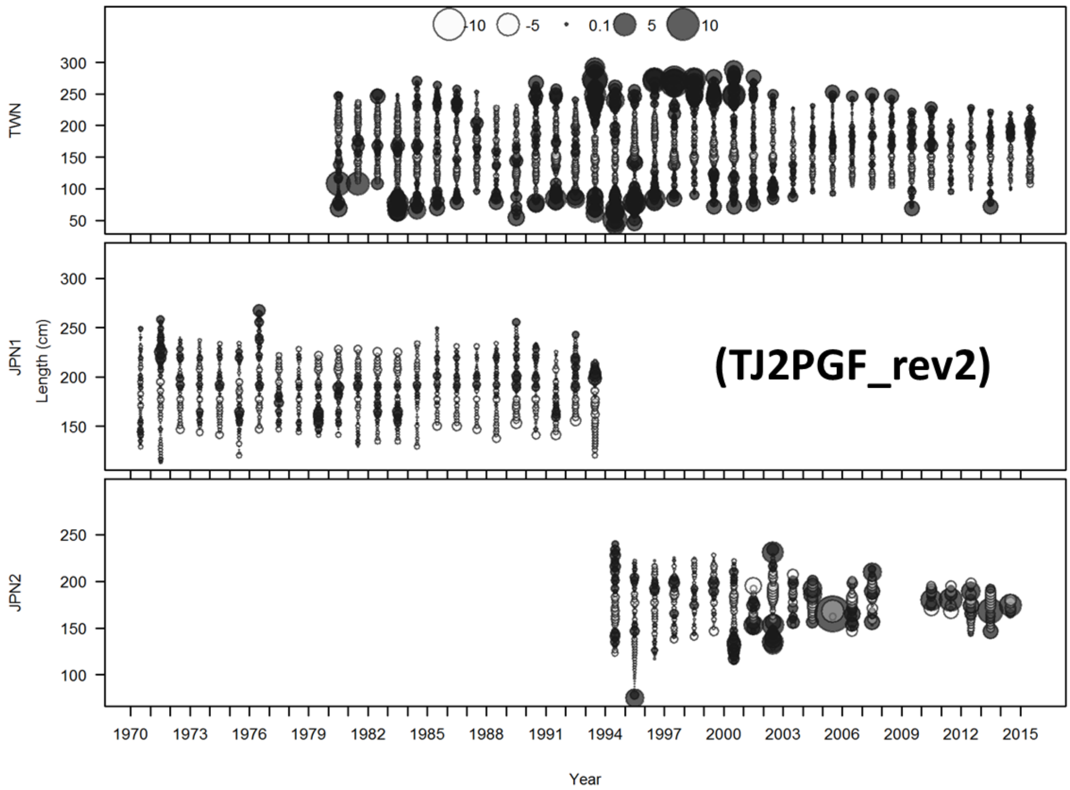


Fig. 14. (Continued).

Table 1. The biological parameters of length-weight relationships, von Bertalanffy growth curve, and maturity and age for striped marlin in the Western and Central North Pacific Ocean (ISC, 2015).

Parameter	Females	Males
Asymptotic size, L_∞ (cm)	243.98	250.19
Growth parameter, K (year^{-1})	0.27	0.25
Age-at-zero-length, t_0 (year)	-2.50	-2.62
Length-weight, A	4.68×10^{-6}	4.68×10^{-6}
Length-weight, B	3.16	3.16
Maturity slope, r_m	0.064	-
Length-at-50%-maturity, L_m (cm)	177.0	-
Maximum age, λ (year)	40	40

Table 2. CPUE data used and model assumptions of scenarios conducted for stock assessment for striped marlin in the Indian Ocean.

Scenario	CPUE series	Time block for JPN	Growth parameter	*h*	*M* ($year^{-1}$)
		Basic Scenario			
TJ1	TWN and JPN		Estimated	0.86	0.45
TJ1GF	TWN and JPN		Fixed	0.86	0.45
TJ1IP	TWN, JPN, IRN and PAK		Estimated	0.86	0.45
TJ2	TWN and JPN	1950-1993 and 1994-2015	Estimated	0.86	0.45
TJ2GF	TWN and JPN	1950-1993 and 1994-2016	Fixed	0.86	0.45
TJ2IP	TWN, JPN, IRN and PAK	1950-1993 and 1994-2017	Estimated	0.86	0.45
		Sensitivity to life-history parameters			
TJ2GF_hhigh	TWN and JPN	1950-1993 and 1994-2018	Fixed	0.95	0.45
TJ2GF_hlow	TWN and JPN	1950-1993 and 1994-2019	Fixed	0.75	0.45
TJ2GF_Mhigh	TWN and JPN	1950-1993 and 1994-2020	Fixed	0.86	0.55
TJ2GF_Mlow	TWN and JPN	1950-1993 and 1994-2021	Fixed	0.86	0.35
		Scenario suggested by WPB			
TJ2GF_rev1	TWN and JPN	1950-1993 and 1994-2010	Fixed	0.86	0.45
TJ2GF_rev2	TWN and JPN_NW	1950-1993 and 1994-2010	Fixed	0.86	0.45

Table 3. The value of negative log-likelihood for each data component based on scenarios conducted for the stock assessment for striped marlin in the Indian Ocean.

		Scenario						
Data component	Fleet	TJ1	TJ1GF	TJ1IP	TJ2	TJ2GF	TJ2GF_rev1	TJ2GF_rev2
Catch	Total	5.4	5.0	72.6	4.0	4.2	0.3	0.9
CPUE	TWN	7.8	1.6	76.2	22.8	13.8	-30.0	-27.4
	JPN	131.4	116.6	207.6	44.8	38.6	-19.4	-2.1*
	IRN			1,250.3				
	PAK			194.8				
	Total	139.2	118.2	1,728.9	67.6	52.4	-49.4	-29.5*
Length-frequency	TWN	670.6	820.7	18,378.0	1,319.0	1,604.3	145.0**	191.2**
	JPN	1,335.9	1,374.7	5,085.1	2,332.1	2,410.6	263.8**	248.5**
	Total	2,006.5	2,195.4	23,463.1	3,651.1	4,014.9	408.8**	439.7**

* Incomparable with other scenarios due to usage of different data.

** Incomparable with other scenarios due to assumption of different effective sample size.

Table 4. The estimates of the quantities of management interests based on scenarios conducted for the stock assessment for striped marlin in the Indian Ocean (Recruitment, R: number; spawning biomass, SB: metric ton).

Scenario	$R0$	SB_0	SB_{2015}	F_{2015}	MSY	F_{MSY}	SB_{MSY}	F_{2015}/F_{MSY}	SB_{2015}/SB_{MSY}	SB_{2015}/SB_0
Basic Scenario										
TJ1	372	6,577	581	1.153	4,401	0.396	1,364	2.911	0.426	0.088
TJ1GF	373	9,025	996	1.221	4,135	0.501	1,640	2.435	0.607	0.110
TJ1IP	312	19,278	5,081	0.351	4,467	0.475	3,767	0.740	1.349	0.264
TJ2	397	6,696	633	1.217	4,540	0.417	1,330	2.915	0.476	0.094
TJ2GF	388	9,373	869	1.462	4,288	0.485	1,701	3.015	0.511	0.093
Sensitivity to life-history parameters										
TJ2GF_hhigh	323	7,836	735	1.808	4,210	0.793	912	2.281	0.806	0.094
TJ2GF_hlow	481	12,870	1,121	1.318	4,354	0.316	3,383	4.169	0.331	0.087
TJ2GF_Mhigh	529	6,941	1,172	1.116	5,000	0.731	1,204	1.527	0.973	0.169
TJ2GF_Mlow	285	13,661	992	1.544	4,136	0.377	2,766	4.092	0.359	0.073
Scenario suggested by WPB										
TJ2GF_rev1	396	10,758	678	2.188	4,960	0.900	1,819	2.431	0.373	0.063
TJ2GF_rev2	472	11,470	706	1.591	5,267	0.644	2,001	2.470	0.353	0.062