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 applied to conduct the stock assessment for striped marlin in the Indian Ocean. The analyses were performed by updating the historical catch, standardized CPUE series and length-frequency data, while life-history parameters and model assumptions remained the same with the scenario for the previous stock assessment adopted in 2018. The results indicated that the current spawning biomass was lower than the MSY level and the fishing mortality was higher than the MSY level. In addition, the current stock status might be more pessimistic than that obtained from the previous stock assessment in 2018.

1. INTRODUCTION

Striped marlin is largely considered to be a non-target species of industrial fisheries. In the recent years, gillnets account for around 50% of total catches in the Indian Ocean, followed by longlines (40%), with remaining catches recorded under troll and handlines. The catches were mainly made by Iran (gillnet, 25%), Taiwan (longline, 20%), Indonesia (longline, 18%), and Pakistan (gillnet, 12%). Catch trends are variable, ranging from 2,000 t to 8,000 t per year, which may reflect the level of reporting and the status of striped marlin as a non-target species. Since 2012, catches of striped marlin have fluctuated between 3,000 t to 5,000 t (IOTC, 2020).

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 were determined to be overfished and subject to overfishing (IOTC, 2013; 2015; 2017; 2018).

Since historical length-frequency data were available for striped marlin in the Indian Ocean and some of life-history parameters could be referred to the information of 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 et al., 2021).

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 fleets. In this year, however, Taiwanese and Japanese CPUE series were only available to be used for conducting the stock assessment. In addition, the length-frequency data were very sparse for most fleets, except for Taiwan and Japan. Therefore, the fleets operating 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 nominal catches (IOTC-2021-WPB19-DATA03-NC) and length-frequency data (IOTC-2021-WPB19-DATA09-SFBIL) were used in this study.

Fig. 1 shows the trends of catches for three fleets. The total catch roughly revealed an increasing trend before the late 1980s, substantially decreased during 1990-1992, reached a peak again and then gradually decreased until the late 2000s. Since the mid-1980s, the catches obviously increased and mainly contributed from OTH fleet.

The standardized CPUE data were available from Taiwan for the periods of 1979-2019 and 2005-2019 and from Japan for the periods of 1979-1993 and 1994-2019 (Taki et al., 2021; Xu, 2021). As the use of the previous assessment in 2018, the area-specific CPUE series of Taiwanese fleet were aggregated into single series using catches as weightings, and the Japanese standardized CPUE series in area NW during 1994-2019 were only used. CPUE series of Taiwanese and Japanese fleets reveal similar trends since the early 2000s (Fig. 2).

The length-frequency 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). However, the sample size for the Japanese length data was very low in recent years and WPB agreed to drop the Japanese length frequency data after 2000 (IOTC, 2018; Wang, 2018).

Fig. 4 shows the data by year for each fleet used in the stock assessment for 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., were not available for striped marlin in the Indian Ocean. In this study, life-history parameters remained the same with the scenario ("S7_M-age0.25_h0.5") for the previous stock assessment adopted in 2018 (IOTC, 2018). The estimates of maturity were from Zhou et al. (2018) for striped marlin in the Indian Ocean. The growth parameters were referred to the used in stock assessment for striped marlin in the Western and Central North Pacific Ocean (see ISC, 2015 for details, Table 1).

2.4 Model structure and assumption

Stock Synthesis (SS) version 3.30.17 (Methot et al., 2021) was used in this study. Equal weightings were assigned to all data components. In this study, model assumptions also remained the same with the scenario ("S7_M-age0.25_h0.5"; IOTC, 2018; Wang, 2018) as following descriptions.

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 period of assessment model was from 1950 to 2019 along with 10-years projection. Sex ratio of female was assumed to be 0.5.

Sex- and age-specific Natural mortality with Lorenzo parameterization (average 0.25) was used for both female and male (Fig. 5). Recruitment was estimated as deviates from the standard Beverton-Holt stock recruitment relationship and was assumed to follow a lognormal distributed deviate with zero mean and standard deviation. The parameter of the stock-recruitment relationship (steepness, *h*), which represented the productivity of the fish, was assumed to be 0.5. 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 1970-2018 in the model and deviates for other years were fixed at zero.

Based on ISC (2015), the growth of striped marlin seems not to be sexually dimorphic (Fig. 6). 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.

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 as TWN because of the lack of length-frequency data for this fleet. Because obvious difference in mean size was observed before and after 2000, time-varied selectivity (time blocks of 1950-2000 and 2001-2019 for Taiwanese longline) was used for TWN.

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 Diagnostics and retrospective analysis

The residual diagnostics of the model fits to the data and the retrospective analysis were using the functions of R package "ss3diags" (Carvalho et al., 2021). In addition, the package was also implemented based on a delta-multivariate lognormal approximation to generate joint error distributions for the relative spawning biomass and fishing mortality to the reference point MSY. The retrospective analysis was conducted by sequentially removing the observed data for the last 5 years.

2.6 Scenario

Based on the life-historical parameters and assumption and structure of the model, various scenarios were also created to examine the model estimated stock status when different input data were used.

0. Data_2018: The catches, CPUE and length-frequency adopted in the previous assessment were used to rerun the model using the new version of SS.
1. Ref: Taiwanese CPUE of 1979-2019 and Japanese CPUE of 1994-2019 were used.
2. TWN_CPUE2005: CPUE of 2005-2019 and Japanese CPUE of 1994-2019 were used.

3. RESULTS AND DISCUSSIONS

3.1. Model fits and diagnostics

Generally, the models can well fit the trends of TWN and JPN CPUE series under three scenarios (Fig. 7). However, the relatively poor model fits for the length-frequency data for TWN before the early 2000s, when more small and large fishes were caught but the models cannot well fit the distribution patterns (Fig. 8). The run test and joint residual plots obtained from both scenarios “Ref” and “TWN_CPUE2005 indicated there was no evidence ($p \geq 0.05$) to reject the hypothesis of randomly distributed residuals for both TWN and JPN CPUE series and length-frequency data, while RMSE revealed relatively low precisions for the models fit to CPUE series (RMSE > 30 %). (Figs. 9 and 10; Winker et al., 2018).

3.2. Model estimates

The estimated selectivity obtained from the model indicated that TWN tended to select smaller fishes with a wider range of body length than JPN and time-varying selectivity of TWN indicated TWN tend to select much more small fishes before 2000 (Fig.11).

Time trajectories of the model-estimated recruitment, spawning biomass and fishing mortality revealed similar trends for both scenarios “Ref” and “TWN_CPUE2005” (Fig. 12). The recruitment and spawning biomass obviously declined from the mid-1980s to 2010 because of a substantial increase in catches. The spawning biomass slightly increased from the late 2000s to the early 2010s and this might be resulted from the strong recruitment and reducing in fishing mortality after the late 2000s. In recent years, however, the recruitment and spawning biomass revealed a continuous decreasing trends since fishing mortality substantially increased again.

Time trajectories of the relative fishing mortality and relative spawning biomass indicated that the current spawning biomass was than its MSY level and less 10% of its unfished level since the early 2000s, while the fishing mortality also exceed the MSY level since about the mid-1980s (Fig. 13). Kobe plot revealed that the stock status of striped marlin in the Indian Ocean was subject to be overfished and overfishing (Fig. 14). The estimates of key quantities of management interests obtained from the scenario “Ref” in Table 2.

3.2. Retrospective analysis

The results of the retrospective analysis indicated that removing recent data has less influence on the historical and recent estimates of the spawning biomass for both scenarios “Ref” and “TWN_CPUE2005” (Fig. 15). Although consistently positive retrospective biases were observed for the estimates of both spawning biomass and fishing mortality but the small values of Mohn's ρ were falling well within the acceptable ranges (0.01-0.08), except for the estimates of spawning biomass from scenario "TWN_CPUE2005" (Mohn's ρ = 0.18).

3.3. Hindcast Cross-Validation and prediction skill

Hindcasting cross-validation results from CPUE and mean lengths were shown in Fig. 16. The mean absolute scaled error (MASE) scores < 1 indicated that both scenarios "Ref" and "TWN_CPUE2005" had an appropriate prediction skill for all CPUE and length-frequency data. Little difference in MASE was observed between TWN and JPN CPUE series. Only TWN length-frequency data were analyzed because JPN length-frequency data after 2000 were not used in this study.

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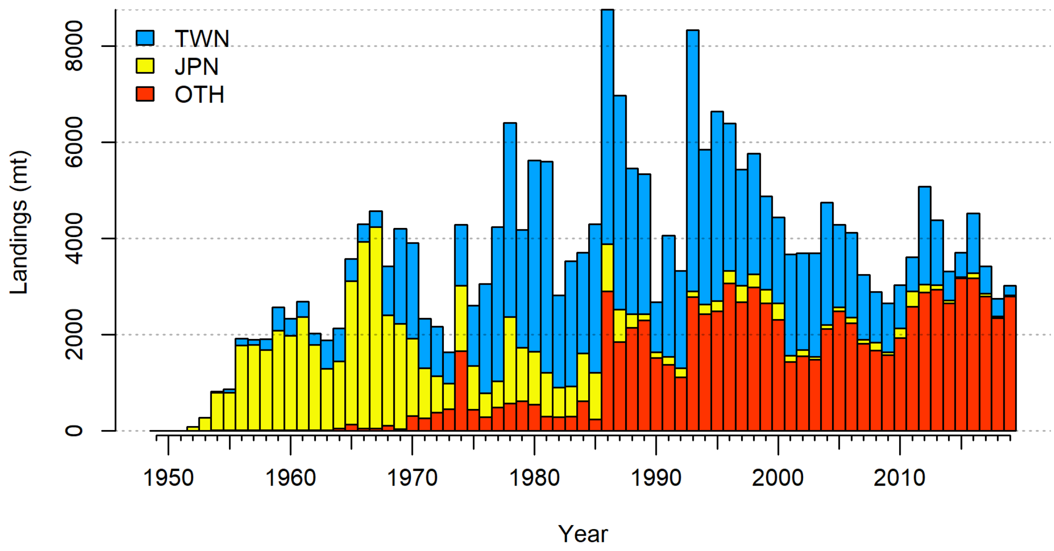


Fig. 1. Annual catches of striped marlin in the Indian Ocean.

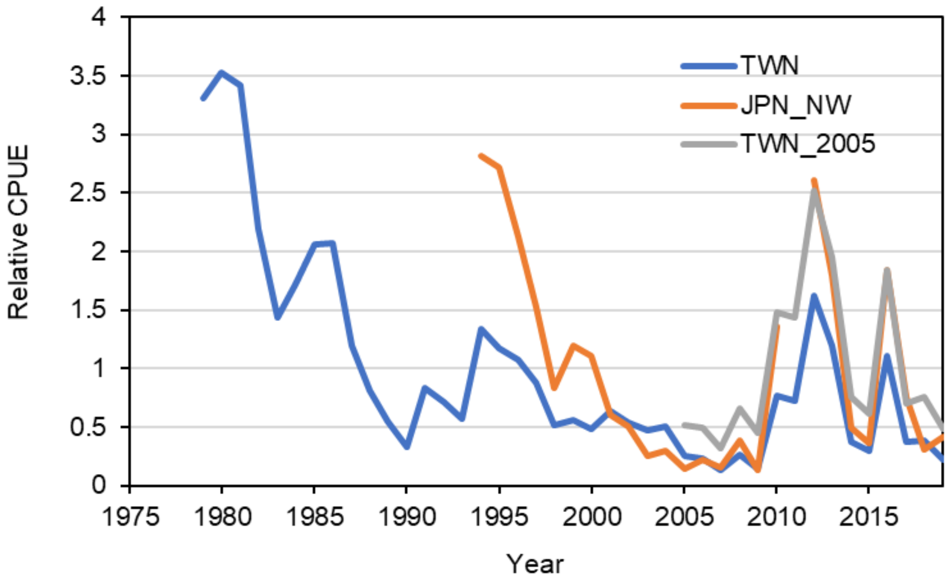


Fig. 2. Standardized CPUE series of striped marlin caught by Taiwanese and Japanese fleets in the Indian Ocean.

TWN

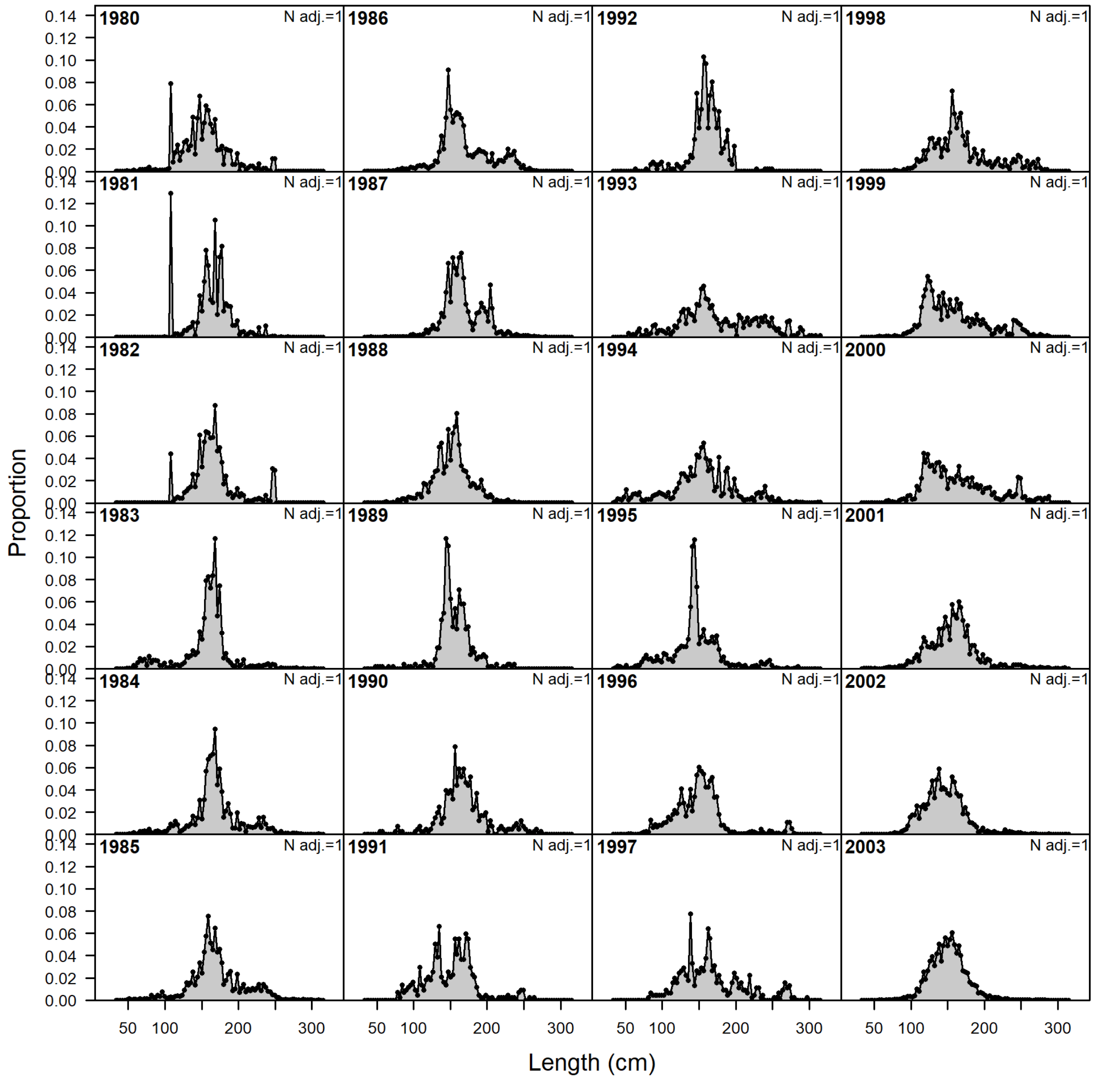


Fig. 3. Observed length-frequency of striped marlin in the Indian Ocean.

TWN

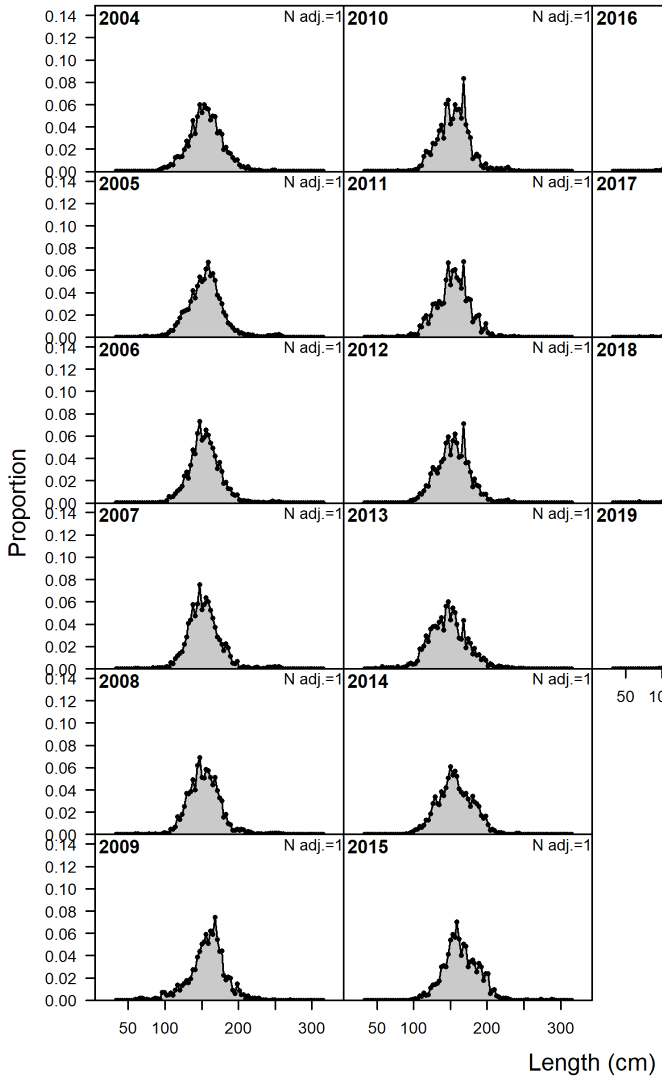


Fig. 3. (continued).

JPN

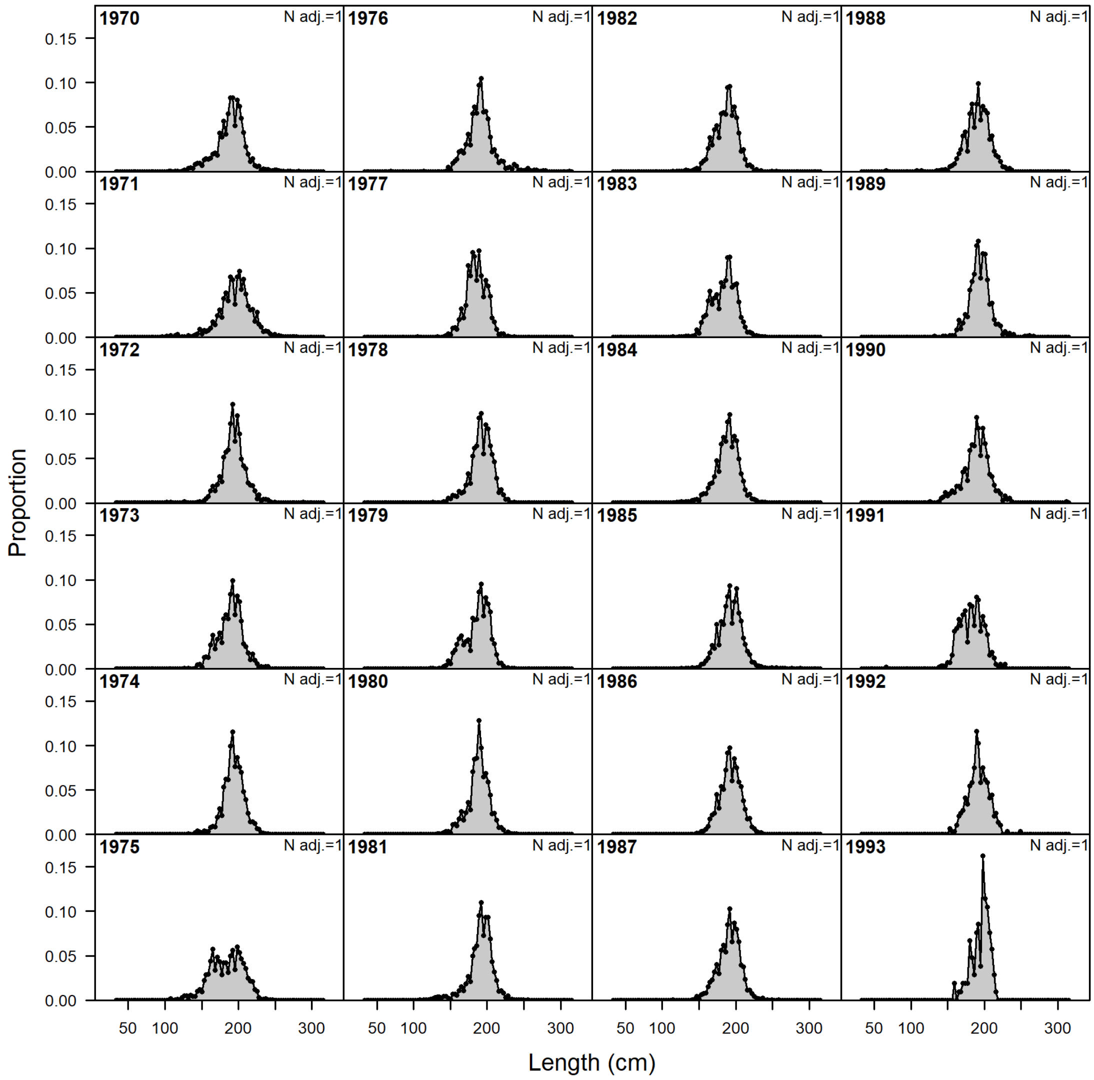


Fig. 3. (continued).

JPN

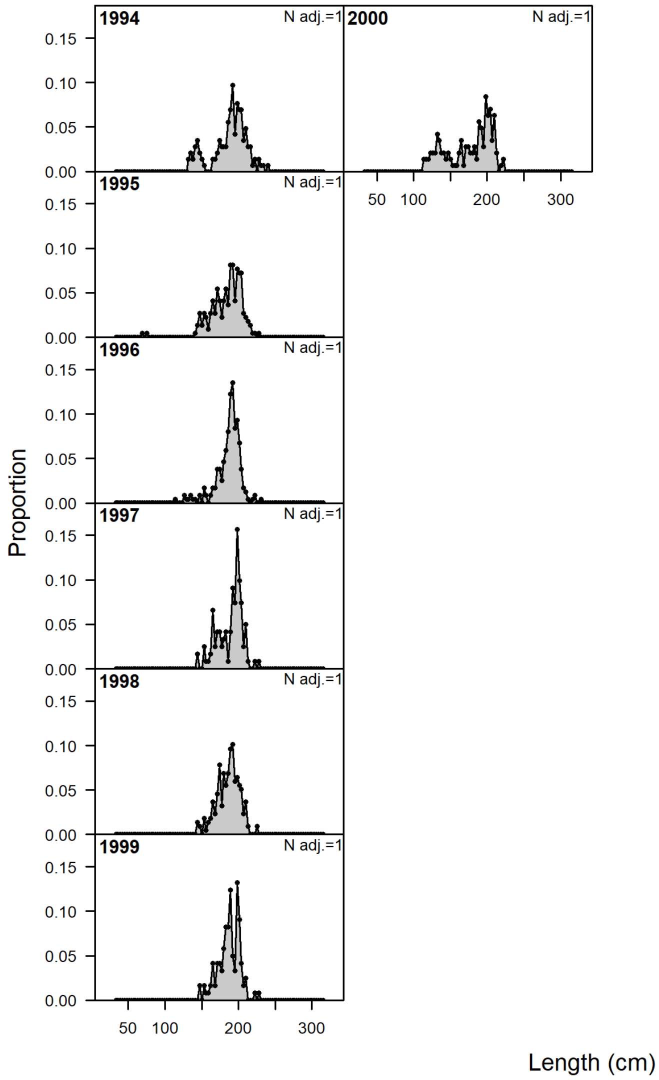


Fig. 3. (Continued).

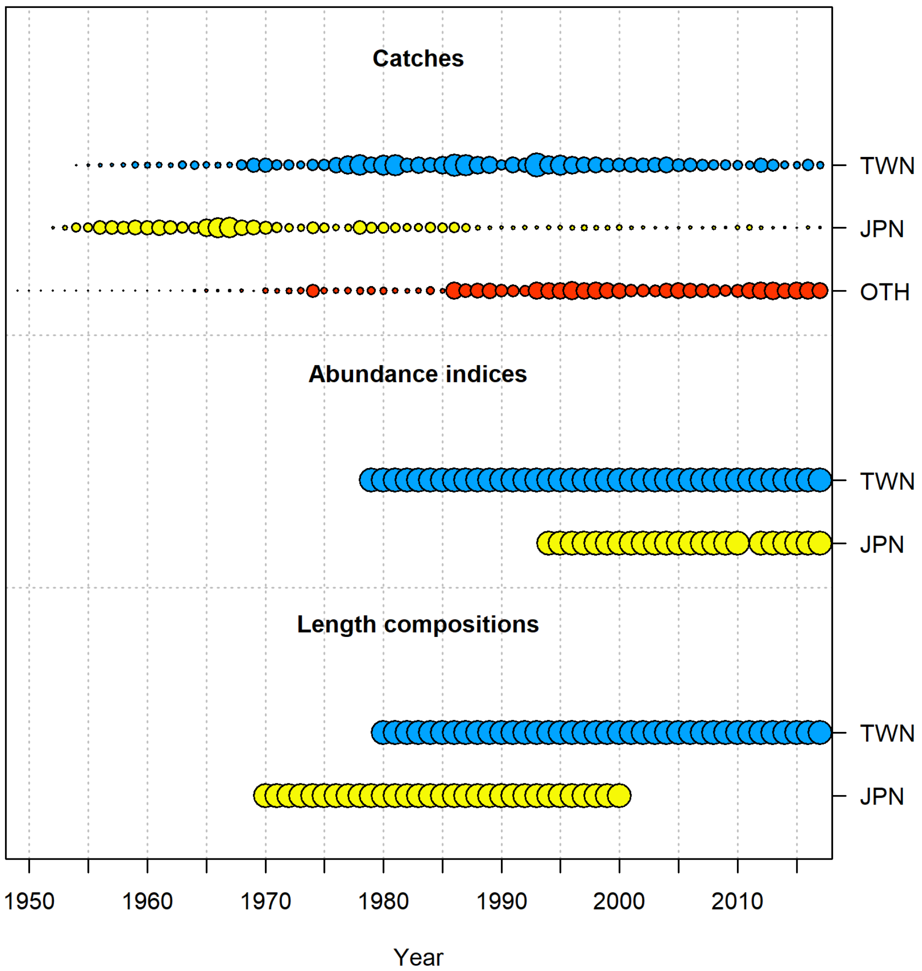


Fig. 4. Data presence by year for each fleet used in the stock assessment of striped marlin in the Indian Ocean.

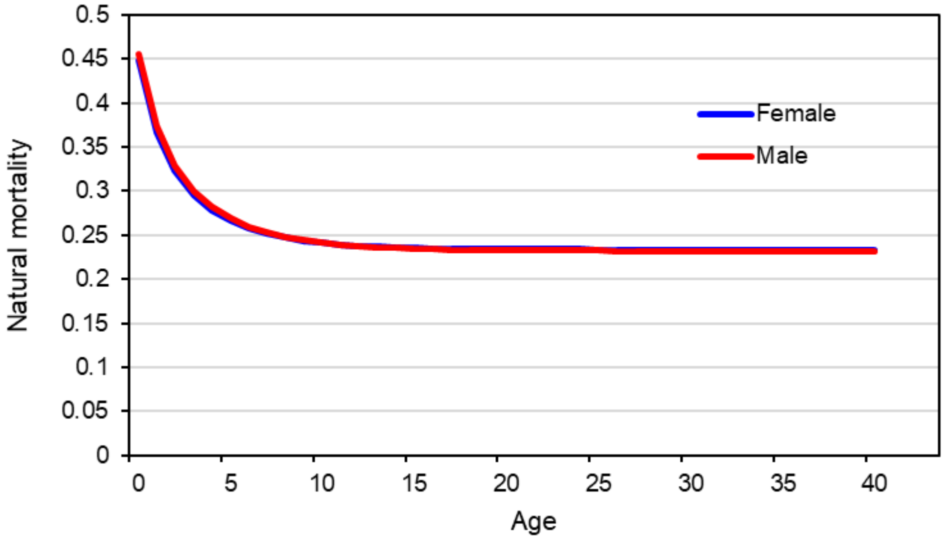


Fig. 5. Age-specific natural mortality for striped marlin in the Indian Ocean.

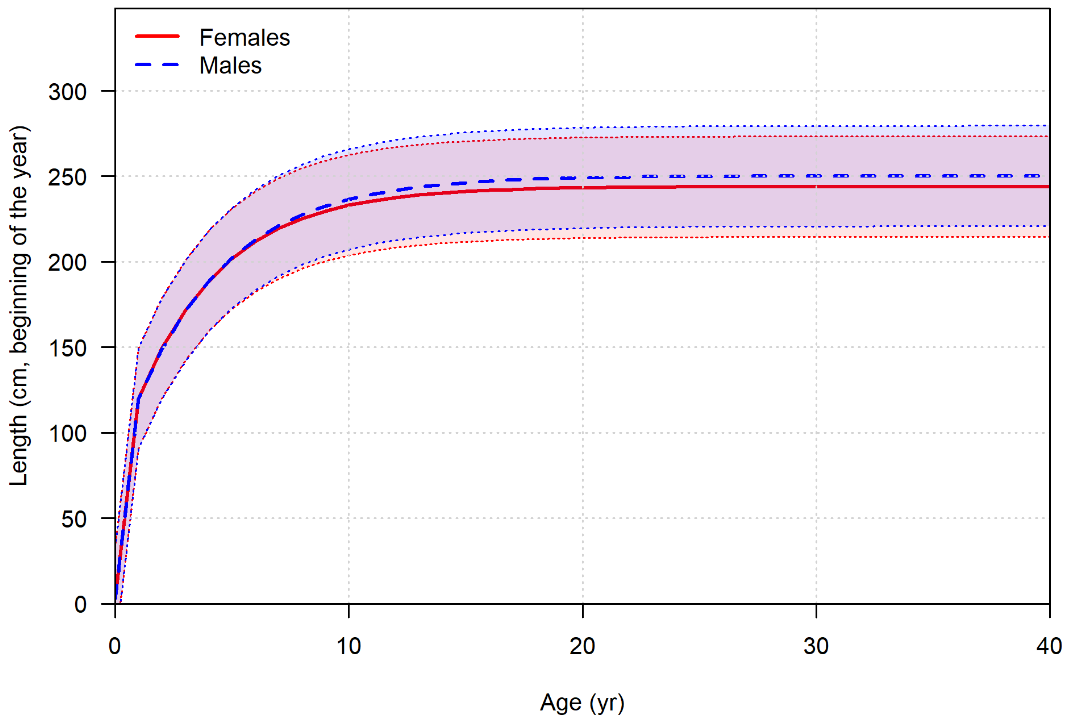
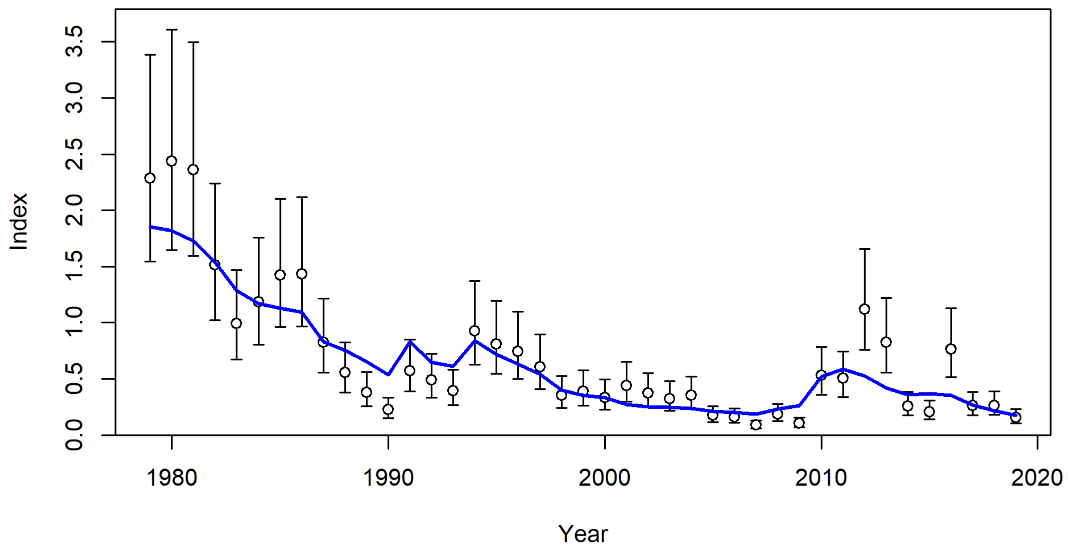


Fig. 6. Growth curves of striped marlin in the Indian Ocean obtained from ISC (2015).

Scenario “Ref”

TWN



JPN

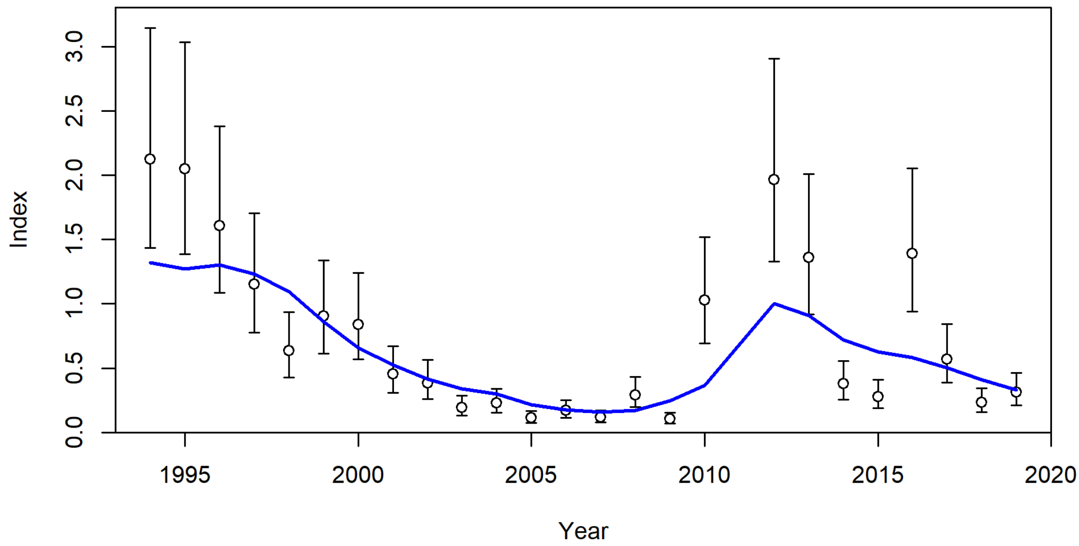
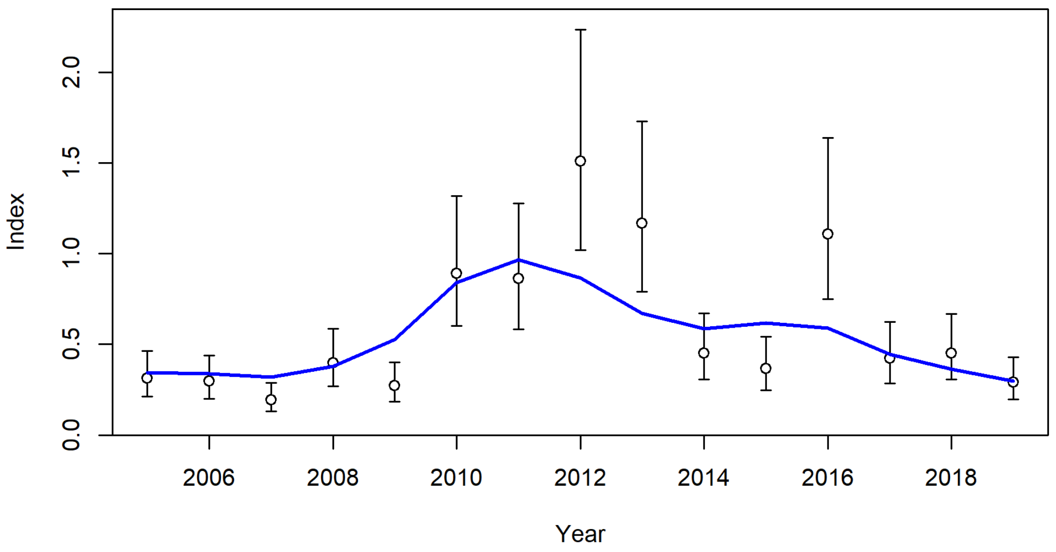


Fig. 8. Observed CPUE (dots) and model-estimated CPUE (lines) of striped marlin in the Indian Ocean.

Scenario "TWN_CPUE2005"
TWN



JPN

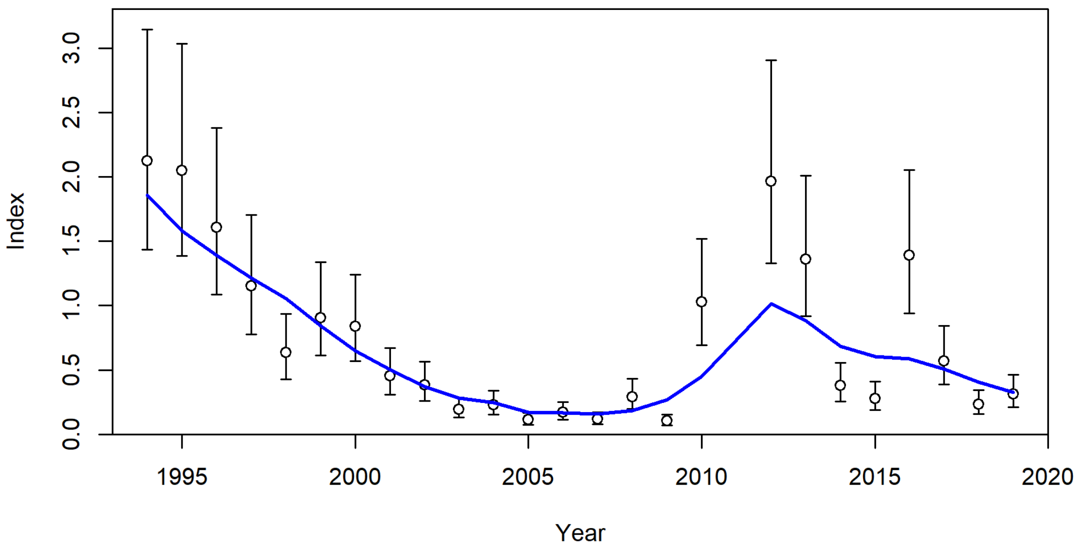


Fig. 7. (Continued).

Scenario "Ref"

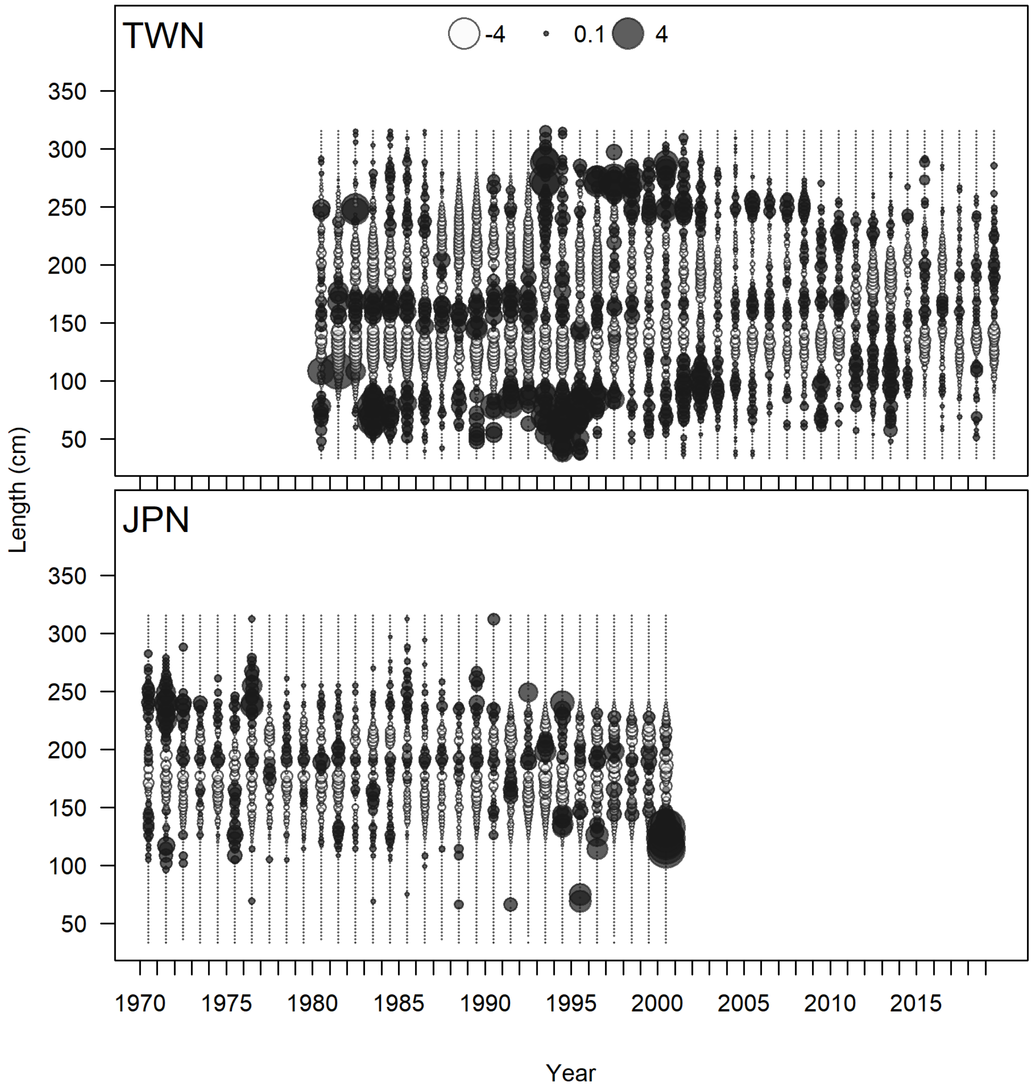


Fig. 8. Pearson residuals of the model fits to length-frequency data of striped marlin in the Indian Ocean. Closed bubbles are positive residuals (observed > expected) and open bubbles are negative residuals (observed < expected).

Scenario “TWN_CPUE2005”

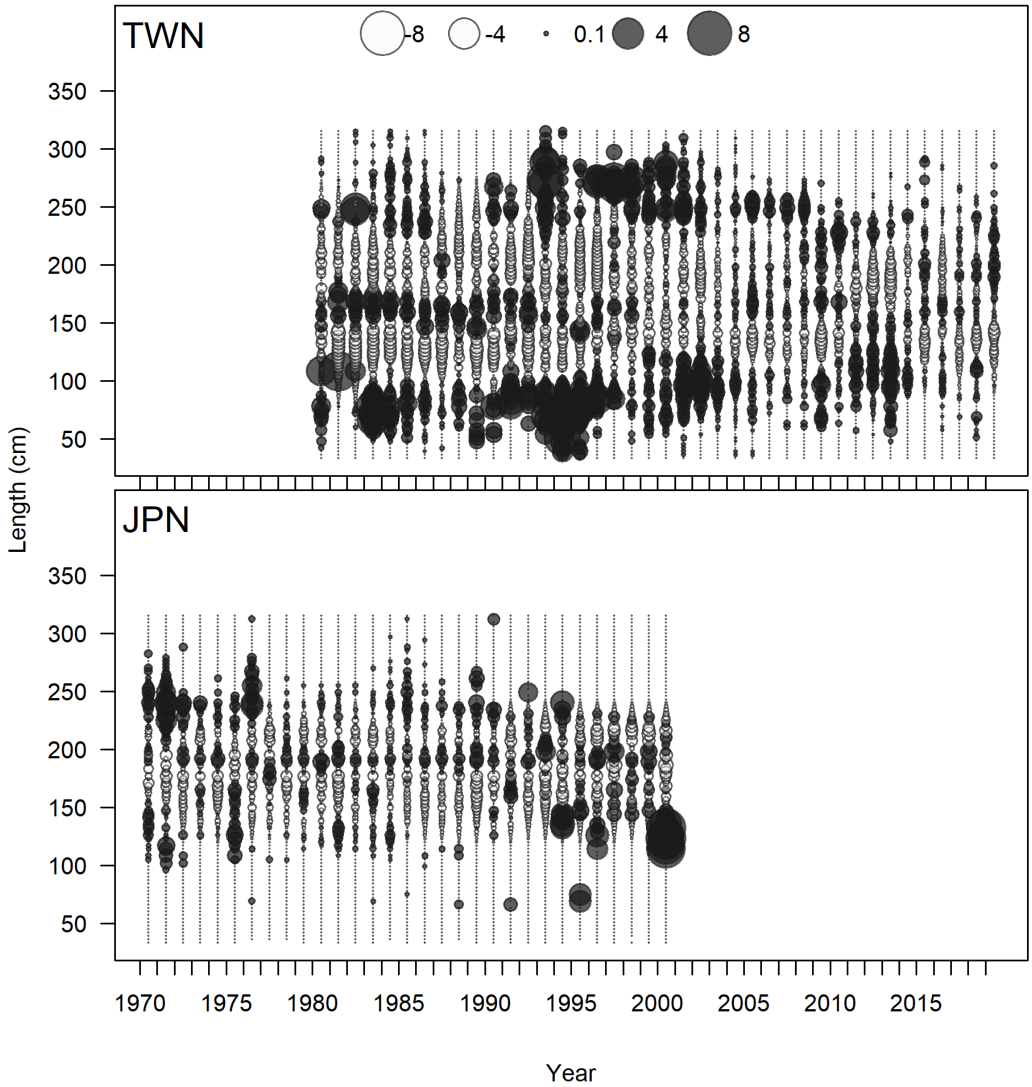


Fig. 8. (Continued).

Scenario “Ref”

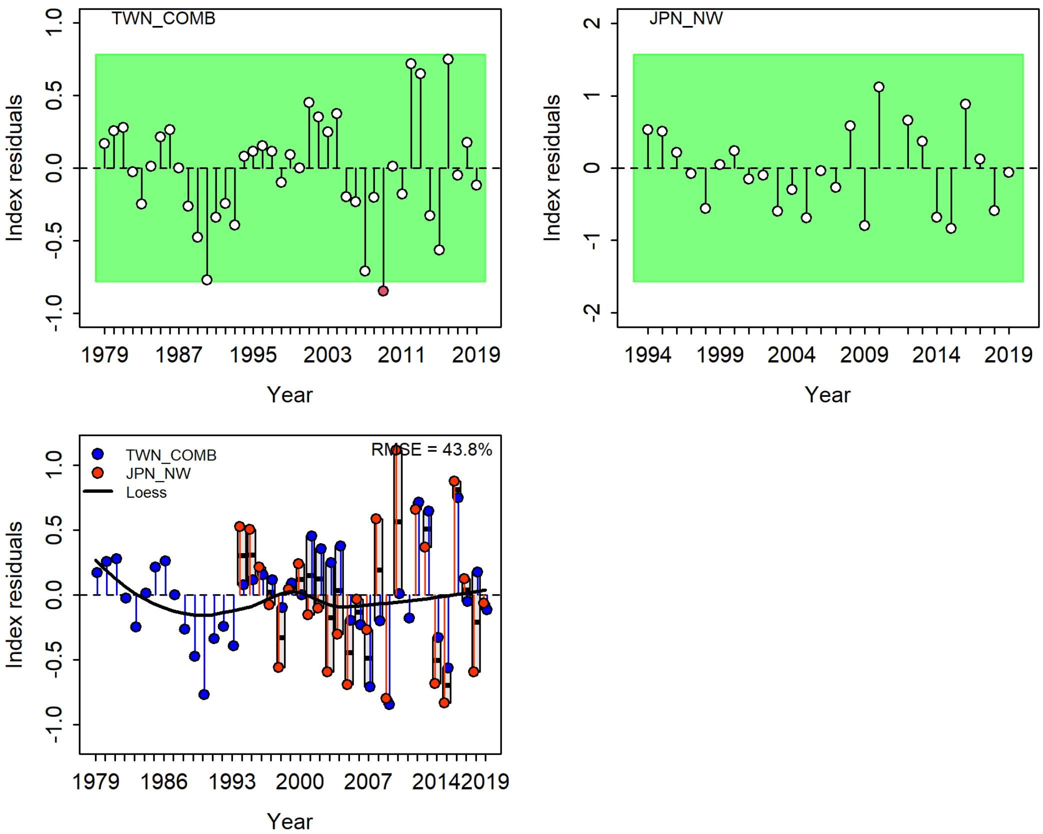


Fig. 9. Runs test plot (green shading indicates no evidence ($p \geq 0.05$) and red shading evidence ($p < 0.05$) to reject the hypothesis of a randomly distributed time-series of residuals, respectively) and Joint residual plot for fits to CPUE indices (vertical lines with points show the residuals, and solid black lines show loess smoother through all residuals, boxplots indicate the median and quantiles in cases where residuals from the multiple indices are available for any given year and root mean squared errors (RMSE) are included in the upper right-hand corner of each plot).

Scenario “TWN_CPUE2005”

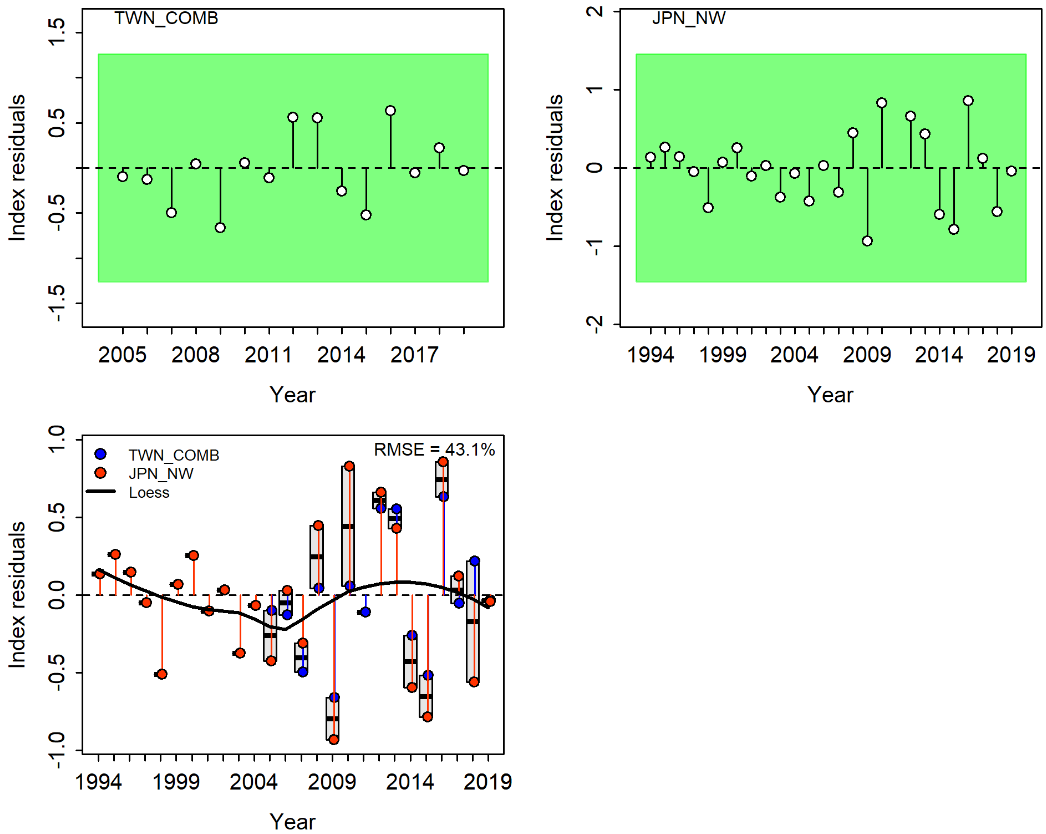


Fig. 9. (continued).

Scenario “Ref”

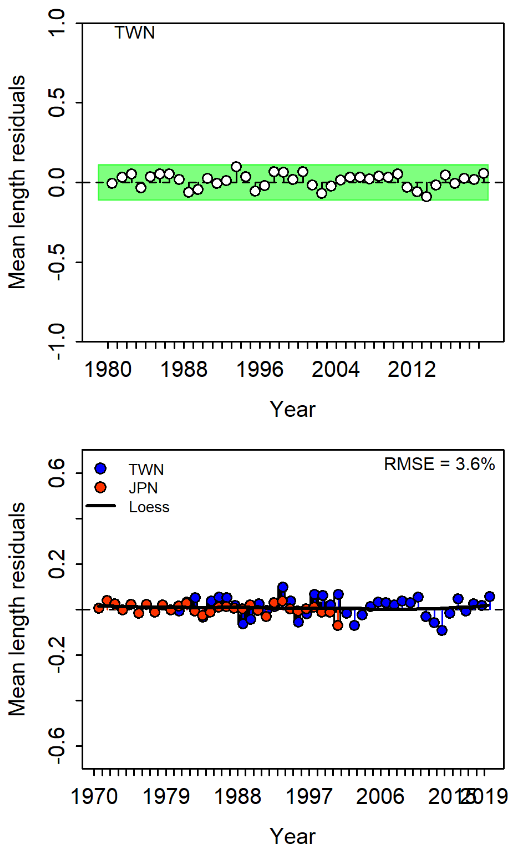


Fig. 10. Runs test plot (green shading indicates no evidence ($p \geq 0.05$) and red shading evidence ($p < 0.05$) to reject the hypothesis of a randomly distributed time-series of residuals, respectively) and joint residual plot for fits to length-frequency data (vertical lines with points show the residuals, and solid black lines show loess smoother through all residuals, boxplots indicate the median and quantiles in cases where residuals from the multiple indices are available for any given year and root mean squared errors (RMSE) are included in the upper right-hand corner of each plot).

Scenario "TWN_CPUE2005"

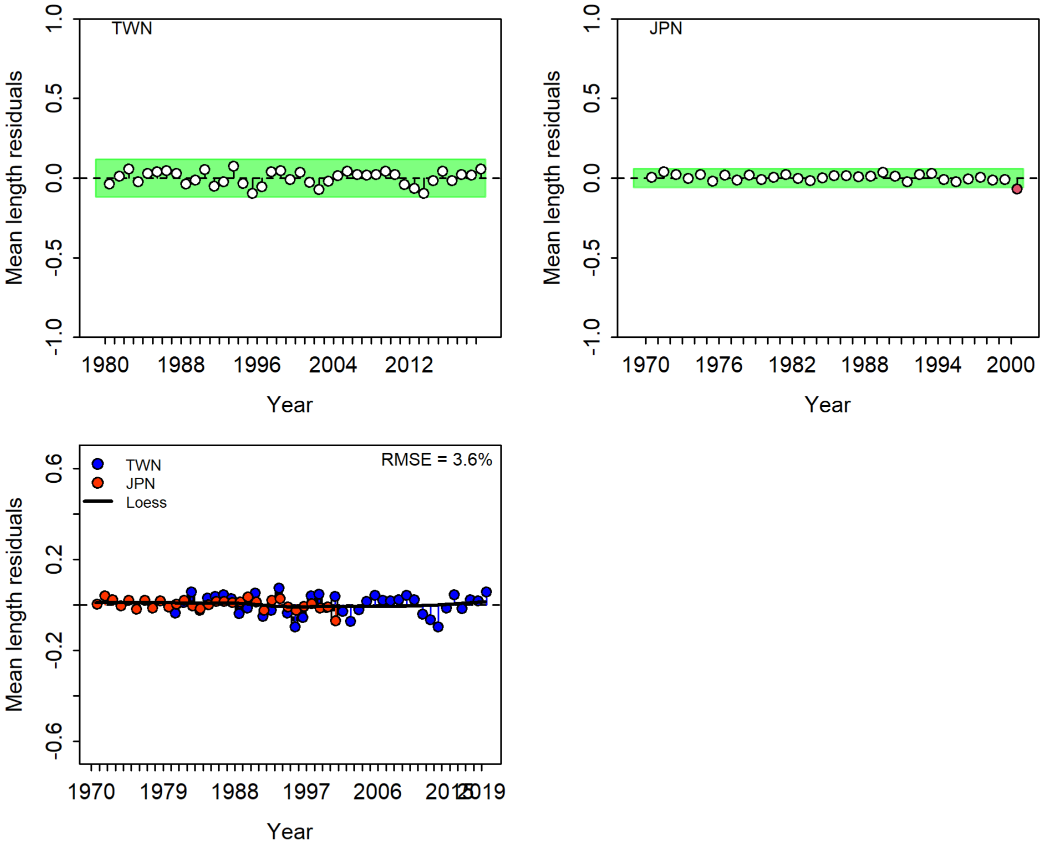
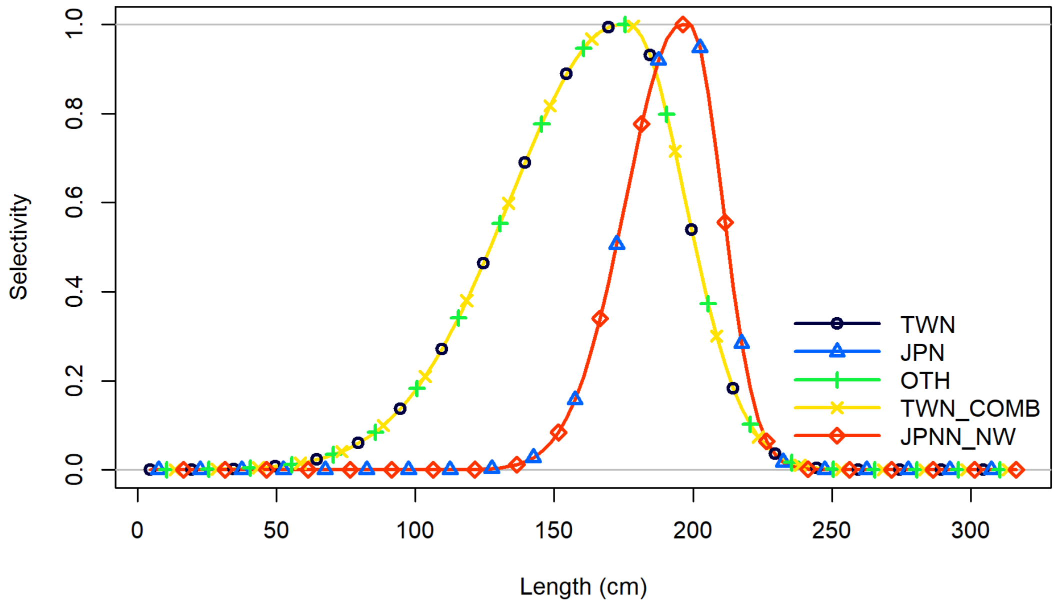


Fig. 10. (continued).

Scenario “Ref”



Time-vary selectivity for TWN

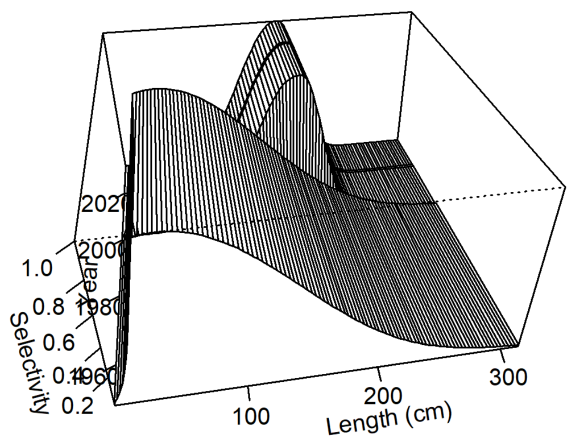
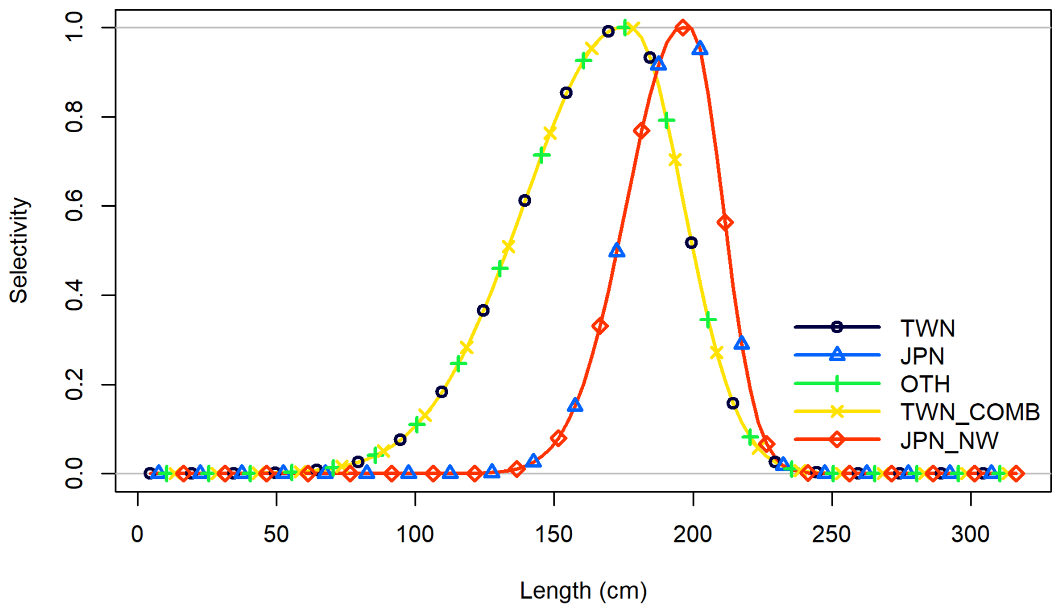


Fig. 11. Model-estimated selectivity for striped marlin in the Indian Ocean.

Scenario“TWN_CPUE2005”



Time-vary selectivity for TWN

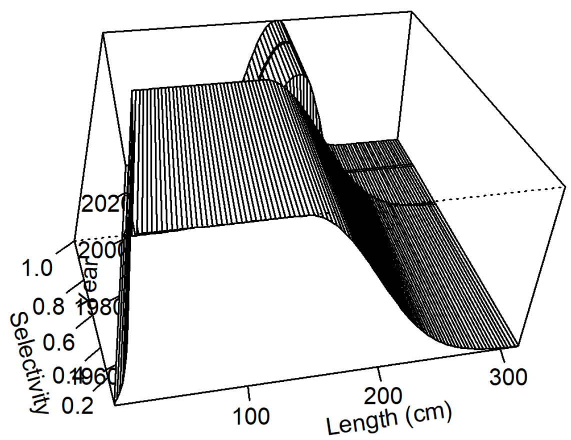


Fig. 11. (continued).

Scenario "Ref"

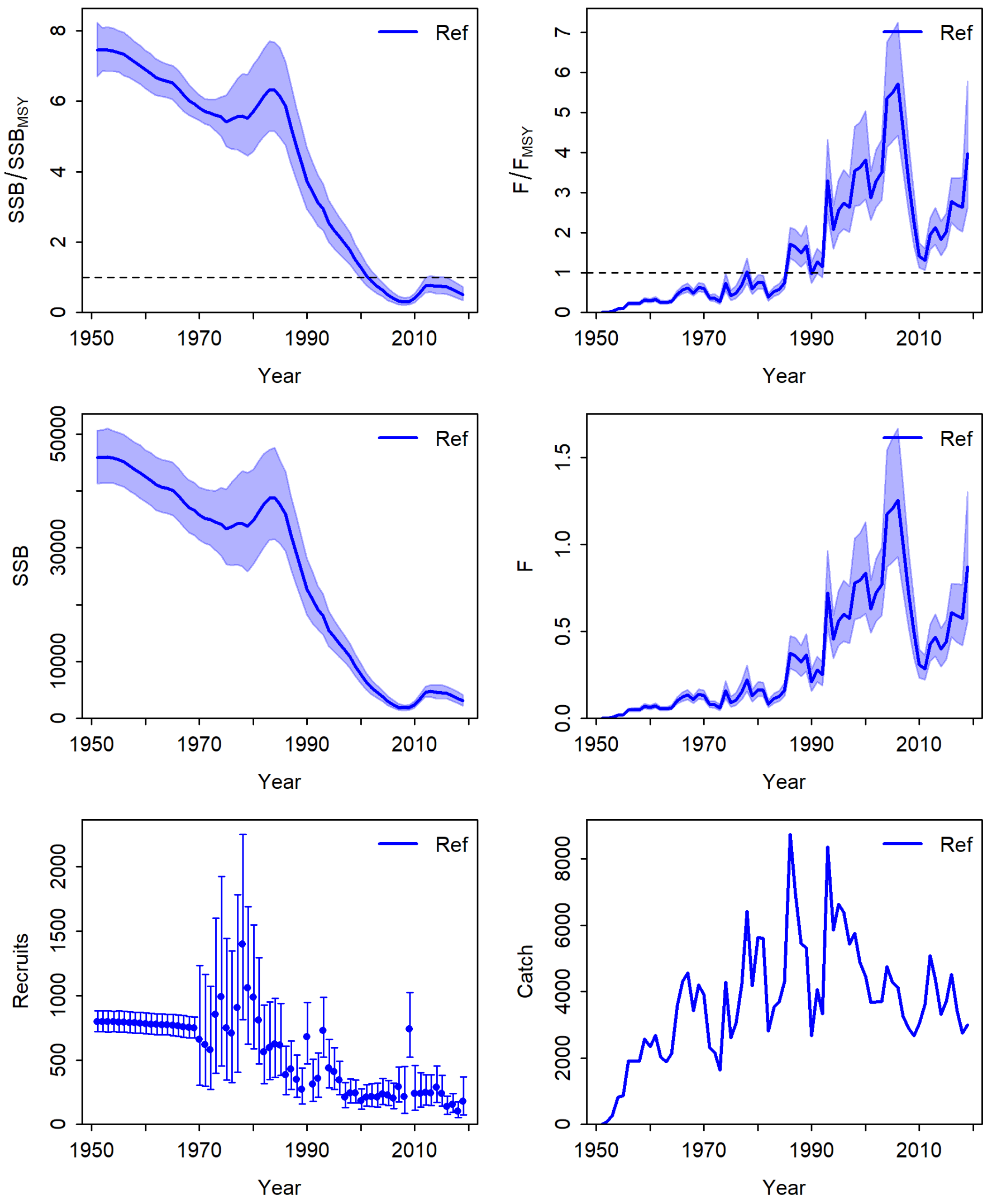


Fig. 12. Time trajectories of the model-estimated recruitment, spawning biomass and fishing mortality of striped marlin in the Indian Ocean.

Scenario "TWN_CPUE2005"

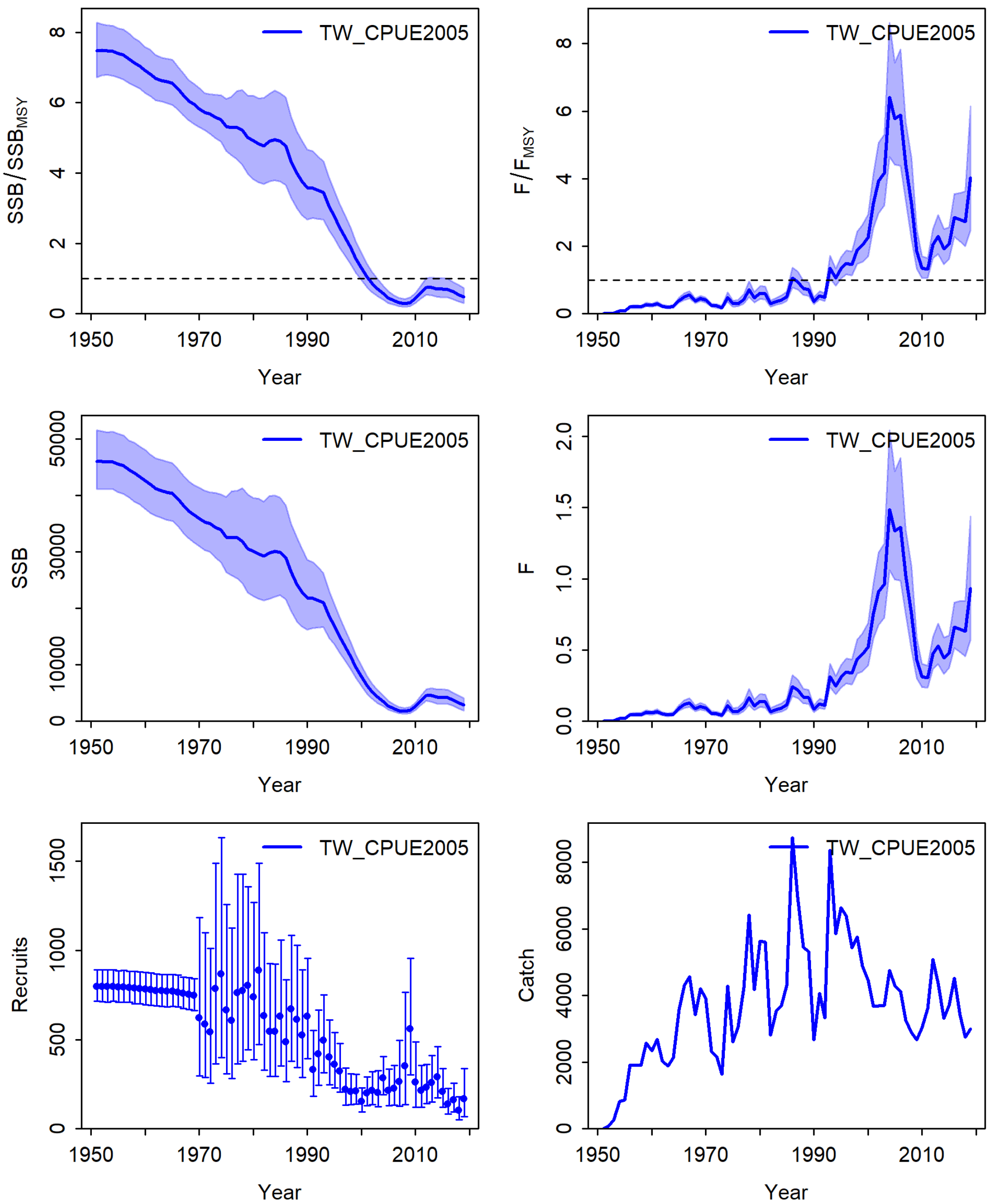


Fig. 12. (continued).

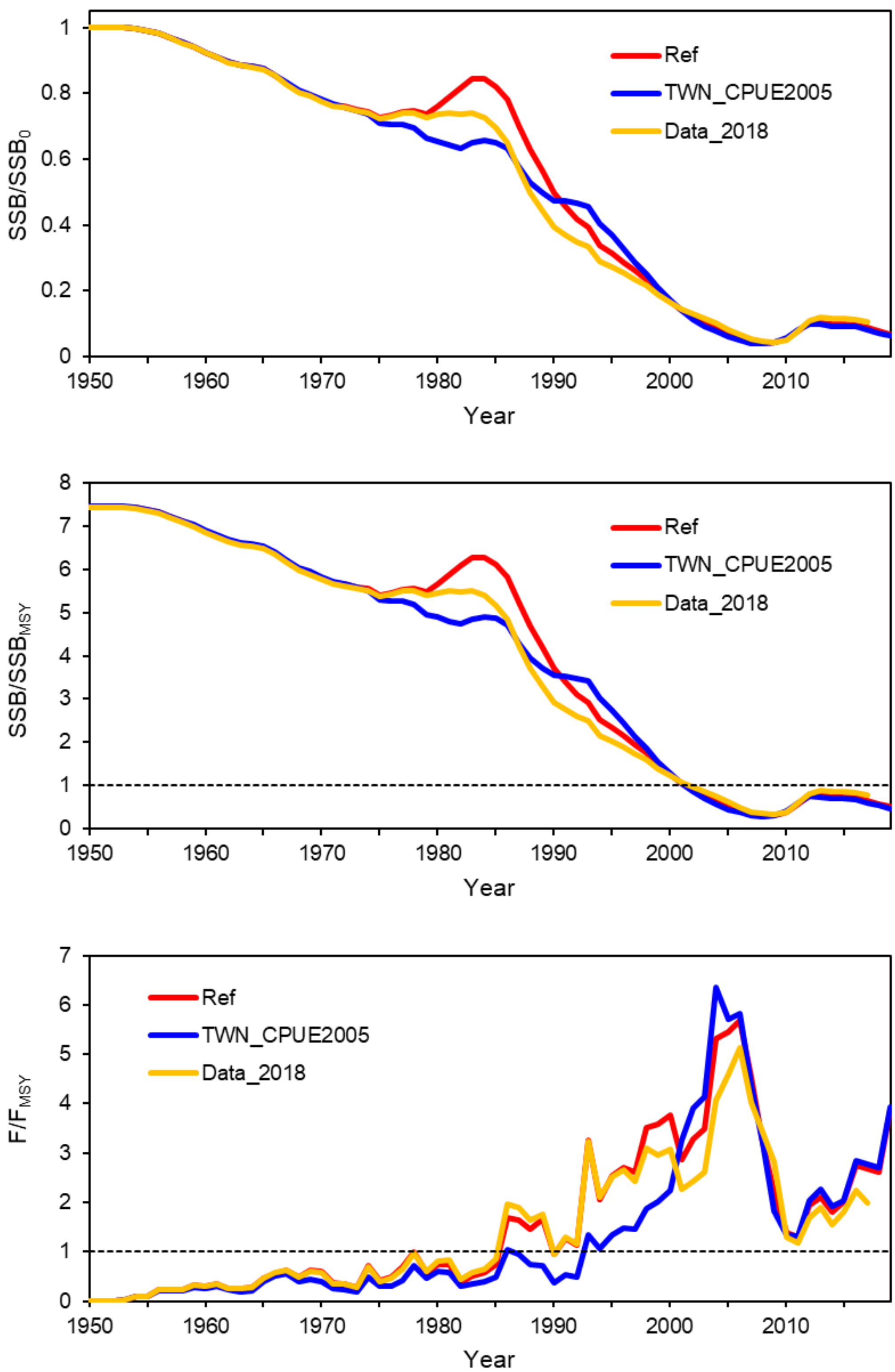


Fig. 13. Time trajectory of the model-estimated relative fishing mortality and spawning biomass of striped marlin in the Indian Ocean.

Scenario "Ref"

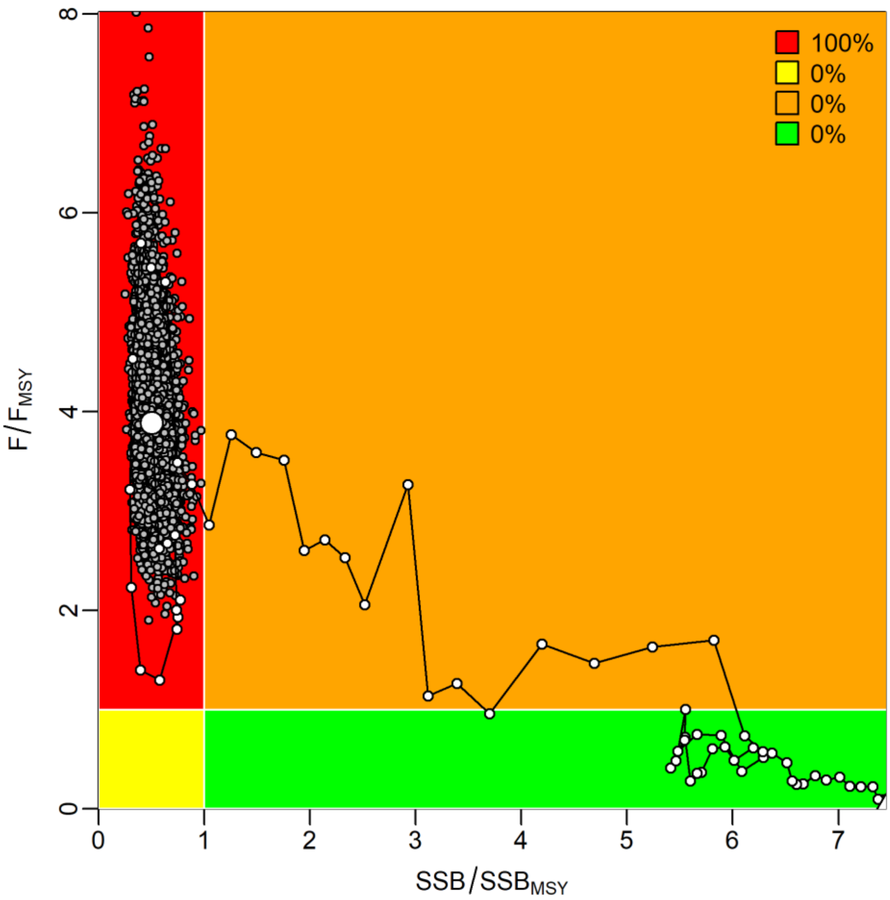


Fig. 14. Kobe plot for striped marlin in the Indian Ocean.

Scenario “TWN_CPUE2005”

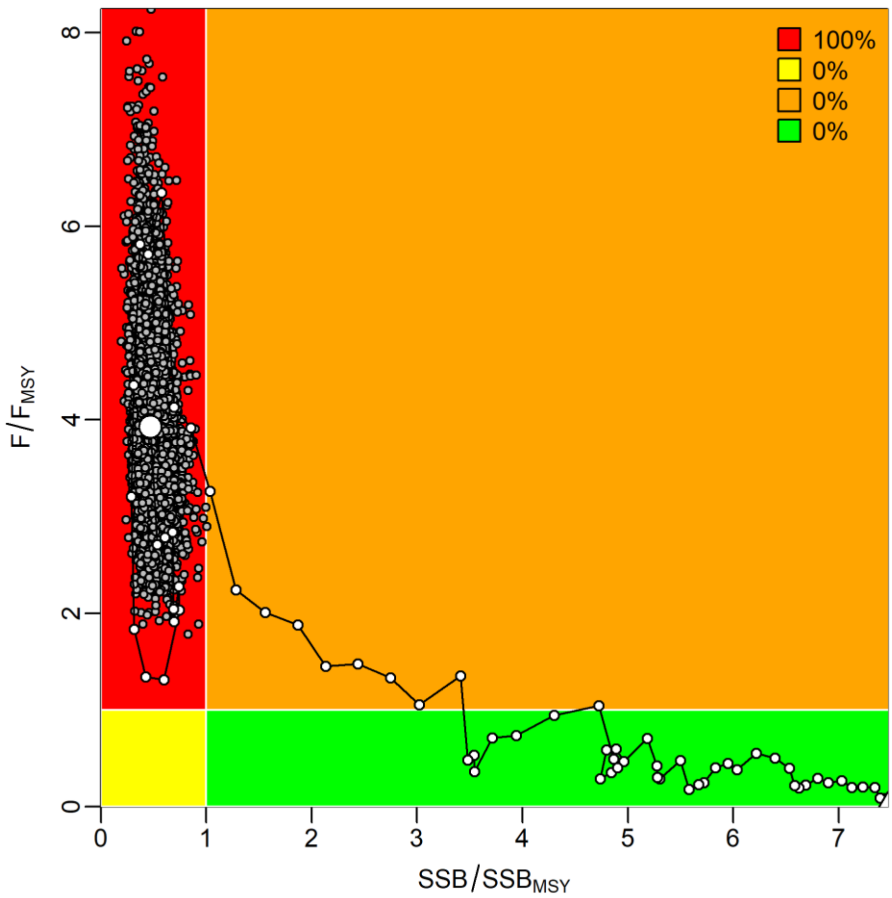


Fig. 14. (continued).

Scenario "Ref"

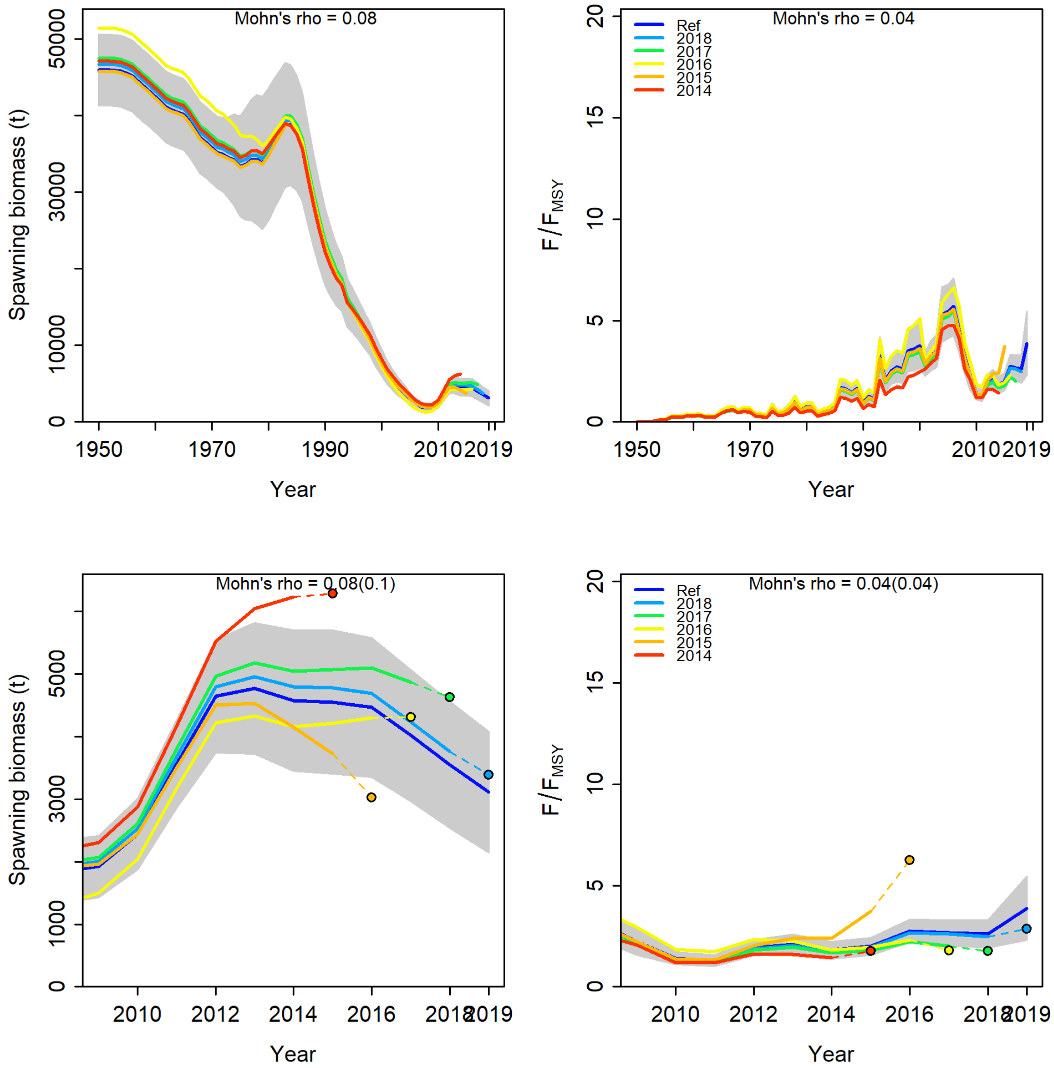


Fig. 15. Retrospective analysis of spawning stock biomass and fishing mortality estimates (F/F_{MSY}) for striped marlin in the Indian Ocean.

Scenario "TWN_CPUE2005"

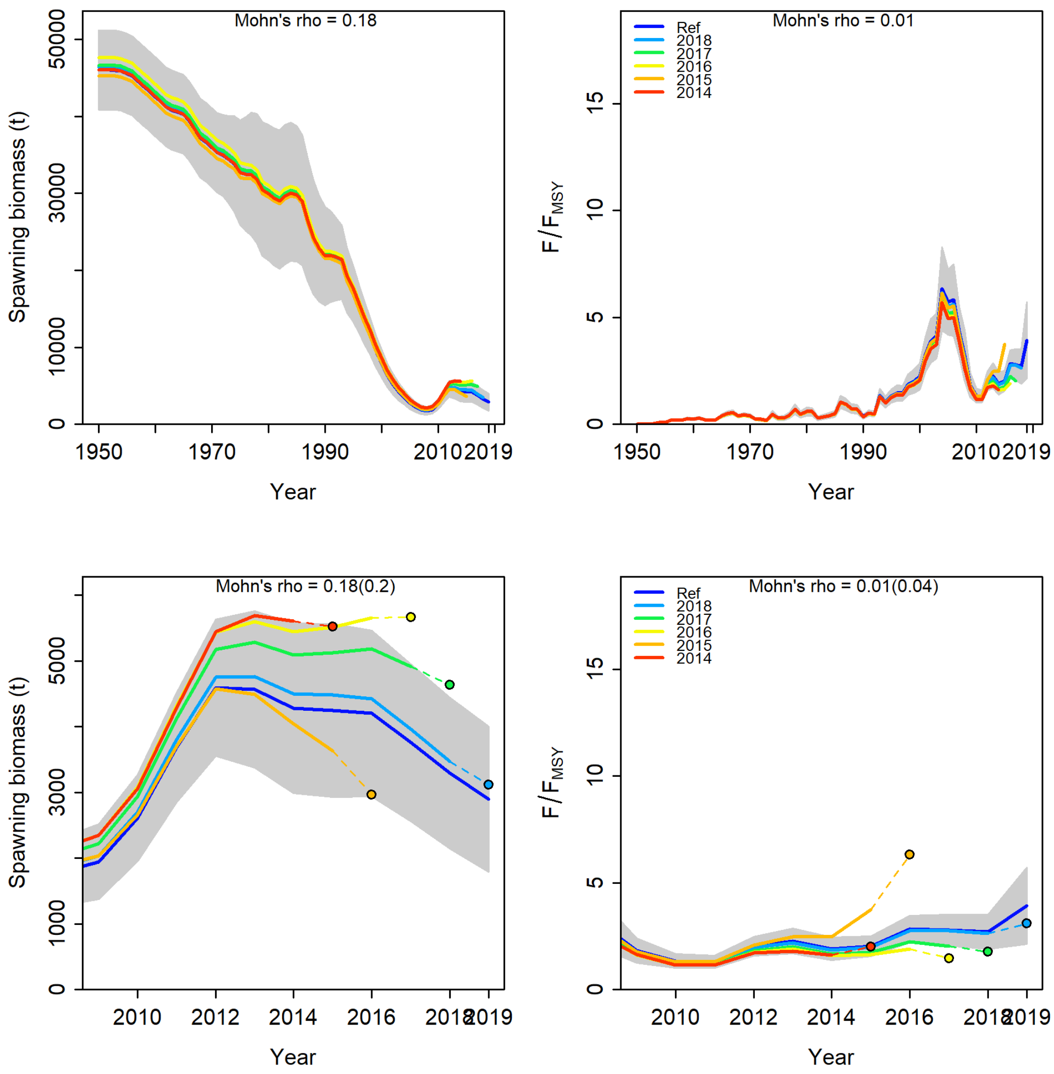


Fig. 15. (continued).

Scenario “Ref”

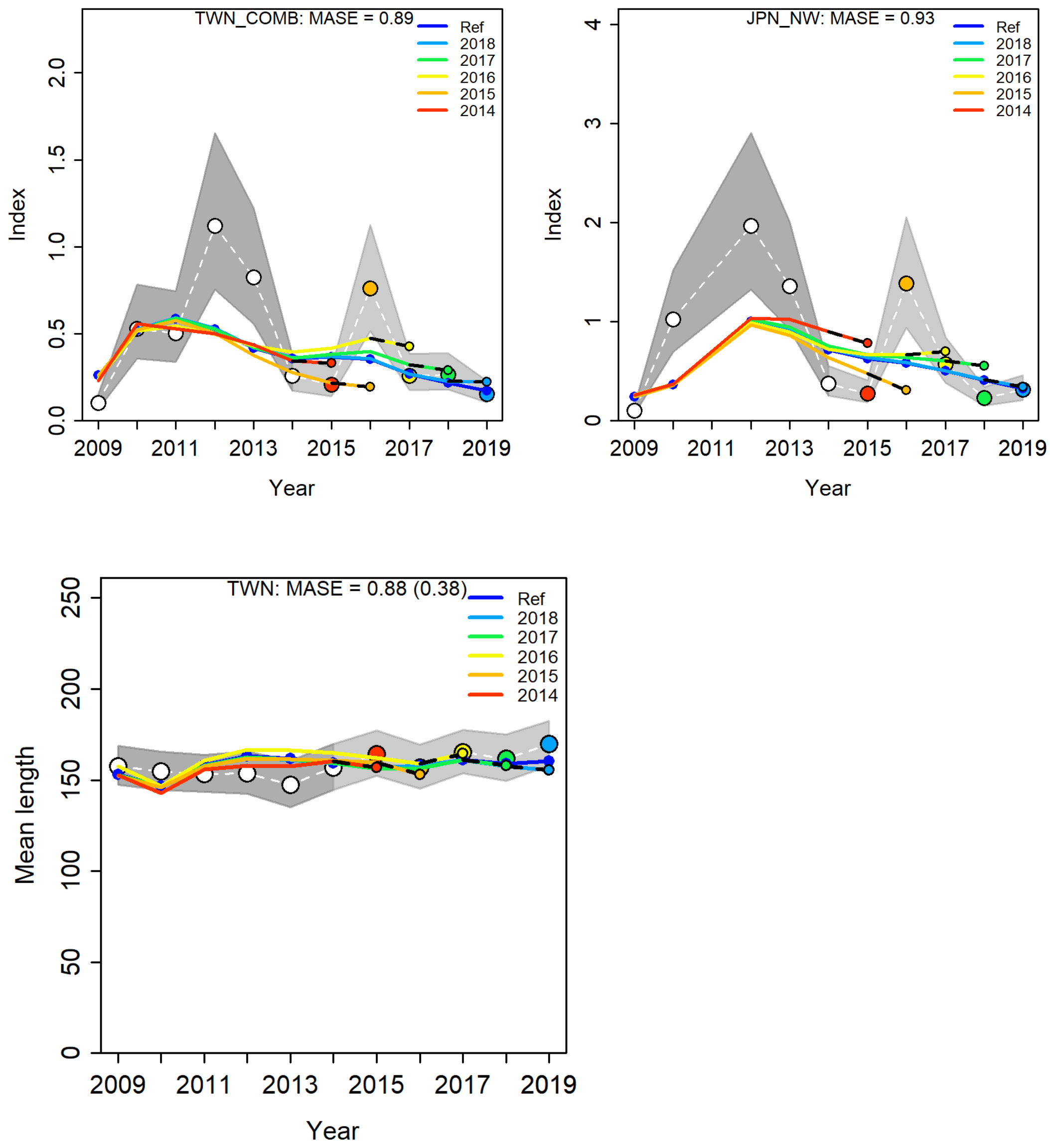


Fig. 16. Hindcasting cross-validation results from CPUE and mean lengths for striped marlin in the Indian Ocean, showing observed (large points connected with dashed line), fitted (solid lines) and one-year ahead forecast values (small terminal points). mean absolute scaled error (MASE) values in brackets are adjusted MASE values for cases where naive predictions have a Mean-Absolute-Error below 0.1.

Scenario “TWN_CPUE2005”

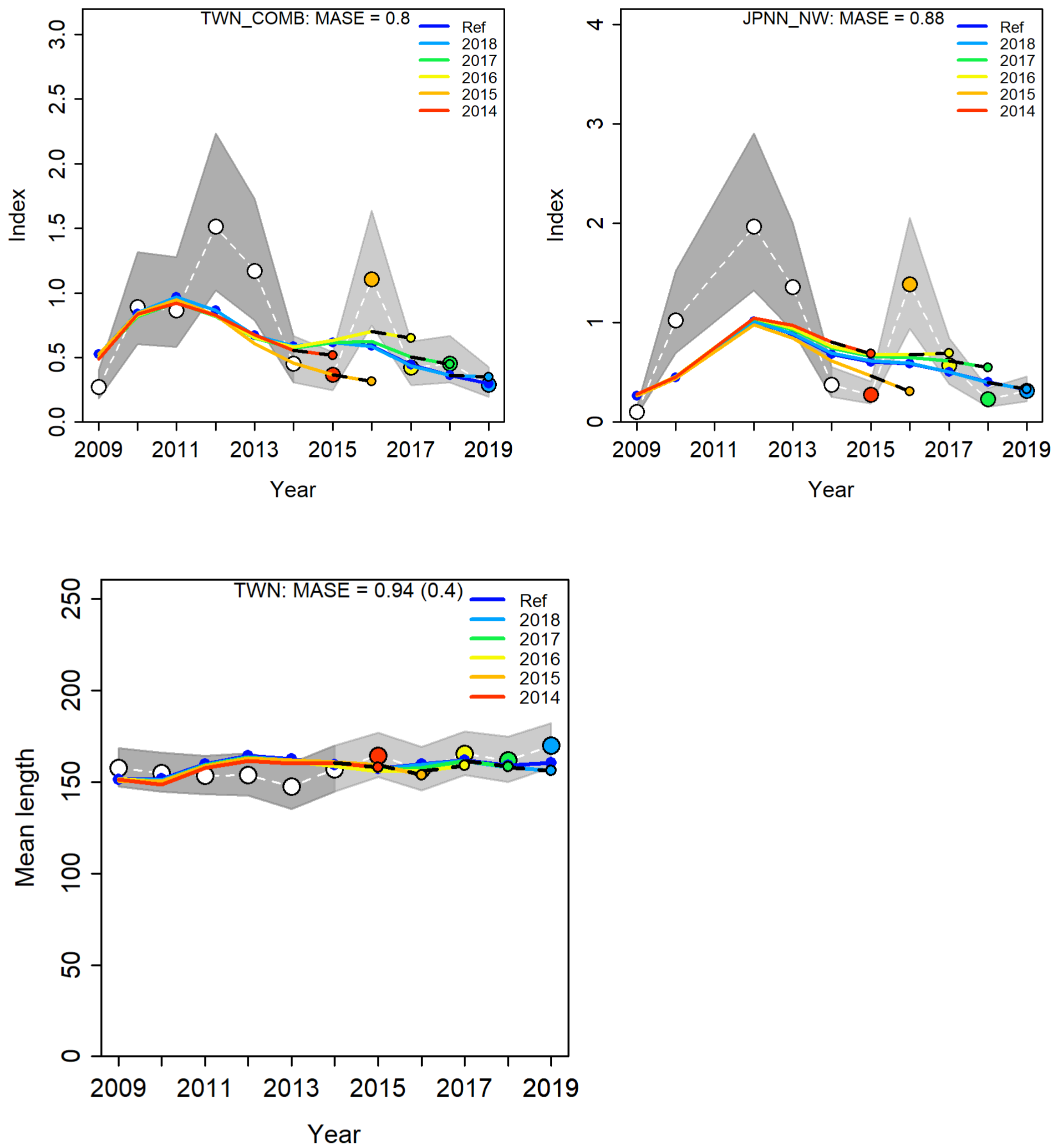


Fig. 16. (continued).

Table 1. The biological parameters of length-weight relationships, von Bertalanffy growth curve, and maturity and age used in the stock assessment for striped marlin in the Indian Ocean.

Parameter	Females	Males
Asymptotic size, L_∞ (cm)[1]	243.98	250.19
Growth parameter, K (year^{-1})[1]	0.27	0.25
Age-at-zero-length, t_0 (year)[1]	-2.50	-2.62
Length-weight, A[1]	$4.68\text{x}10^{-6}$	$4.68\text{x}10^{-6}$
Length-weight, B[1]	3.16	3.16
Maturity slope, r_m[2]	0.0482	-
Length-at-50%-maturity, L_m (cm)[2]	177.04	-
Maximum age, λ (year)	40	40

1. ISC (2015).
2. Zhou et al. (2018).

Table 2. The estimates of key quantities of management interests for striped marlin in the Indian Ocean.

	Scenario	
Management Quantity	**Ref**	**TWN_CPUE2005**
2019 catch estimate	3,001	3,001
Mean catch from 2015–2019	3,477	3,477
MSY (1000 t) (80% CI)	4.819 (4.477, 5.162)	4.819 (4.477, 5.162)
Data period (catch)	1950–2019	1950–2019
F_{MSY} (80% CI)	0.219 (0.215, 0.223)	0.231 (0.229, 0.232)
SB_{MSY} (1,000 t) (80% CI)	6.162 (6.343, 5.837)	6.161 (6.368, 5.746)
F_{2019}/F_{MSY} (80% CI)	3.883 (3.013, 0.021)	3.925 (2.297, 5.306)
SB_{2019}/SB_{MSY} (80% CI)	0.506 (0.395, 0.647)	0.470 (0.349, 0.630)
SB_{2019}/SB_{1950} (80% CI)	0.068 (0.054, 0.083)	0.063 (0.048, 0.079)