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, standardized CPUE series, length-frequency data and life-history parameters. The results indicated that the current spawning biomass is lower than the MSY level and the fishing mortality is higher the MSY level. However, the results are influenced by the assumptions of life-history parameters and assuming higher values of natural mortality and steepness of stock-recruitment relationship can lead to relatively optimistic stock status.

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, 2017).

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, stock reduction analysis and Stock Synthesis and the stock status was determined to be overfished and subject to overfishing (IOTC, 2013; 2015; 2017).

Since historical length-frequency data were available for striped marlin in the Indian Ocean and life-history parameters could be obtained from striped marlin in other oceans, 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. However, Taiwanese and Japanese CPUE series are appropriate to be adopted for conducting the stock assessment analysis because poor convergence of model estimation occurred and unreasonable estimates were obtained when incorporating IRN and PAK CPUE series (Wang, 2017). In addition, the length-frequency data were very sparse for most of fleets, except for Taiwan and Japan. Therefore, the fleets operated in the Indian Ocean were simply aggregated into the three fleets (TWN: Taiwanese longline; JPN: Japanese longline; OTH: Other fleets).

2.2 Data used

The historical catches in weight and length-frequency data were provided by Indian Ocean Tuna Commission (IOTC). The revised catches and species compositions from IDN DGCF (IOTC-2018-WPB16-DATA03b - NC Scenario 2) were adopted in this study.

Fig. 1 shows the trends of catches for three fleets. The total catch roughly revealed an increasing before the late 1980s, substantially decreased during 1990-1992, reached a peak again 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 and Japanese (Ijima, 2018; Wang 2018). The area-specific CPUE series of Taiwanese fleet were aggregated into single series using catches as weightings (Wang, 2018). Based on the discussions in WPB 15, the Japanese standardized CPUE series from NW area was used in this study. CPUE series of Taiwanese and Japanese fleets reveal similar trends since early 2000s (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 1970-2016 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. Selectivity of OTH was set to be the same with TWN because of lack of length-frequency data for this fleet.

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 Basic scenarios

Comparing to the assessment conducted in WPB 15, catchability of Japanese fleet was not set to be time-varied because Japanese CPUE from 1994-2017 was only used in this study. To take the changes in the fishing characters of Taiwanese and Japanese fleets, four scenarios were implemented based on the assumption of time-varied selectivity for these two fleets. The selectivities were separated into two time blocks for Taiwanese and Japanese fleets when the length-frequency data revealed obviously different pattern (1950-1993 and 1994-2017 for Japanese fleet; 1950-2000 and 2000-2017 for Taiwanese fleet). The four scenarios were implemented with varying time-blocks for selectivity parameters as follows:

- T1J1 (reference case): constant selectivity
- T1J2: 1950-1993 and 1994-2017 time blocks for Japanese longline selectivity.
- T2J1: 1950-2000 and 2000-2017 for time blocks for Taiwanese longline selectivity.
- T2J2: 1950-1993 and 1994-2017 time blocks for Japanese longline selectivity, and 1950-2000 and 2000-2017 for time blocks for Taiwanese longline selectivity.

2.6 Scenarios suggested by WPB16

According to the discussion during the WPB16, the scenario J2T1 (time-varied selectivity for only Taiwanese fleet) was selected and 9 additional scenarios were suggested based on different assumptions for life-history parameters, including new estimates of maturity (Zhou et al., 2018), natural mortality and steepness of stock-recruitment relationship (Table 2). In addition, the sample size for the Japanese length data was very low in recent years and WPB agree to drop the Japanese length frequency data from 2001-2017.

3. RESULTS AND DISCUSSIONS

3.1 Basic scenarios

Fig. 6 shows the estimated selectivity obtained from the model. TWN tended to select fishes with wider range of body length than JPN. the selectivity of TWN revealed obviously different pattern for two time periods. Generally, assuming time-varied selectivity for TWN can substantially improve the model fits to CPUE data for both TWN and JPN, while assuming time-varied selectivity of JPN can only slightly improve the model fits to length-frequency data (Table 3). In addition, the sample size of length-frequency data is very low for JPN and may lead to highly uncertain estimates of selectivity for JPN. Therefore, the scenario J2T1 (time-varied selectivity for only Taiwanese fleet) was selected as a base-case for further assessment analysis.

3.2 Scenarios suggested by the WPB

Fig. 7 shows the estimated selectivity obtained from various scenarios. The estimates of selectivity obviously influenced by the assumed life-history parameters, which may lead to different estimates for age structure of the population.

Generally, the model roughly fitted to the trend of TWN and JPN CPUE series except for some peak values in early years and recent years (Fig. 8). The model fits to JPN length-frequency data were better than the fits to TWN data (Fig. 9). TWN obviously has more catches of small and large fishes before early 2000s but the model cannot fit to the distribution patterns for all of scenarios. In addition, the model fits to catch, CPUE and length-frequency data were only slightly changed when assuming different life-history parameters although model fits to JPN CPUE may impacted by the assumptions (Table 4).

Time trajectories of the model-estimated recruitment, spawning biomass and fishing mortality reveal quite different values although their trends seem to be similar, which indicated that the recruitment and spawning biomass obviously declined from the mid-1980s to 2010 because of substantial increase in fishing mortality, while the recruitment and spawning biomass slightly increased in recent years and this might be resulted from the strong recruitment and reducing in fishing mortality after the late 2000s (Fig. 10). This could be understood because assuming different steepness of stock-recruitment relationship and natural mortality can lead to different productivity and population dynamics and the stock would be estimated from different levels of initial biomass.

Time trajectories of the relative fishing mortality and relative spawning biomass are shown in Fig. 11. Although the estimated values of these quantities were varied based on the assumptions of life-history parameters, the trends indicated that the fishing mortality decreased and spawning biomass increased in recent years and current spawning biomass was still 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 mid-1990s but it obviously decreased to about the MSY level in recent years. Fig. 12 shows the Kobe plot based on the different scenarios and the results of most scenarios indicated that the stock status of striped marlin in the Indian Ocean was subject to be overfished and overfishing. However, the results were influenced by the assumptions of life-history parameters and assuming higher values of natural mortality and steepness of stock-recruitment relationship can lead to relatively optimistic stock status.

The estimates of key quantities of management interests are also show in Table 5. Although the estimates related to absolute biomass and fishing mortality were very sensitive to the assumed values of life-history parameters, the estimates of MSY and relative biomass and fishing mortality were relatively robust except for assuming a extreme values for natural mortality and steepness of stock-recruitment relationship. The estimates of key quantities of management interests obtained from the scenario selected by WPB are also show in Table 6.

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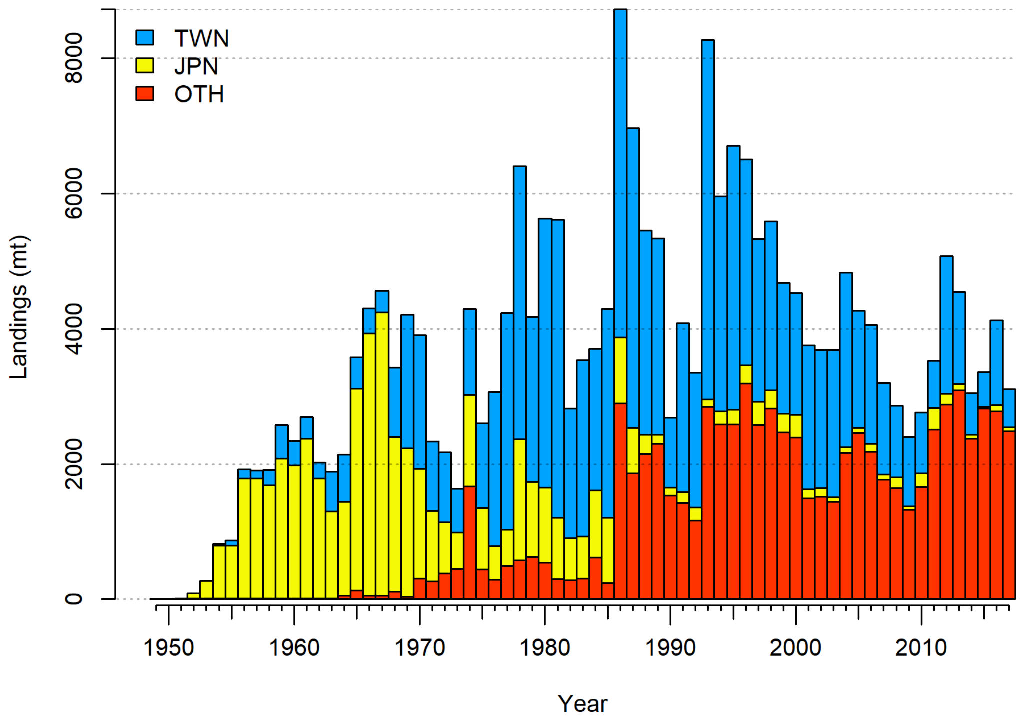


Fig. 1. Annual catches of striped marlin in the Indian Ocean.

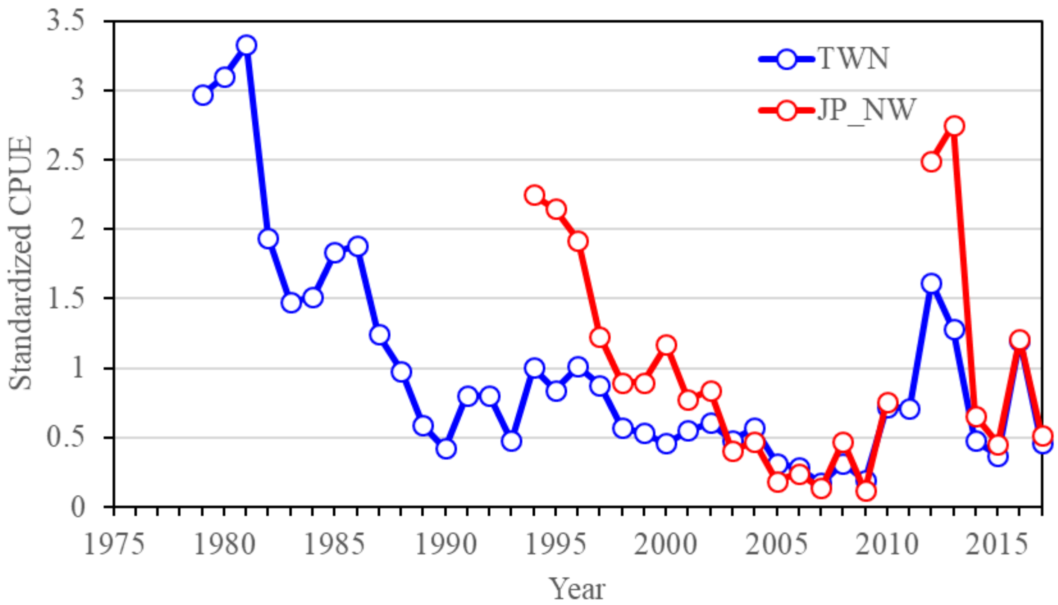


Fig. 2. Standardized CPUE series of striped marlin caught by Taiwanese and Japanese fleets in the Indian Ocean.

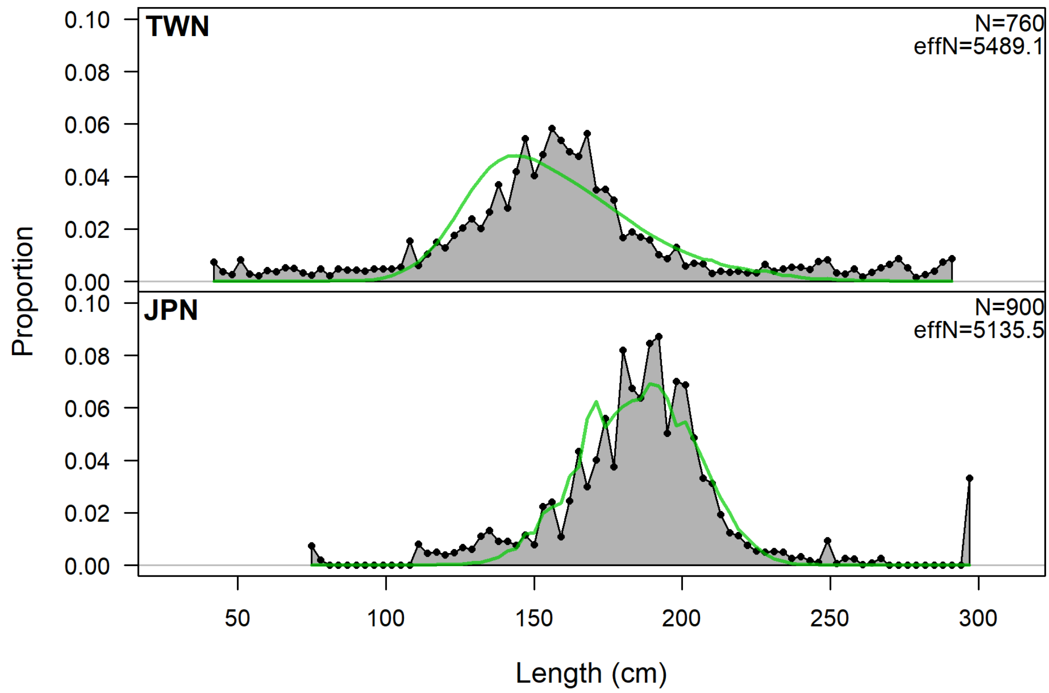


Fig. 3. Observed (histograms) and model-estimated (lines) length-frequency of striped marlin in the Indian Ocean shown by the data aggregated across years.

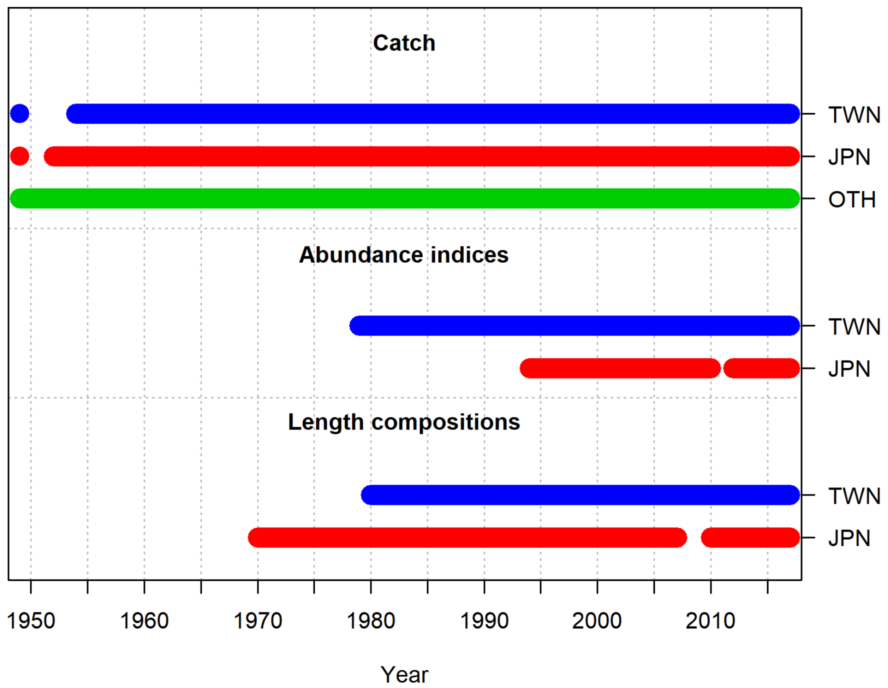


Fig. 4. Data presence by year for each fleet used in the stock assessment of striped marlin in the Indian Ocean.

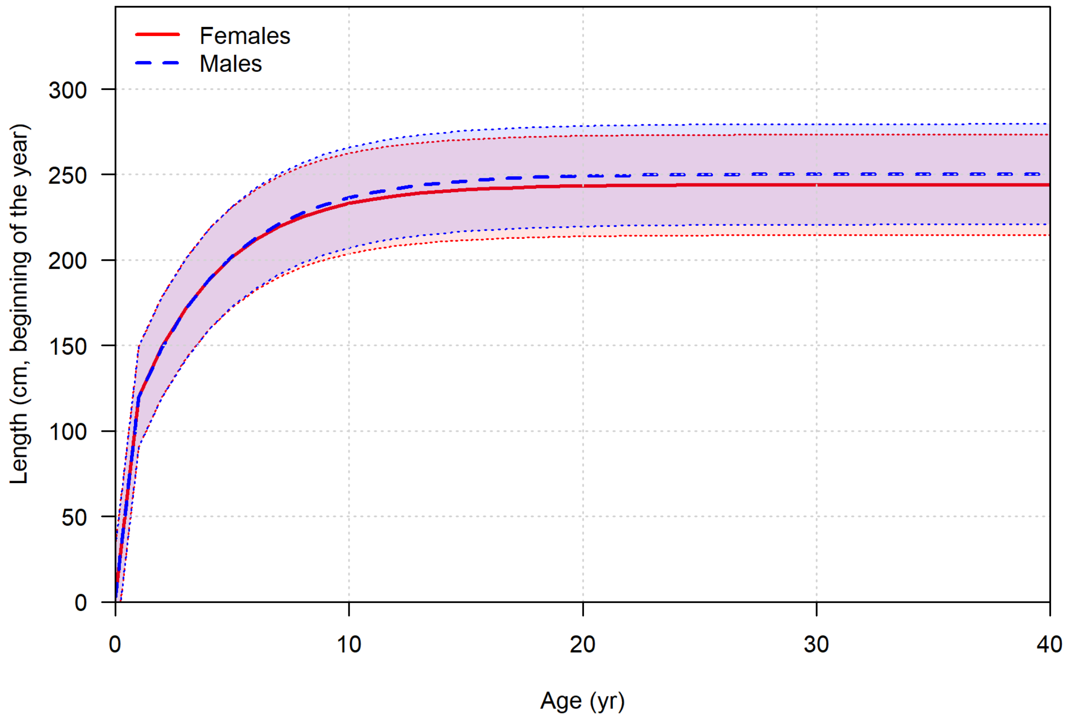


Fig. 5. Growth curves of striped marlin in the Indian Ocean obtained from ISC (2015).

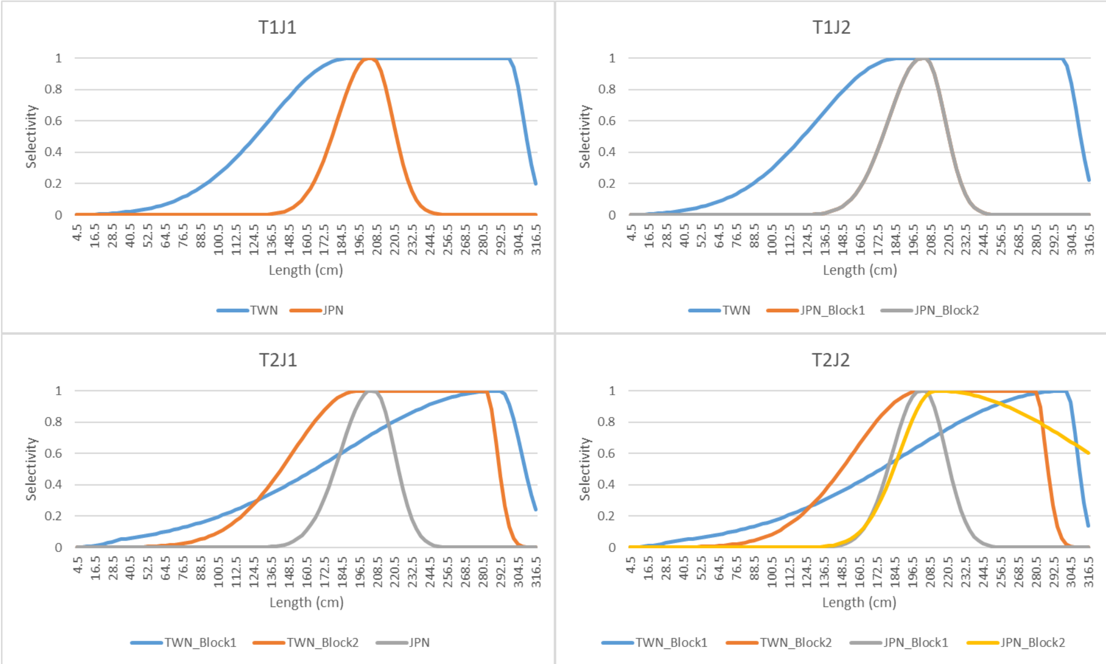


Fig. 6. Model-estimated selectivity for striped marlin in the Indian Ocean based on the basic scenarios.

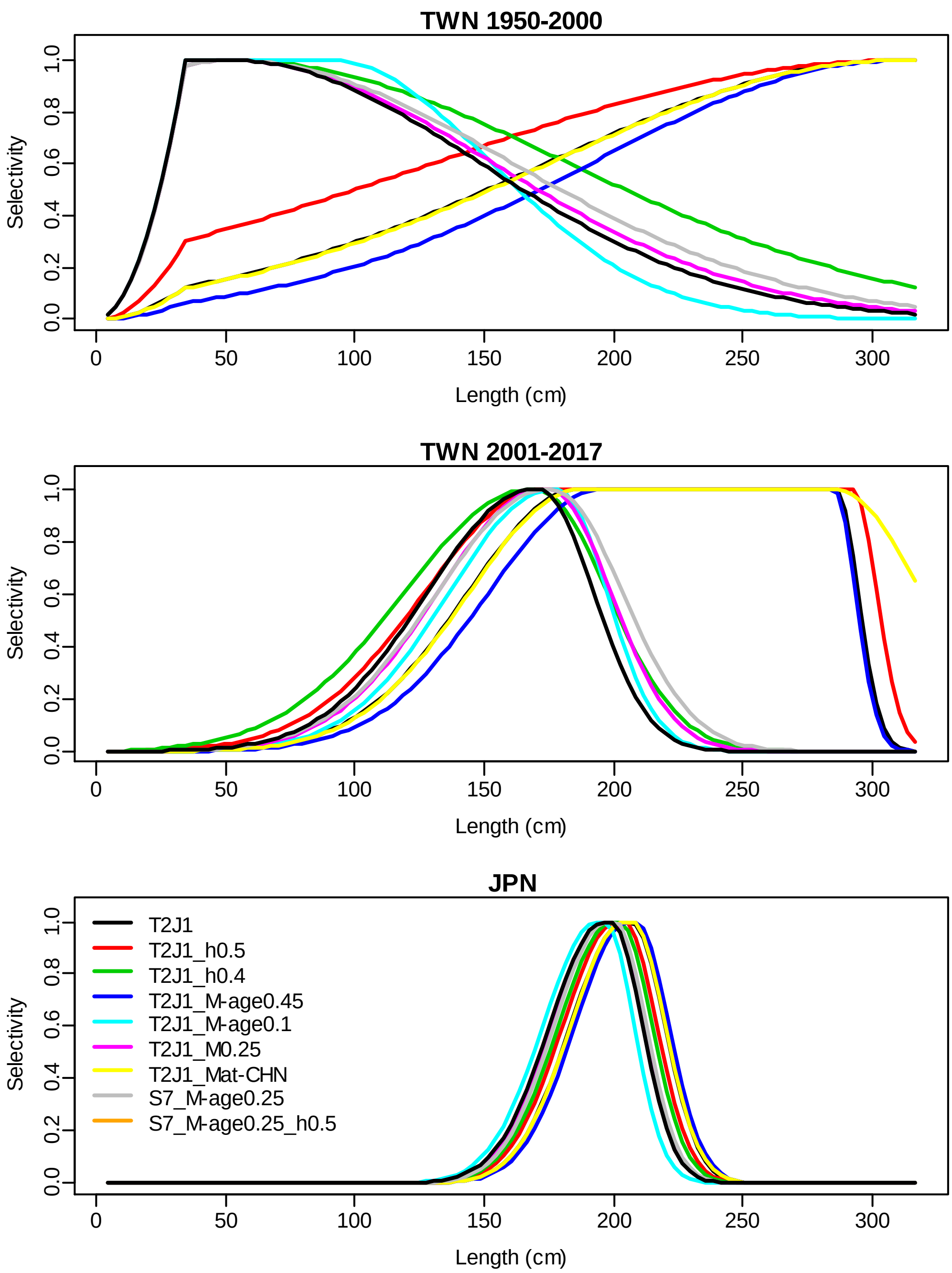


Fig. 7. Model-estimated selectivity for striped marlin in the Indian Ocean based on the scenarios suggested by WPB.

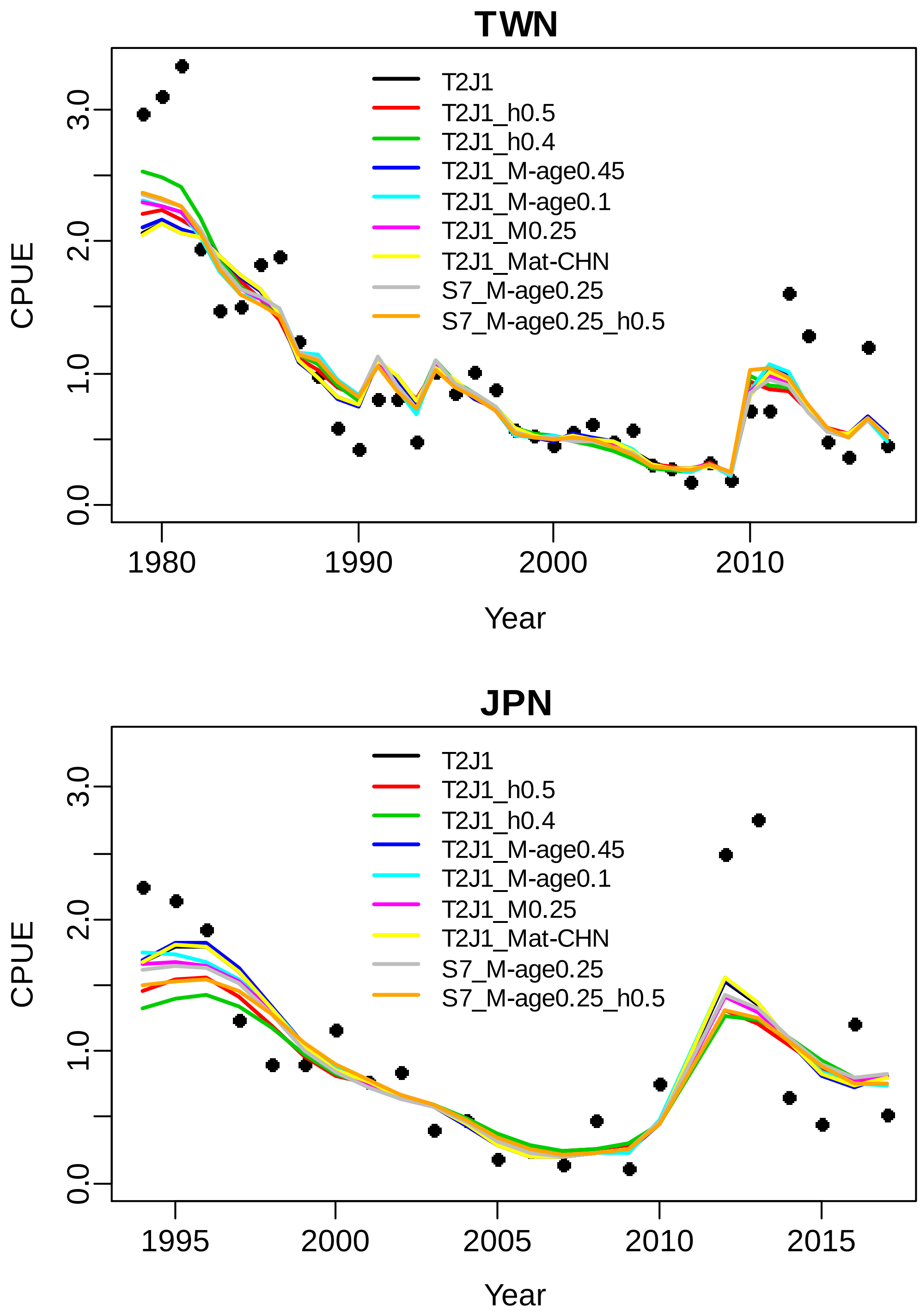


Fig. 8. Observed CPUE (dots) and model-estimated CPUE (lines) of striped marlin in the Indian Ocean based on the scenarios suggested by WPB.

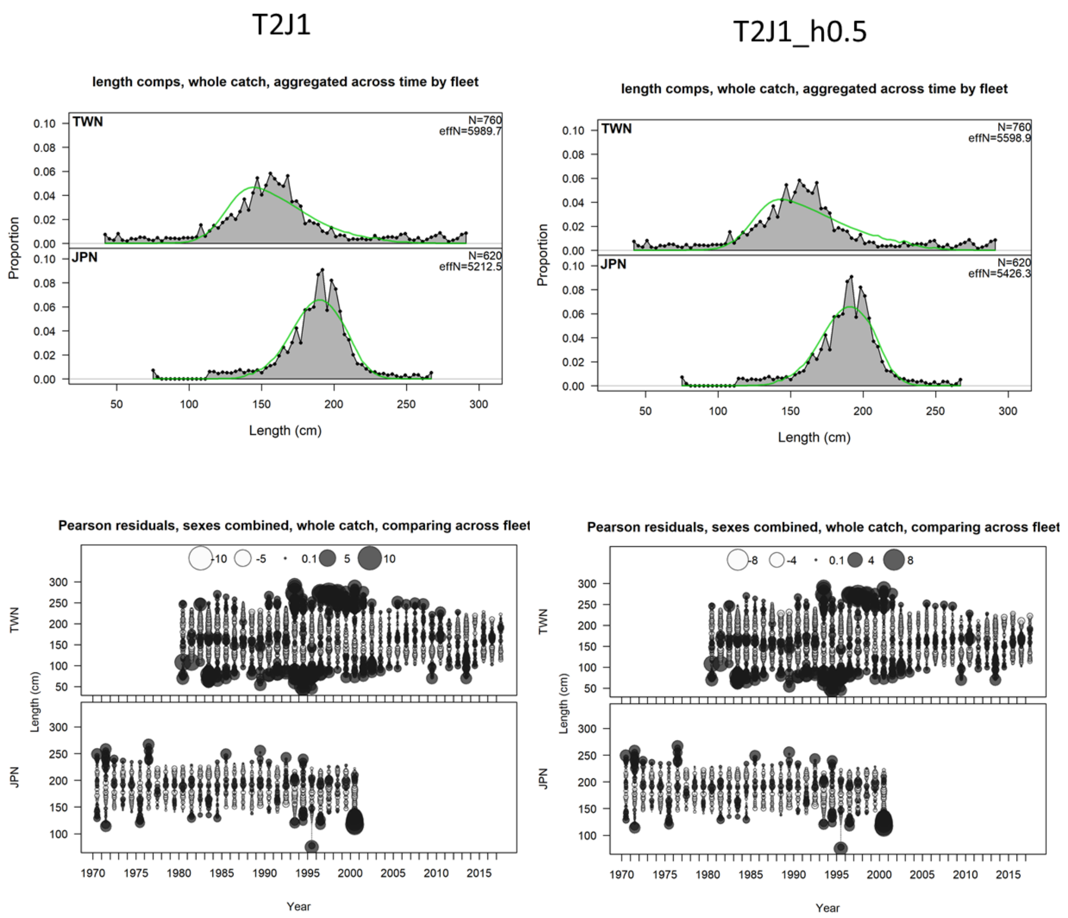


Fig. 9. Observed (histogram) and model-estimated length-frequency (lines) and Pearson residuals of the model fits to length-frequency data of striped marlin in the Indian Ocean based the scenarios suggested by WPB. Closed bubbles are positive residuals (observed > expected) and open bubbles are negative residuals (observed < expected).

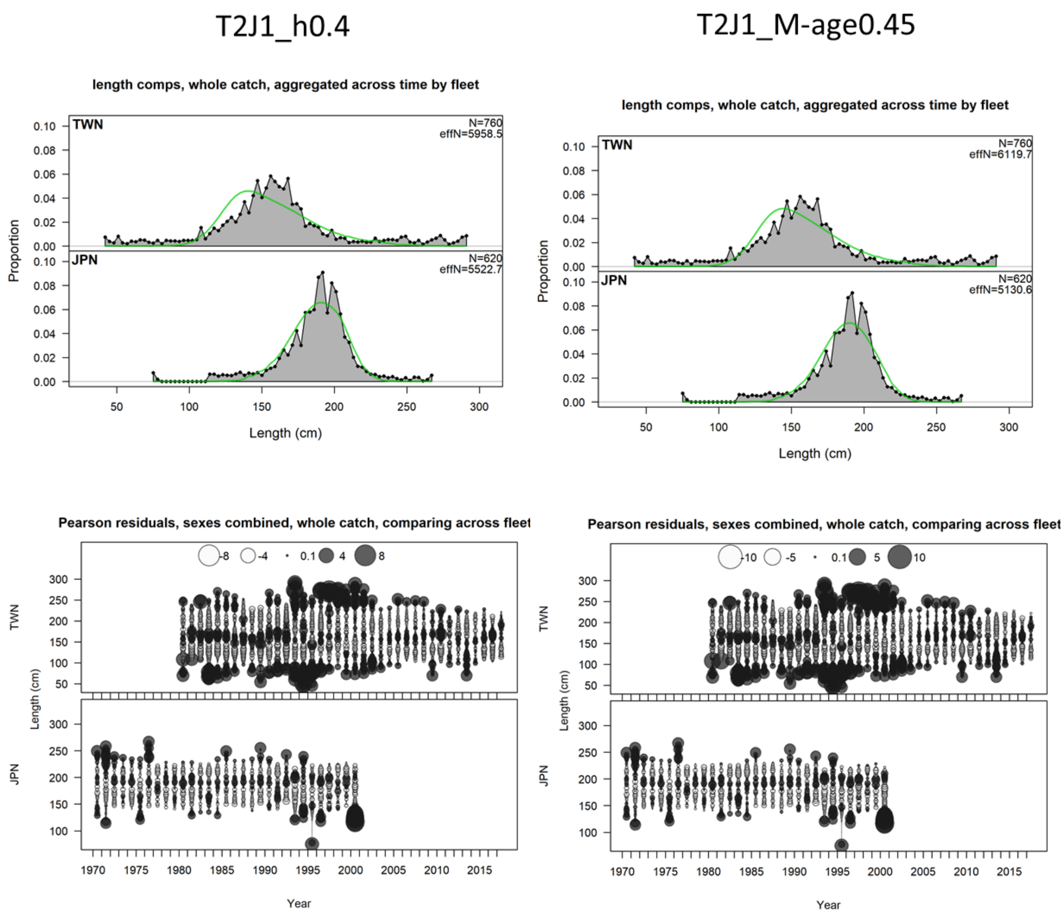


Fig. 9. (Continued).

T2J1_M-age0.1

T2J1_M0.25

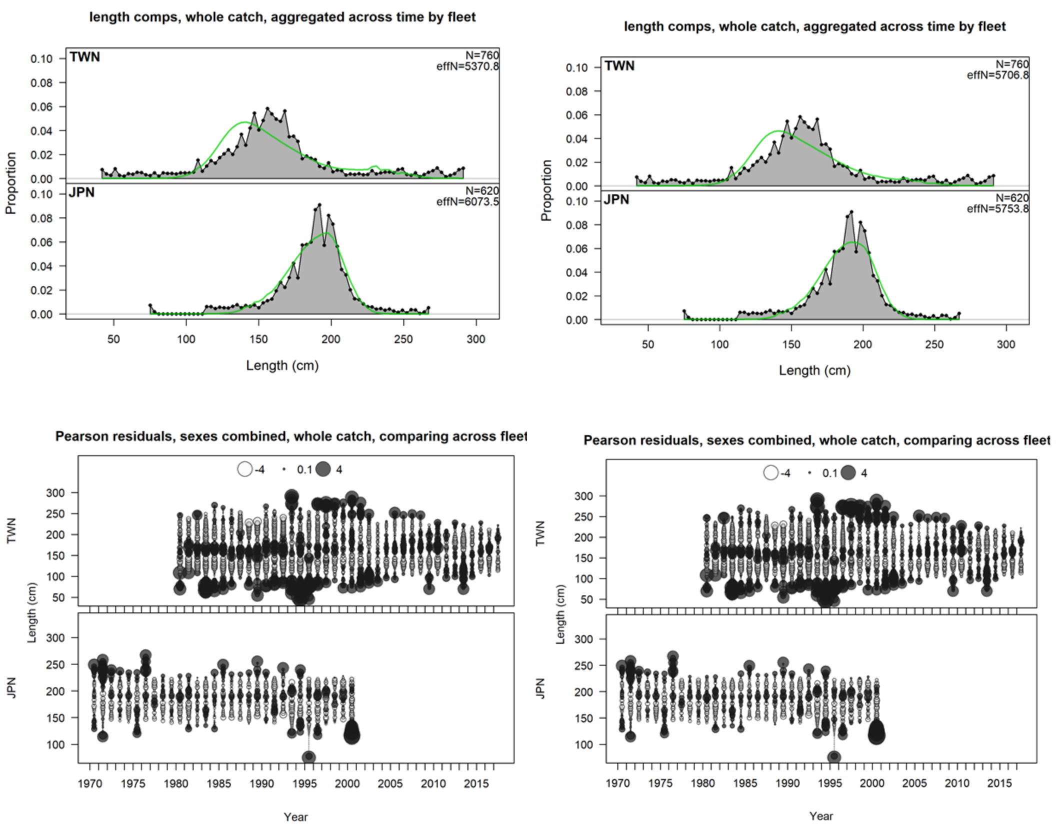
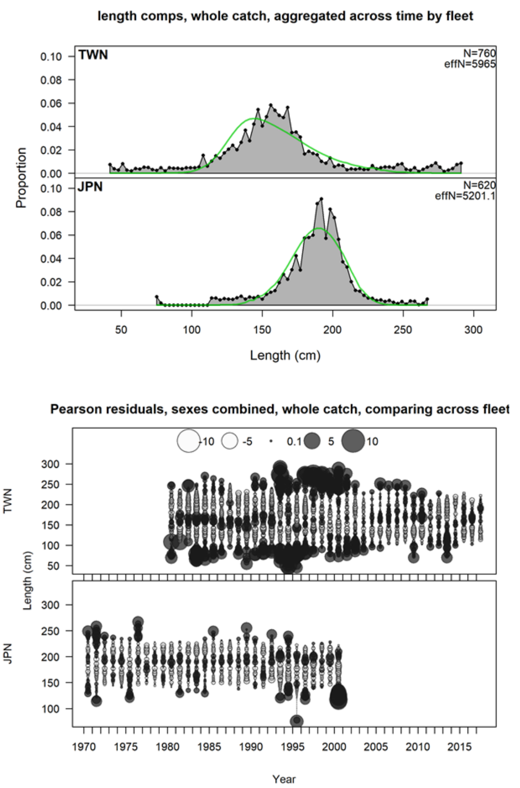


Fig. 9. (Continued).

T2J1_M-Mat-CHN



S7_M-age0.25

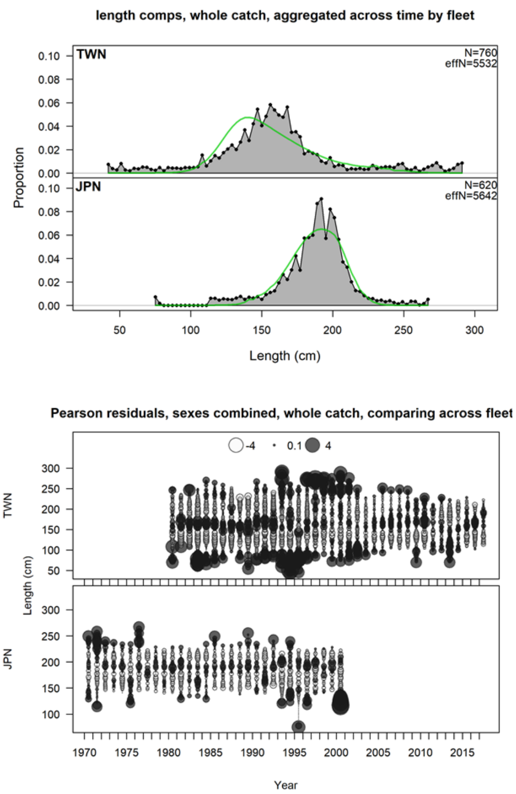
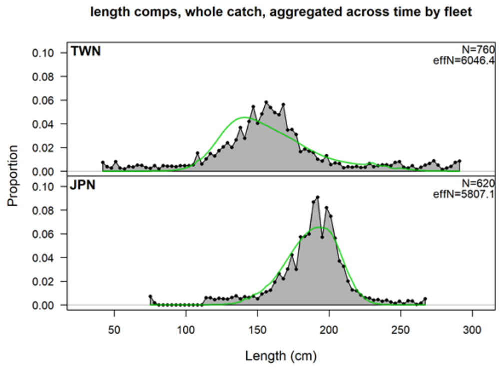


Fig. 9. (Continued).

S7_M-age0.25_h0.5



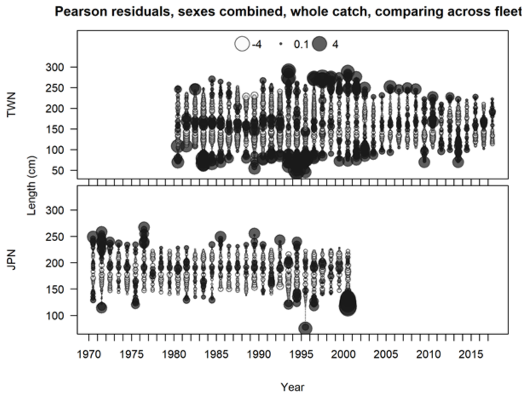


Fig. 9. (Continued).

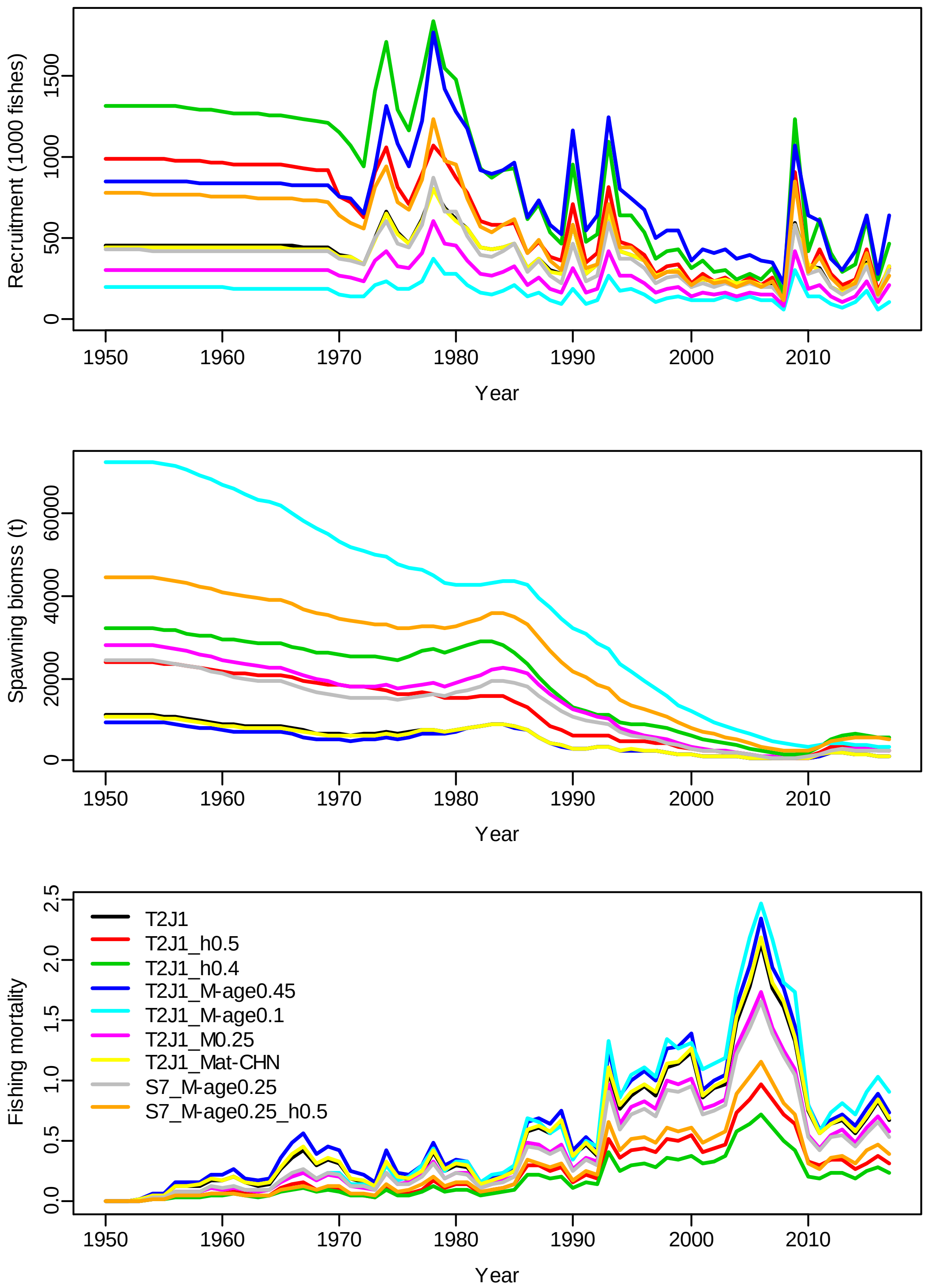


Fig. 10. Time trajectories of the model-estimated recruitment, spawning biomass and fishing mortality of striped marlin in the Indian Ocean based on the scenarios suggested by WPB.

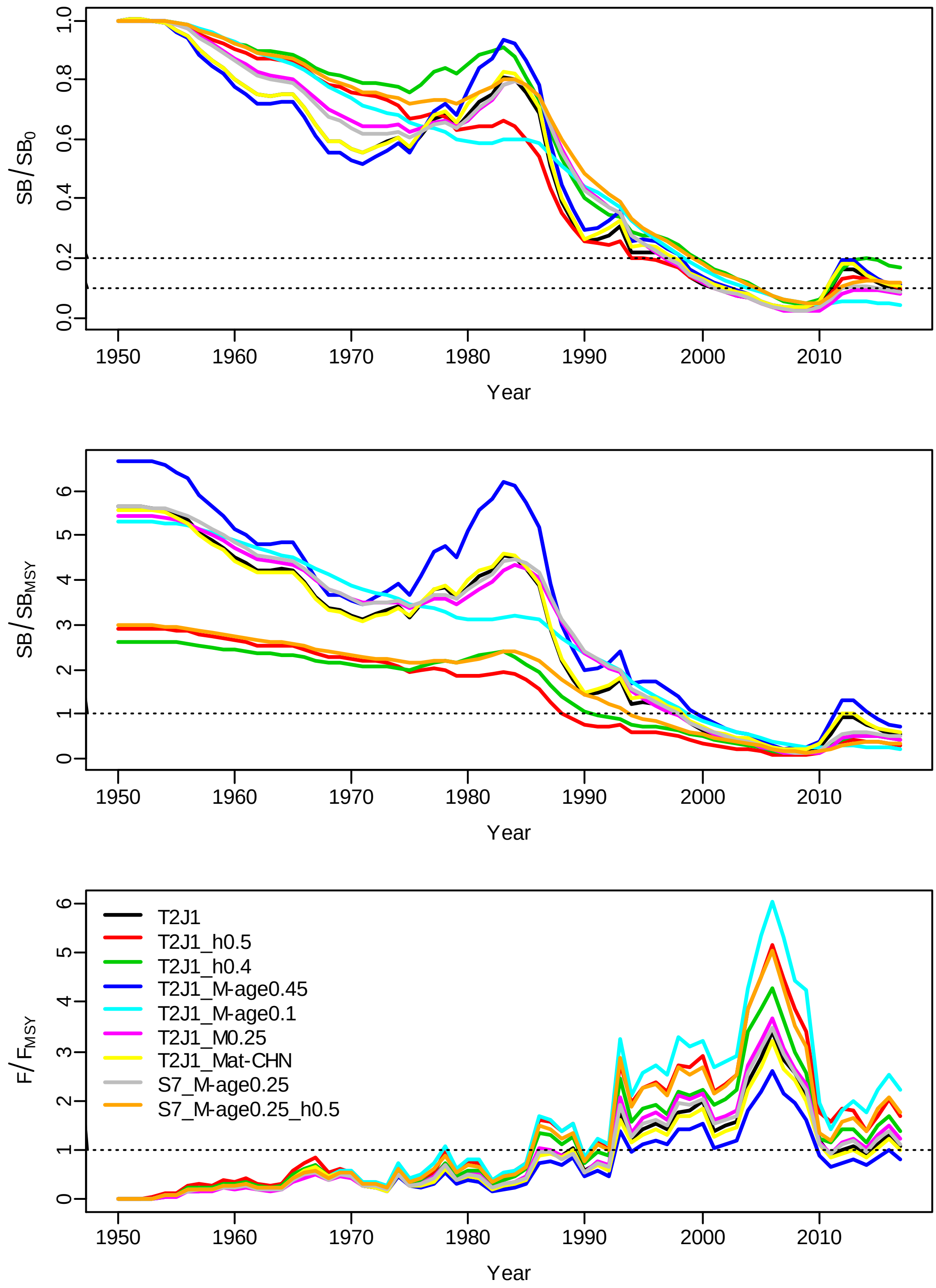


Fig. 11. Time trajectory of the model-estimated relative fishing mortality and spawning biomass of striped marlin in the Indian Ocean based on the scenarios suggested by WPB.

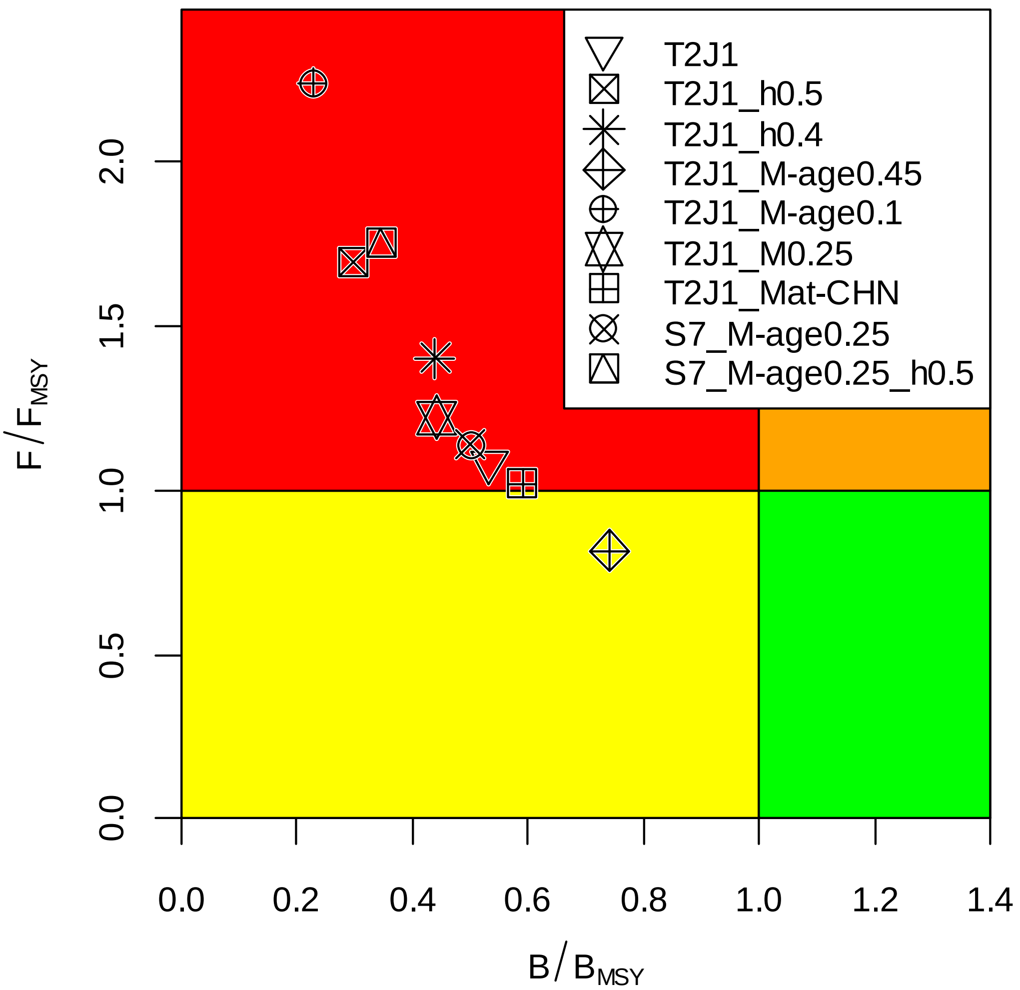


Fig. 12. Kobe plot for striped marlin in the Indian Ocean based on the estimates for 2017 based on the scenarios suggested by WPB.

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	4.68x10^{-6}	4.68x10^{-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. Scenarios suggested by WPB to be implemented for the stock assessment of striped marlin in the Indian Ocean.

Scenario	h	M	Note
T2J1	0.86	0.45	
T2J1_h0.5	0.50	0.45	
T2J1_h0.4	0.40	0.45	
T2J1_M-age0.45	0.86	Age-specific	Natural mortality Lorenzo parameterization (average 0.45)
T2J1_M-age0.1	0.86	Age-specific	Natural mortality Lorenzo parameterization (average 0.1)
T2J1_M0.25	0.86	0.25	
T2J1_Mat-CHN	0.86	0.45	New maturity estimates from the Indian Ocean
S7_M-age0.25	0.86	Age-specific	Natural mortality Lorenzo parameterization (average 0.25)
S7_M-age0.25_h0.5	0.50	Age-specific	Natural mortality Lorenzo parameterization (average 0.25)

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

	CPUE			Length-frequency				
Scenario	All	TWN	JPN	All	TWN	JPN	Catch	Total
T1J1	7.41	-16.32	23.74	515.52	222.94	292.59	0.93	498.21
T1J2	7.24	-17.72	24.96	507.24	219.75	287.48	0.79	491.39
T2J1	-2.18	-20.51	18.32	512.61	223.14	289.47	0.90	484.96
T2J2	-4.72	-22.39	17.67	510.14	225.74	284.41	0.95	479.62

Table 4. The value of negative log-likelihood for each data component for the stock assessment for striped marlin in the Indian Ocean based on the scenarios suggested by WPB.

	CPUE			Length			
Scenario	TWN	JPN	All	TWN	JPN	All	Catch
T2J1	-20.90	15.31	-5.58	219.25	79.55	298.79	0.62
T2J1_h0.5	-19.62	26.31	6.68	214.59	77.17	291.76	0.35
T2J1_h0.4	-22.31	32.23	9.92	210.88	77.24	288.12	0.17
T2J1_M-age0.45	-23.51	14.62	-8.89	220.70	80.51	301.21	0.56
T2J1_M-age0.1	-24.78	12.46	-12.33	216.02	73.24	289.26	0.41
T2J1_M0.25	-21.36	18.98	-2.37	208.86	74.19	283.05	0.42
T2J1_Mat-CHN	-20.91	14.96	-5.95	219.80	79.66	299.46	0.63
S7_M-age0.25	-21.83	19.78	-2.06	210.83	75.23	286.06	0.45
S7_M-age0.25_h0.5	-22.34	23.80	1.46	206.46	75.15	281.61	0.19

Table 5. The estimates of the quantities of management interests based on scenarios conducted for the stock assessment for striped marlin in the Indian Ocean based on the scenarios suggested by WPB (Recruitment, R: number; spawning biomass, SB: metric ton).

Scenario	$R0$	SB_0	SB_{2017}	F_{2017}	MSY	F_{MSY}	SB_{MSY}	F_{2017}/F_{MSY}	SB_{2017}/SB_{MSY}	SB_{2017}/SB_0
T2J1	457	11107	1049	0.681	5247	0.626	1970	1.087	0.533	0.094
T2J1_h0.5	989	24053	2441	0.322	5724	0.190	8214	1.694	0.297	0.101
T2J1_h0.4	1320	32104	5358	0.237	5073	0.169	12215	1.403	0.439	0.167
T2J1_M-age0.45	848	9379	1043	0.734	5447	0.898	1407	0.817	0.741	0.111
T2J1_M-age0.1	191	72621	3127	0.919	4195	0.410	13714	2.243	0.228	0.043
T2J1_M0.25	304	28177	2297	0.580	5153	0.474	5188	1.223	0.443	0.082
T2J1_Mat-CHN	442	10586	1122	0.698	5193	0.683	1901	1.021	0.590	0.106
S7_M-age0.25	424	24412	2173	0.538	5143	0.473	4336	1.138	0.501	0.089
S7_M-age0.25_h0.5	774	44597	5186	0.404	4564	0.230	14973	1.755	0.346	0.116

Table 6. The estimates of key quantities of management interests for striped marlin in the Indian Ocean (Scenario "S7_M-age0.25_h0.5").

Management Quantity	**Aggregate Indian Ocean**
2017 catch estimate	3,094
Mean catch from 2013–2017	3,587
MSY (1000 t) (80% CI)	4.564 (4.289, 4.839)
Data period (catch)	1950–2017
F_{MSY} (80% CI)	0.230 (0.214, 0.247)
SB_{MSY} (1,000 t) (80% CI)	14.973 (14.152, 15.788)
F_{2017}/F_{MSY} (80% CI)	1.755 (1.397, 2.112)
SB_{2017}/SB_{MSY} (80% CI)	0.346 (0.265, 0.437)
SB_{2017}/SB_{1950} (80% CI)	0.116 (0.090, 0.142)