2Stock assessment of blue marlin in the Indian Ocean using Stock Synthesis

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ABSTRACT

In this study, Stock Synthesis (SS) was adopted to conduct the stock assessment for blue marlin in the Indian Ocean by incorporating historical catch, CPUE and length-frequency data. The results of most scenarios indicated that the current stock status of blue marlin in the Indian Ocean was not overfished and not overfishing, but it may be subject to slightly overfishing or/and overfished. However, the model cannot appropriately fit the CPUE series of Taiwanese and Japanese fleets between the early 1990s and the mid-1990s when CPUE trends obviously conflicted for these two fleets. The models cannot well fit the length-frequency data before the early 2000s when high proportions of small fishes were observed, and the model fits were also deteriorated for Japanese length-frequency data after the early 2000s due to the sparse sample sizes. In addition, most of the life-history parameters used in this study were based on the values of blue marlin in the Pacific Ocean. These may lead to the uncertainties in the evaluation of the stock status of blue marlin in the Indian Ocean.

1. INTRODUCTION

Blue marlin are largely considered to be a non-target species of industrial and artisanal fisheries. Longline catches6 account for around 70% of total catches in the Indian Ocean, followed by gillnets (24%), with remaining catches recorded under troll and handlines. Based on the catches data from 2012 to 2017, main fleets consisted of Taiwan (longline, 34%), Indonesia (fresh longline, 31%), Pakistan (gillnet, 12%), I.R. Iran (gillnet, 9%), and Sri Lanka (6%). Catches reported by drifting longliners were more or less stable until the late-70's, at around 3,000 t to 4,000 t, and have steadily increased since then to reach values between 8,000 t and to over 10,000 t since the early 1990's. The highest catches reported by longliners have been recorded since 2012, and are likely to be the consequence of higher catch rates by some longline fleets which appear to have resumed operations in the western tropical Indian Ocean. (IOTC, 2018).

Since historical standardized CPUE and length-frequency data were available for blue marlin in the Indian Ocean, and parts of auxiliary information, such as life-history parameters, could be obtained from previous stock assessment for blue marlin in the other oceans, the integrated stock assessment approach can be applied to evaluate the stock status for blue marlin in the Indian Ocean. Therefore, this study attempt to conduct the stock assessment for blue marlin in the Indian Ocean using Stock Synthesis (SS, Methot, 2012; Methot and Wetzel, 2014).

2. MATERIALS AND METHODS

2.1 Fishery definition

Blue marlin was mainly exploited by longline fleets (Taiwan, Japan and Indonesia) and gillnet fleets (Pakistan, Iran, and Sri Lanka). However, standardized CPUE series and length-frequency data were only available for Taiwanese, Japanese and Indonesian fleets. For length-frequency data, long term data were only for available Taiwanese and Japanese fleets although the data were also available in recent years for some other fleets but the sample sizes were sparse for most of the years. In addition, the catch data were not appropriate to be used to conduct a spatial model even though previous studies suggested that the relative abundance indices and size compositions may be varied by areas. Therefore, the fleets operated in the Indian Ocean were simply aggregated into the 4 fisheries (JPN: Japanese longline; TWN: Taiwanese longline; IDN: Indonesian longline; OTH: Other fleets).

2.2 Data used

The historical catches in weight and length-frequency data from for all fleets were provided by Indian Ocean Tuna Commission (IOTC). Fig. 1 shows the trends of catches for fours fisheries. The total catch obviously increased since early 1990s and the increase in catch mainly contributed from OTH and TWN.

The length data of blue marlin in the Indian Ocean were mainly collected by Japanese and Taiwanese longline fleets. Although the data also collected by other fleets, such as Korea, Sri Lanka, EU countries and China, the time series of the data were generally short or incomplete. All of the length-frequency data were converted into the measurement of eye fork length (EFL) and aggregated into 3 cm length interval. The relative abundance indices used in this study were based on the standardized CPUE of Taiwanese, Japanese and Indonesian longline fleets (Setyadji et al., 2019; Taki et al., 2019; Wang 2019). In addition, the standardized CPUE of Taiwanese and Japanese fleets were conducted by areas (Fig. 2) and thus the assessment models were derived by incorporating different combinations of the standardized CPUE series.

Fig. 3 shows the data presence by year for each fleet used in the stock assessment of blue marlin in the Indian Ocean, including catch, length-frequency and CPUE data.

2.3. Life-history parameters

Because the life-history parameters are still not available for blue marlin in the Indian Ocean, the assessment models were performed using the same parameters adopted in Wang and Huang (2016).

Growth of blue marlin has been known to be sexual dimorphic and females grow faster than males (e.g. Lee et al., 2013; 2014). 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. In this study, growth parameters were fixed to those adopted by Lee et al. (2013, 2014) for the assessment of blue marlin in the Pacific Ocean.

Setyadji et al. (2014) provided a relationship for blue marlin in the Indian. However, EFL data can be converted into unreasonable high weights for fishes with large lengths when relationship of Setyadji et al. (2014) was used. Therefore, the length-weight relationship used by (Lee et al., 2013; 2014) was adopted in this study.

There is little information about natural mortality (M) for blue marlin in the Indian. Lee et al. (2013, 2014) used sex- and age-specific natural mortality for the assessment of blue marlin in the Pacific Ocean. Based on the age-specific natural mortality used in Lee et al. (2013, 2014), the values were fixed as 0.42 year^{-1} for age 0, 0.37 year^{-1} for age 1, 0.32 year^{-1} for age 2, 0.27 year^{-1} for age 3, and 0.22 year^{-1} for age above 4 for female and 0.42 year^{-1} for age 0, 0.37 year^{-1} for age above 1 for male. In this study, the values for adult fishes (0.22 year^{-1} for female and 0.37 year^{-1} for male) were used for the assessment of blue marlin in the Indian Ocean.

The maturity ogive of blue marlin in the western Pacific Ocean (Sun et al., 2009) was used in this study. The value of length at 50% maturity was 179.76 cm and slope of the logistic function was -0.2039.

The standard Beverton-Holt stock-recruitment relationship was used in this study. There is also little information about the parameters of the stock-recruitment relationship (steepness, *h*), which represented the productivity of the fish. Therefore, the assumption used in Lee et al. (2013, 2014) was adopted in this study and value of *h* was assumed to be 0.87.

The values of life-history parameters used in this study are listed in Table 1 and these values were used as the base-case.

2.4 Model structure and assumption

In this study, the population structure was sex-specific although sex specific data were not available but the model population age structure can be differentiated by sexes. The maximum age used in the model was 40 years. The time period of assessment model was from 1950 to 2017 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 (σ_R). In this study, the σ_R was assumed to be 0.4, which was commonly adopted in previous stock assessment for tunas and billfishes. 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 because the length-frequency compositions tended to concentrate at specific ranges for fleets. In addition, selectivity was time-invariant for all fleets. Due to the incomplete time-series or insufficient sample sizes for the length-frequency data of IDN and OTH, the selectivities of IDN and OTH were assumed to be the same with TWN.

Catchability was estimated assuming that survey indices are proportional to vulnerable biomass with a scaling factor of catchability. It was assumed that catchability was constant over time for all indices (Lee et al. 2013). As Methot (2012) recommended in most cases, fishing mortality (F) was modelled the method of a hybrid F method that does a Pope's approximation to provide initial values for iterative adjustment of the Baranov continuous F values to closely approximate the observed catch.

Stock Synthesis version 3.24f (Methot, 2012) was used in this study. Equal weightings were assigned to all data components. The Markov Chain Monte Carlo (MCMC) method was used to develop Bayesian posterior distributions for the parameters of the model and the key quantities of management interests. The posterior distributions were constructed based on 500 samples generated by conducting 600,000 cycles of the MCMC algorithm, ignoring the first 100,000 cycles as the burn in" period, and selecting every 1000th parameter vector thereafter.

2.5 Scenarios

The standardized CPUE series revealed different patterns by fleets and areas although the trends may be relatively similar within fleets (Fig. 2). To include all of possible information on the relative trend of abundance, the standardized CPUE series of Taiwanese, Japanese and Indonesian fleets were all adopted for the assessment models and the models were derived by incorporating different combinations of area-specific standardized CPUE series of Taiwanese and Japanese fleets (Table 2).

3. RESULTS AND DISCUSSIONS

The model can generally fit the trends of CPUE series of three fleets with slight influence by scenarios, but the model cannot appropriately fit the TWN and JPN CPUE series between the early 1990s and the mid-1990s when CPUE trends obviously conflicted for these two fleets (Fig. 4).

The difference in the model fits of length-frequency data were negligible for different scenarios and only the fits for scenario TNWJCE are shown in Figs. 5 and 6 as an example. The models cannot well fit the length-frequency data of TWN before the early 2000s when high proportions of samples with lengths less than 100 cm were observed, and the model fits were also deteriorated for JPN after the early 2000s due to the sparse sample sizes (Fig. 6). However, the problem in the model fits of length-frequency data cannot be determined by the comparison between TWN and JPN data because all of catches caught by JPN were larger than 100 cm.

The model estimated selectivity curves by scenarios are shown in Fig. 7 and negligible differences were observed among scenarios. TWN obviously tended to select the smaller fishes than those of JPN and OTH, while JPN tended to select large fishes with a wide range of body size.

Time trajectories of total fishing mortality, recruitment and spawning biomass estimated by the model are shown in Figs. 8-10. Generally, the trajectories of these quantities were very similar among scenarios before the early 2000s but revealed different patterns thereafter, and this might result from different CPUE series adopted in the model. Fishing mortality gradually increased since the early 1990s when the catches substantially increased, and this resulted in the substantial declines in recruitment and spawning biomass (Figs. 1 and 8). Although strong recruitments were observed in around1990s, spawning biomass continuously decreased due to the substantial increases in catch and fishing mortality. It seems that spawning biomass recovered in recent years because strong recruitments occurred again during the early and the mid-2010s. However, spawning biomass in 2017 has been decreased to about 17-30% of that in 1950 (Fig. 11).

Time trajectories of the fishing mortality and spawning biomass as a ratio of that at which MSY is achieved are shown in Figs. 12 and 13. The results of most scenarios indicated that the current spawning biomass was still higher than its MSY level, while the fishing mortality has exceeded its MSY level since the early 2000s.

Table 3 shows the model estimates of the key management quantities obtained from various scenarios. Adopting Taiwanese CPUE in the northwest area and Japanese CPUE in the central east area (TNWJCE) led to the highest levels of biomass and MSY along with the lowest levels of fishing exploitation, while the lowest biomass and MSY and highest fishing exploitation were obtained when Taiwanese CPUE in the northeast area and Japanese CPUE in the northwest area (TNEJNW).

Fig. 14 shows the Kobe plot based on the estimates obtained from various scenarios. Overall, the results of most scenarios indicated that the current stock status of blue marlin in the Indian Ocean was not overfished and not overfishing, but it may be subject to slightly overfishing or/and overfished.

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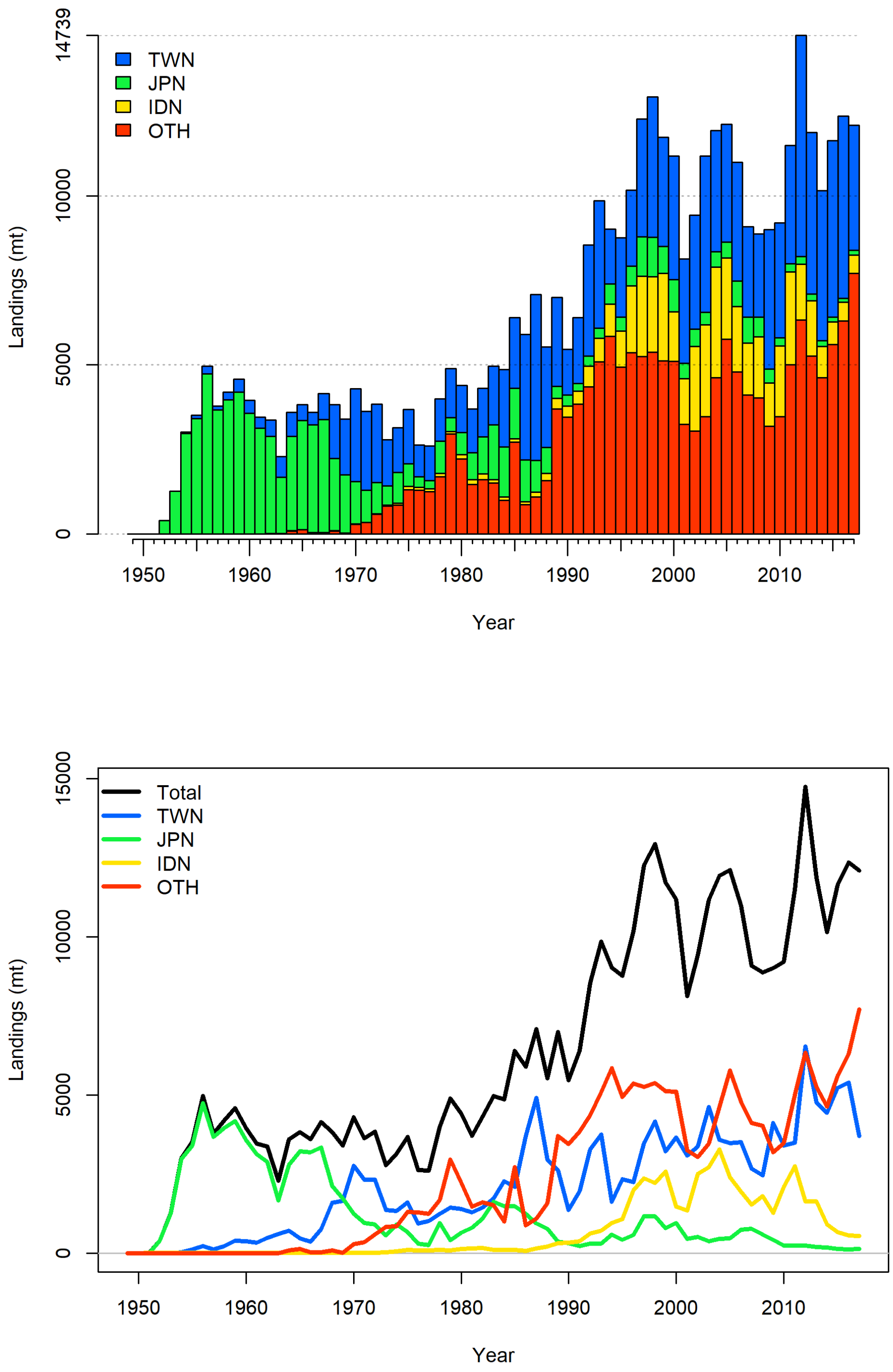


Fig. 1. Annual catches of blue marlin in the Indian Ocean by fleets.

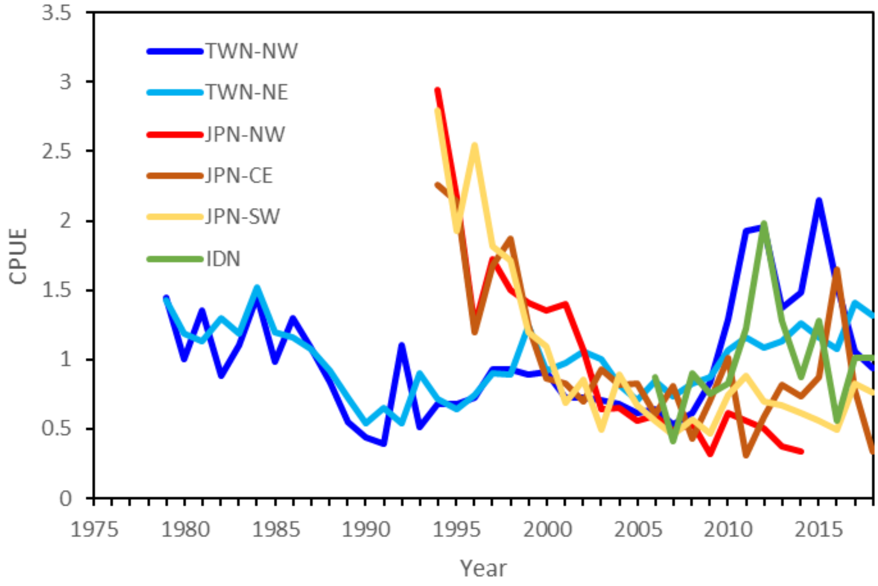


Fig. 2. Standardized CPUE series by fleets and areas used for the stock assessment of blue marlin in the Indian Ocean.

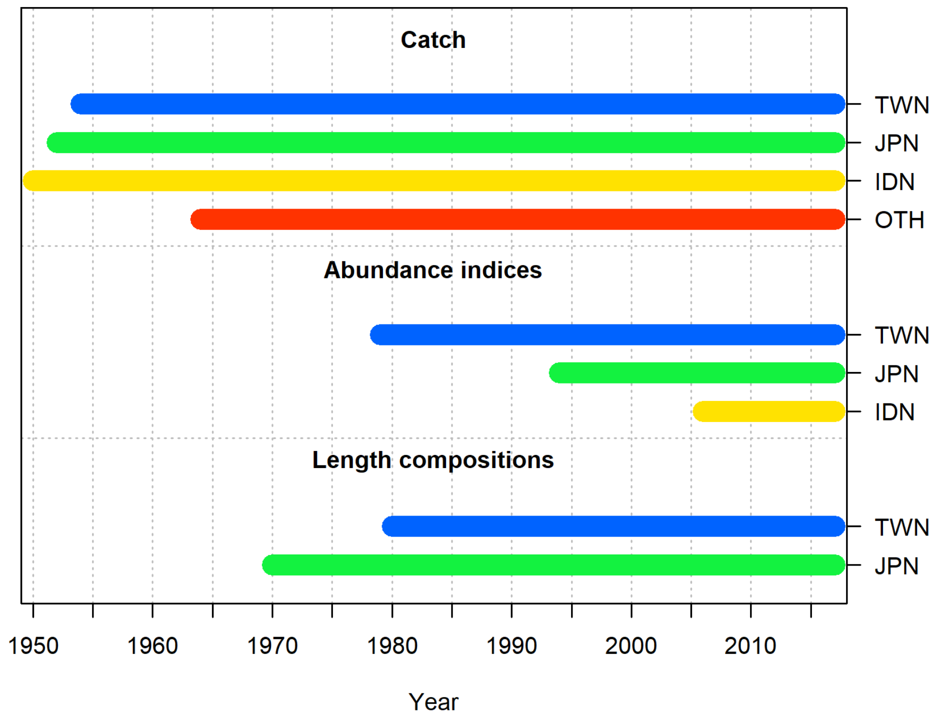


Fig. 3. Data presence by year for each fleet used for the stock assessment of blue marlin in the Indian Ocean.

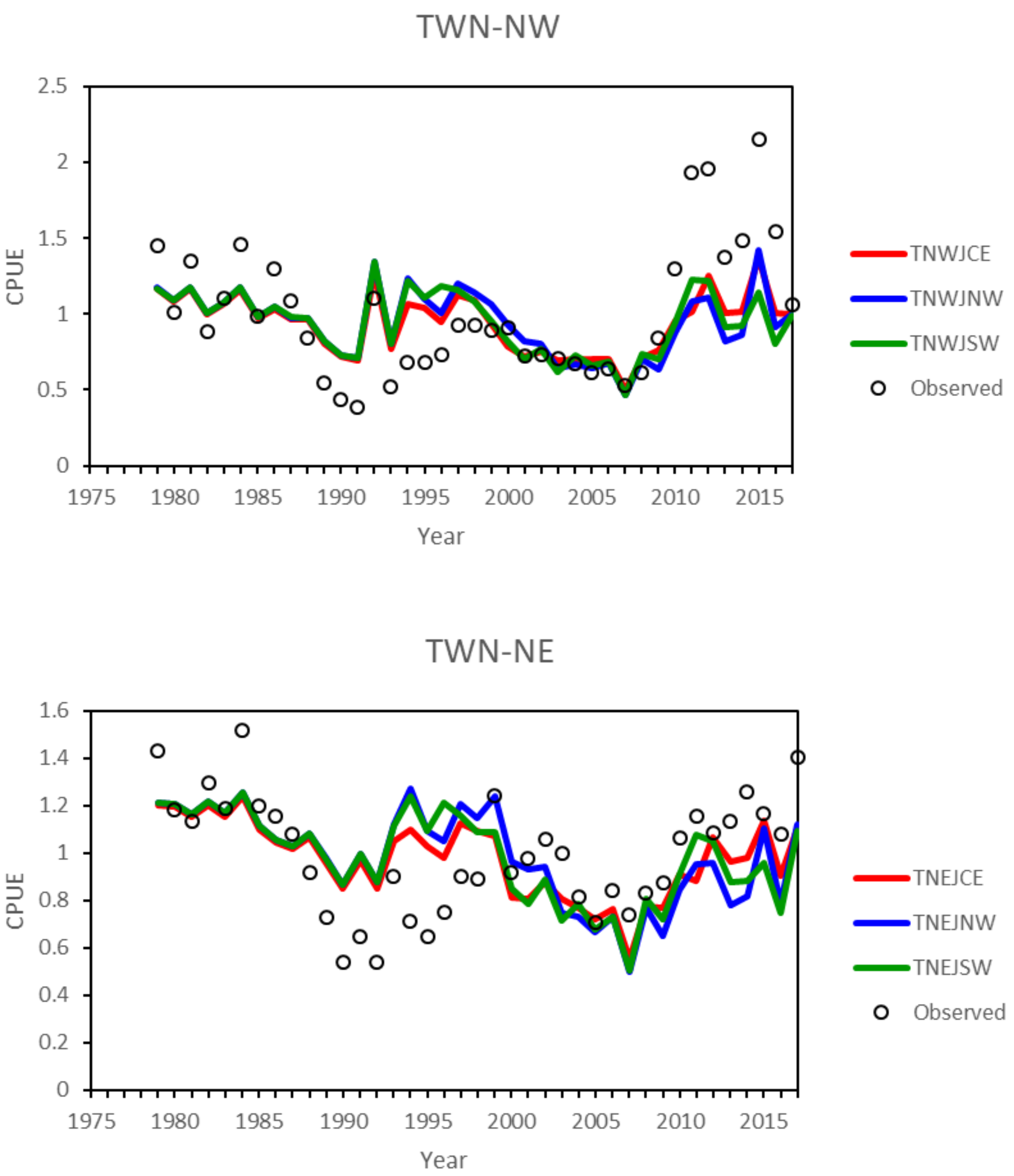
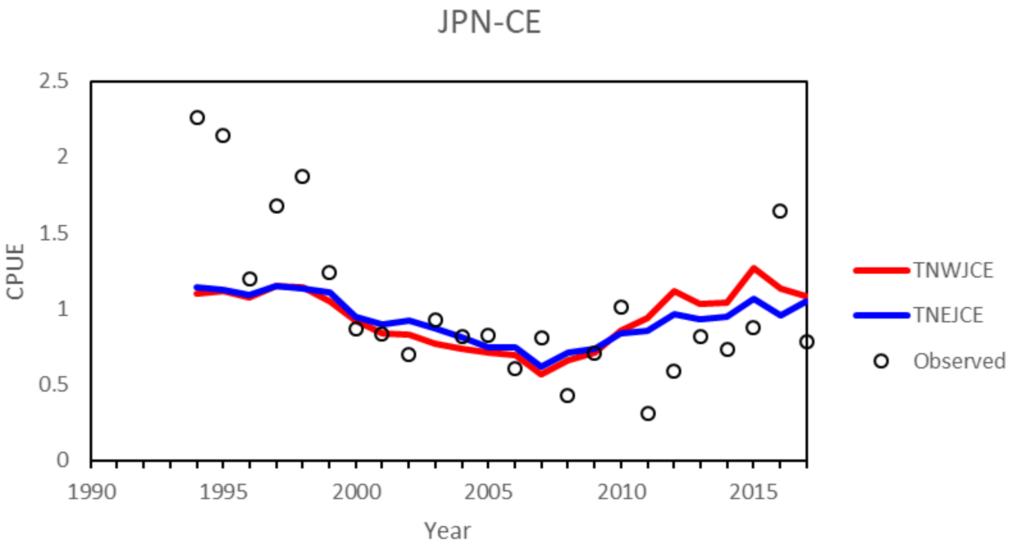


Fig. 4. Observed CPUE (dots) and model-estimated CPUE (lines) of blue marlin in the Indian Ocean obtained from various scenarios.



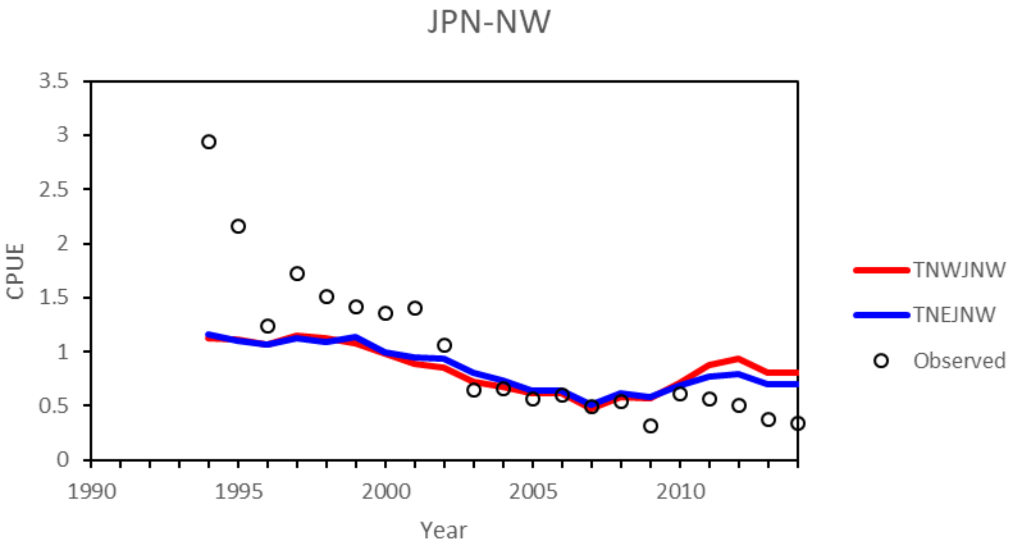
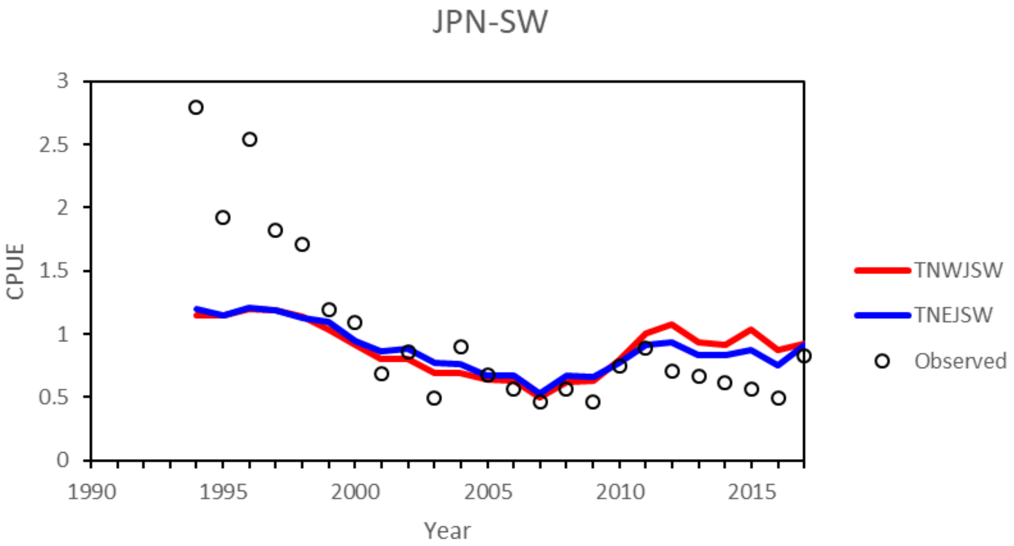
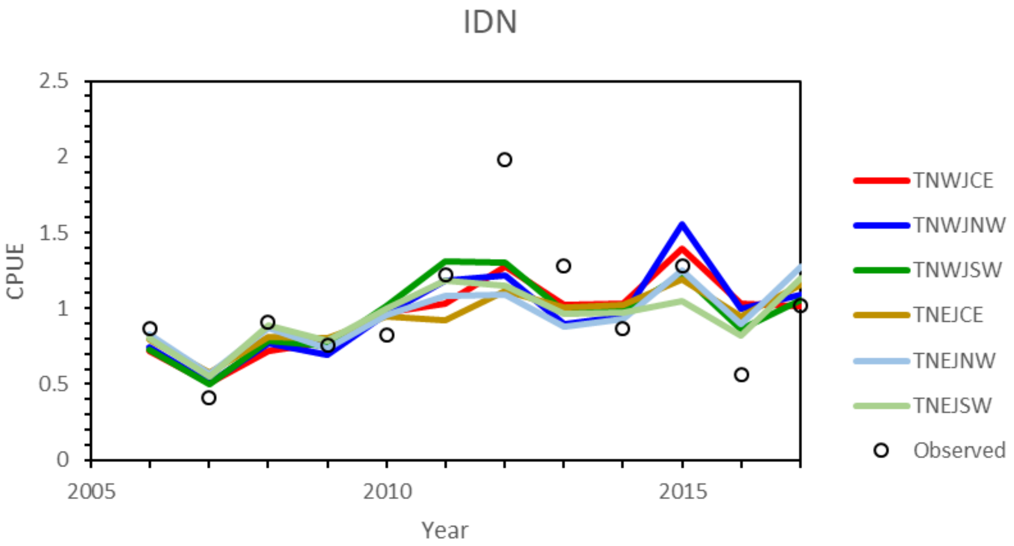


Fig. 4. (Continued).





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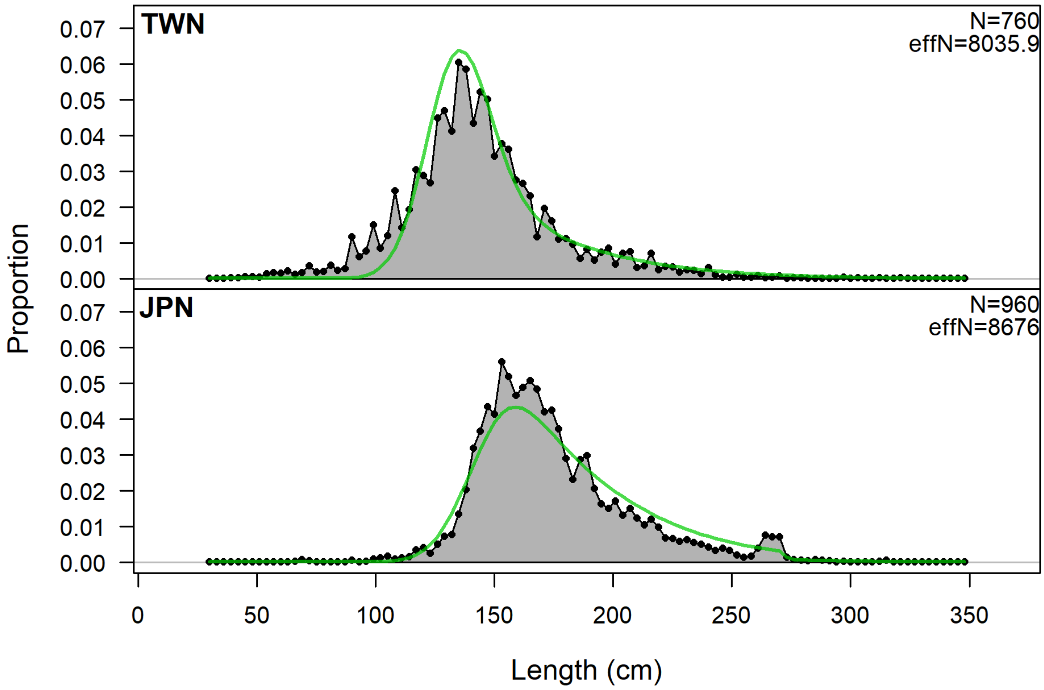
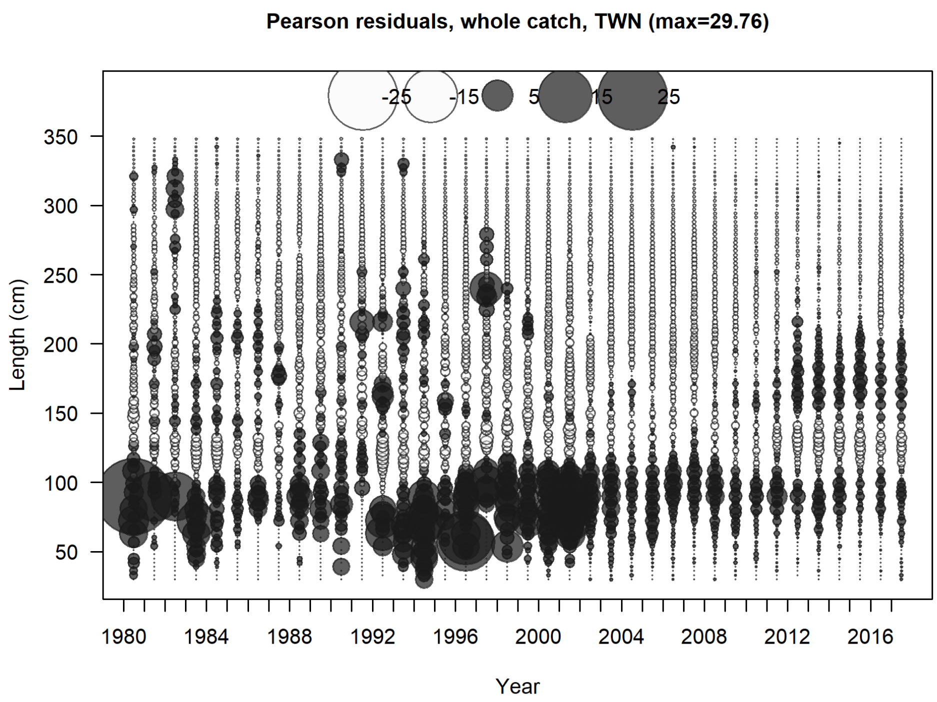


Fig. 5. Observed (shaded areas) and model-estimated (lines) length-frequencies of blue marlin in the Indian Ocean obtained from scenario of TNWJCE. The data were aggregated across time by fleets based on the base-case.



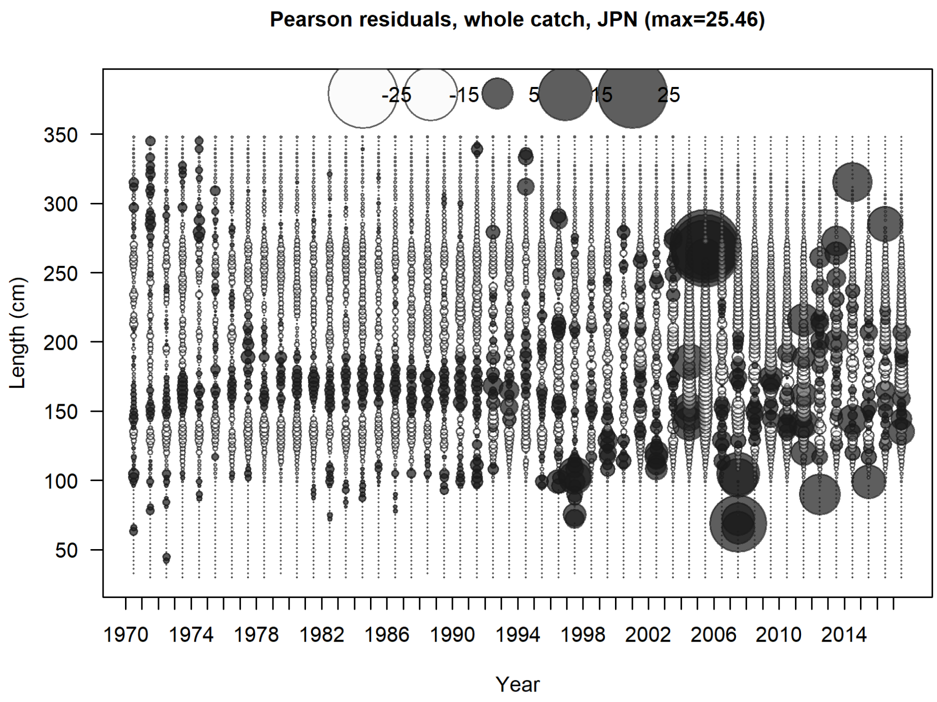


Fig. 6. Pearson residuals of the model fits to length-frequency data of blue marlin in the Indian Ocean obtained from scenario of TNWJCE. Closed bubbles are positive residuals (observed > expected) and open bubbles are negative residuals (observed < expected). Upper panel for JPN and lower panel for TWN.

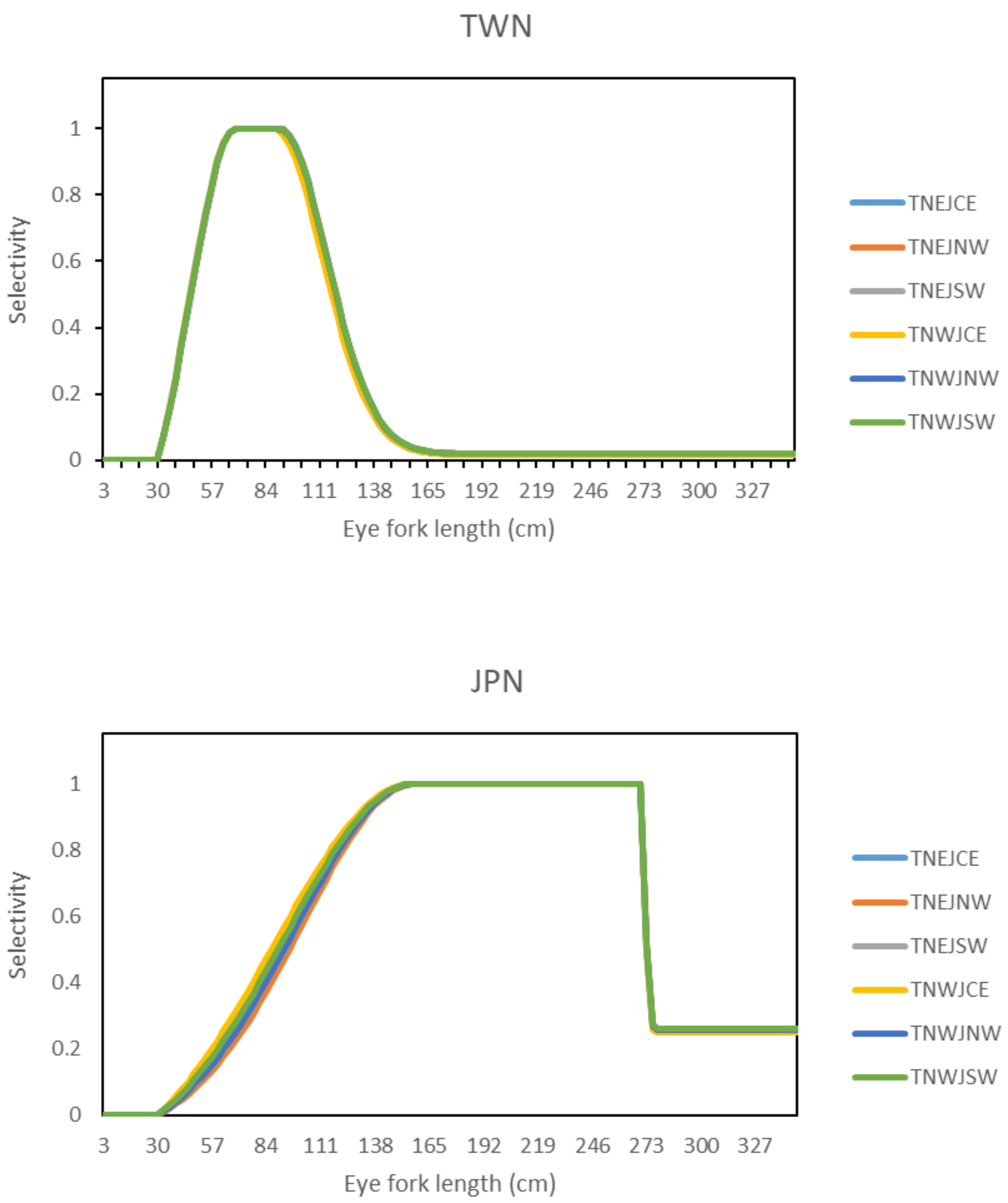


Fig. 7. Model estimated Selectivity at length for blue marlin in the Indian Ocean obtained from various scenarios.

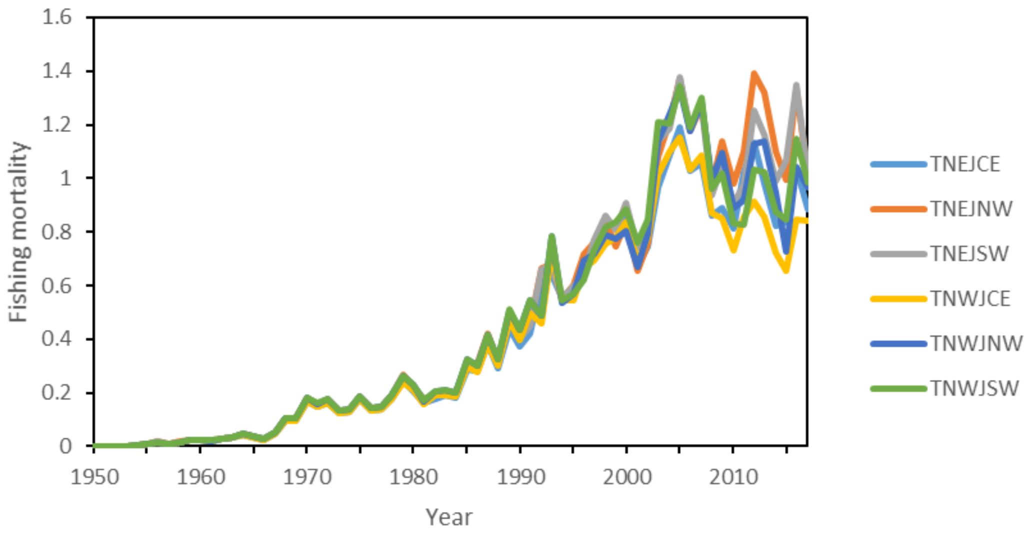


Fig. 8. Time trajectory of the maximum likelihood estimate of total fishing mortality for blue marlin in the Indian Ocean obtained from various scenarios.

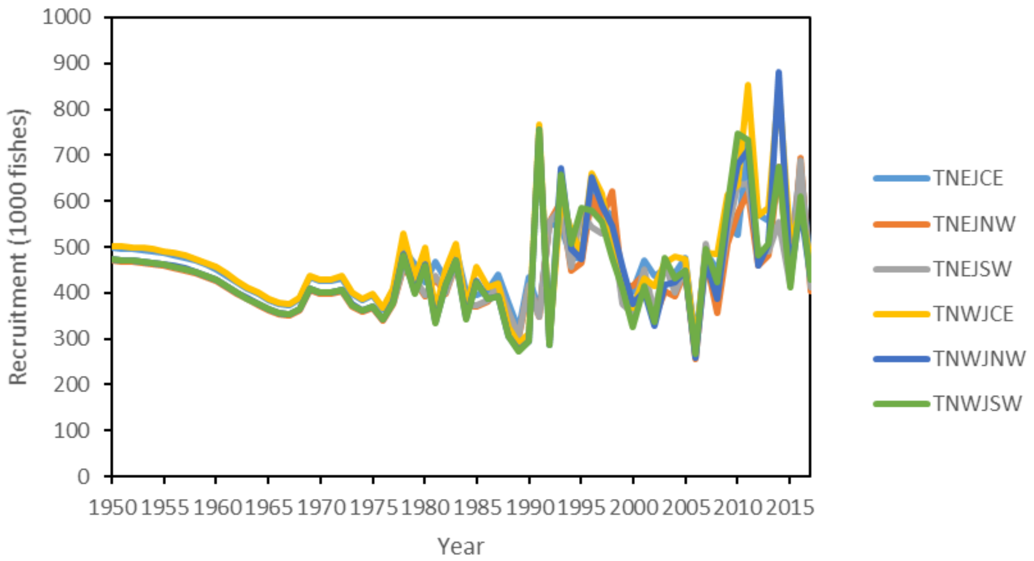


Fig. 9. Time trajectory of the maximum likelihood estimate of recruitment for blue marlin in the Indian Ocean obtained from various scenarios.

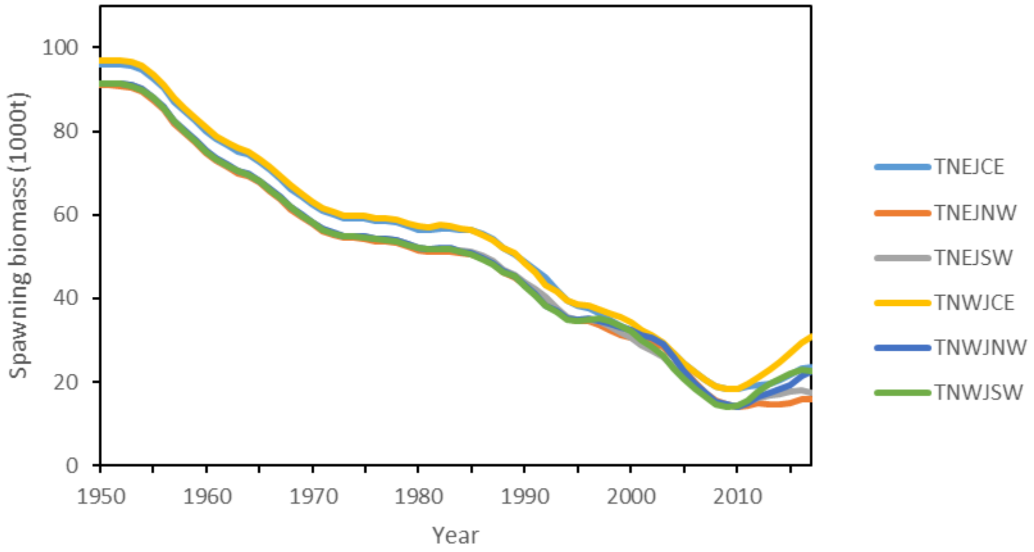


Fig. 10. Time trajectory of the maximum likelihood estimate of spawning biomass for blue marlin in the Indian Ocean obtained from various scenarios.

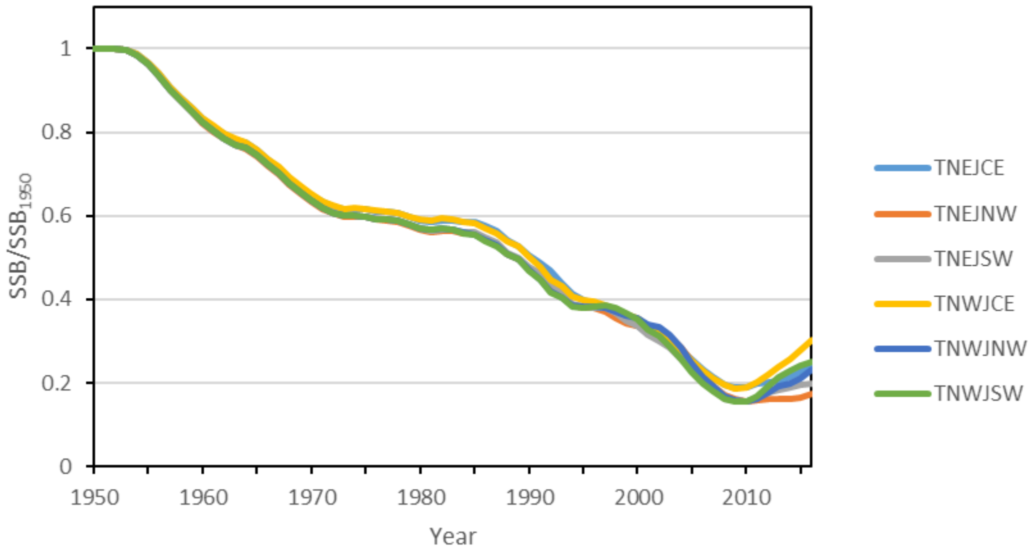


Fig. 11. Time trajectory of the maximum likelihood estimate of the spawning biomass as a ratio of its initial level for blue marlin in the Indian Ocean obtained from various scenarios.

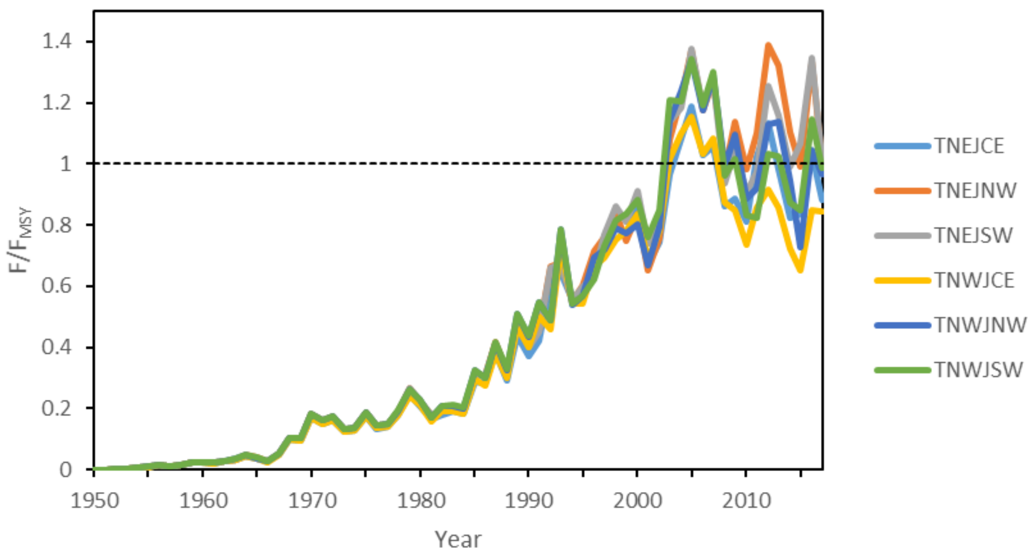


Fig. 12. Time trajectory of the maximum likelihood estimate of the fishing mortality as a ratio of that at which MSY is achieved for blue marlin in the Indian Ocean obtained from various scenarios.

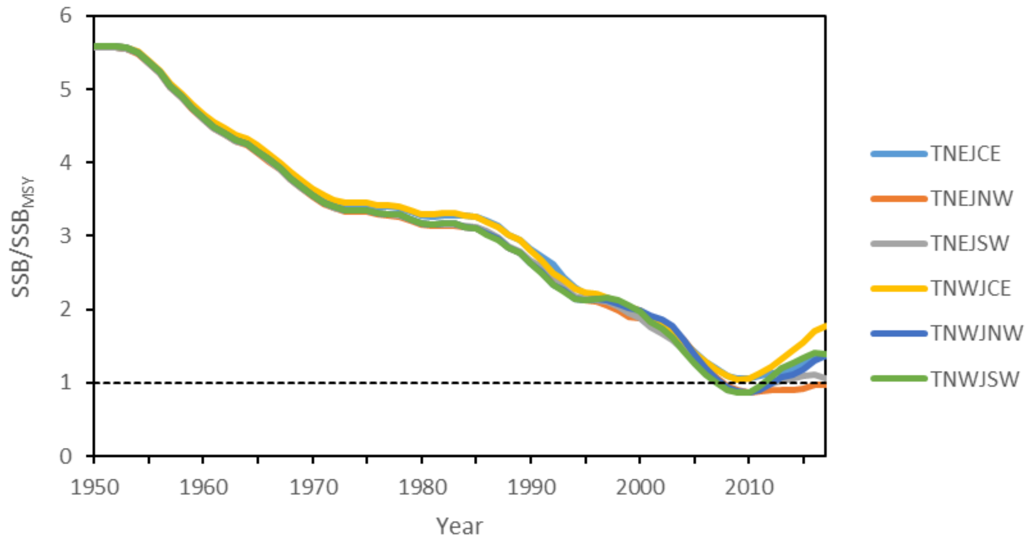


Fig. 13. Time trajectory of the maximum likelihood estimate of the spawning biomass as a ratio of that at which MSY is achieved for blue marlin in the Indian Ocean obtained from various scenarios.

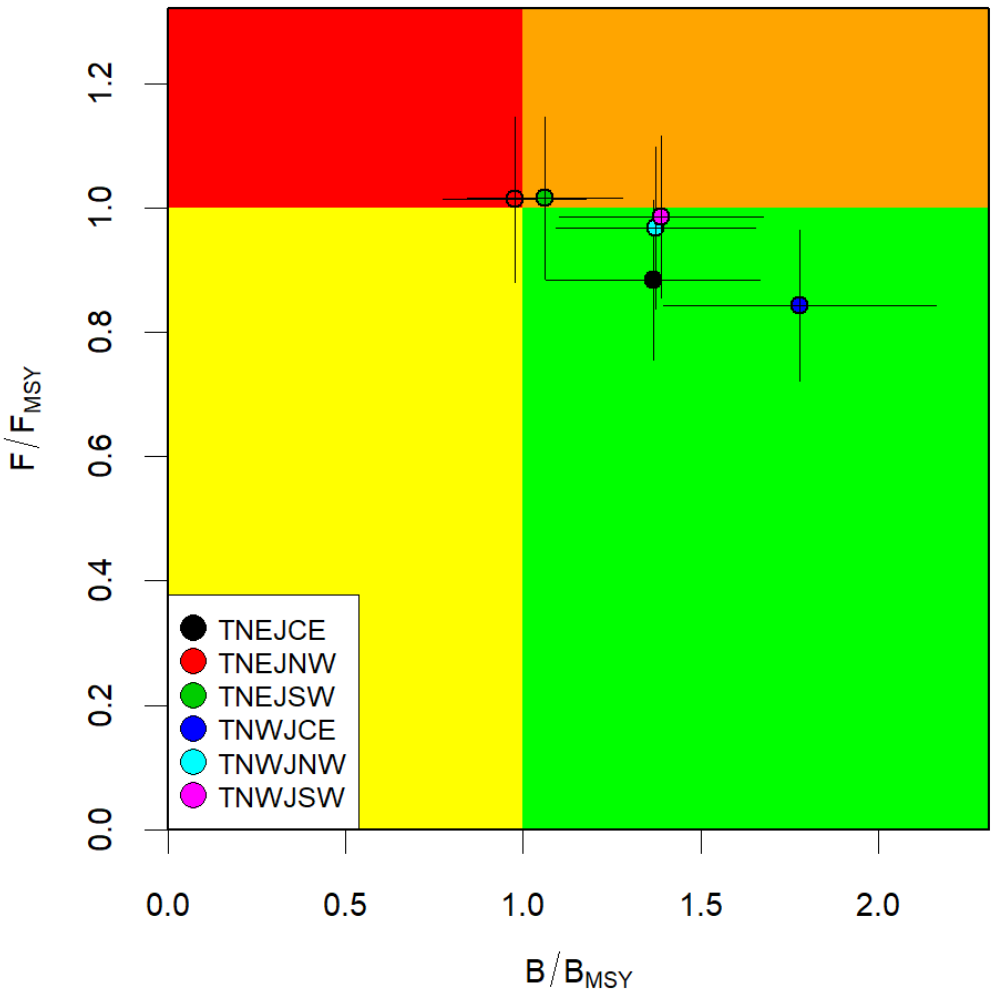


Fig. 14. Kobe plot for blue marlin in the Indian Ocean based on the estimates and standard errors obtained from various scenarios.

Table 1. Life-history parameters of blue marlin used in this study.

Parameter	Female	Male
Natural mortality (*M*, year^{-1})	0.22	0.37
Length at youngest age (*L*1, cm)	144.000	144.000
Length at oldest age (*L*2, cm)	304.178	226.000
Growth coefficient (*K*, year^{-1})	0.107	0.211
Length-Weight (*a*)	1.844E−5	1.37E−05
Length-Weight (*b*)	2.956	2.975
Length at 50% maturity (cm)	179.76	
Maturity slope	-0.25	
Spawner-recruit steepness (*h*)	0.87	0.87
Variation in recruitment (σ)	0.4	0.4

Table 2. Model assumptions of scenarios conducted for sensitivity analysis.

Scenario	CPUE used
TNWJCE	TWN_NW+JPN_CE+IDN
TNWJNW	TWN_NW+JPN_NW+IDN
TNWJSW	TWN_NW+JPN_SW+IDN
TNEJCE	TWN_NE+JPN_CE+IDN
TNEJNW	TWN_NE+JPN_NW+IDN
TNEJSW	TWN_NE+JPN_SW+IDN

Table 3. The estimates of key management quantities for blue marlin in the Indian Ocean obtained from various scenarios.

Scenario	R_0	SSB_0	SSB_{2017}	MSY	F_{MSY}	SSB_{MSY}	Dep[1]	Bratio[2]	Fratio[3]
TNWJCE	511.7	97,190	30,831	9,272	7.005	17,322	0.318	1.780	0.843
TNWJNW	483.6	91,856	22,476	8,823	6.054	16,376	0.246	1.372	0.967
TNWJSW	482.5	91,646	22,694	8,811	6.000	16,335	0.249	1.389	0.985
TNEJCE	507.6	96,423	23,553	9,260	6.754	17,236	0.245	1.367	0.884
TNEJNW	480.7	91,306	15,935	8,831	5.866	16,325	0.175	0.976	1.014
TNEJSW	482.9	91,720	17,387	8,870	5.828	16,391	0.190	1.061	1.016

1. SSB_{2017}/SSB_{1950}
2. SSB_{2017}/SSB_{MSY}
3. F_{2017}/F_{MSY}