Stock assessment of striped marlin (*Kajikia audax*) in the Indian Ocean using a sex-specific age-structured integrated approach

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ABSTRACT

This study evaluated the stock status of striped marlin in the Indian Ocean based on a sex-specific age-structured integrated approach (ASIA). The model generally fits to the observed length frequency data well, except for fisheries other than longline fisheries. The model cannot fit to CPUE data very well for Japanese longline fleet in early years because Japanese CPUE sharply decreased in early years but catchability was assumed to be constant over time. The assessment results indicated that the current fishing intensity and spawning biomass were lower than MSY level. This indicated that the stock status of striped marlin in the Indian Ocean might be overfished but not be overfishing. However, the assessment results might be highly uncertain because of absence of life history parameters and insufficiency of length-frequency data for striped marlin in the Indian Ocean.

INTRODUCTION

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), State Space Bayesian production model and stock reduction analysis and the results of three models indicated that the stock is determined to be overfished and subject to overfishing (IOTC, 2013). In previous assessment, catch and CPUE data were only used to fit to the assessment models. Since historical length-frequency data are available for striped marlin in the Indian Ocean, the length-based assessment methods (e.g. Fournier et al., 1998; Wang et al., 2005; Wang et al., 2007; Methot and Wetzel, 2013; Wang et al., 2015) can be applied to assess the population status. Therefore, this study attempt to evaluate the stock status of striped marlin in the Indian Ocean using a sex-specific age-structured integrated approach.

MATERIALS AND METHODS

Data used

The data used for assessment are the catches, length–frequencies, and CPUE-based indices of abundance. The historical catches in weight and length-frequency data from 1950 to 2014 for all fisheries were provided by Indian Ocean Tuna Commission (IOTC). All of the length-frequency data were aggregated into 3 cm interval length-compositions for each fishery.

The relative abundance indices used in this study were based on the standardized CPUE of Taiwanese (1980-2013) and Japanese (1976-2013) longline fisheries (Ijima et al., 2015; Wang 2015).

Striped marlin are caught almost exclusively under drifting longlines (72%) with remaining catches recorded under gillnets and troll lines. The catches under drifting longlines have been recorded under Taiwan, Japan, Republic of Korea fleets and, recently, Indonesia and several NEI fleets. Taiwanese and Japanese longline fisheries historically exploited striped marlin in the Indian Ocean as bycatch and their striped catches mainly concentrated in northwestern west and northeastern Indian Ocean, respectively, In recent years, the fleets of Taiwan (longline) and to a lesser extent Indonesia (longline) are attributed with the highest catches of striped marlin (IOTC, 2014). Except for Taiwanese and Japanese longline fisheries, however, sample sizes of length-frequency data fleets were very low for other fisheries. Due to catches distribution and data availability for striped marlin, fisheries operated in the Indian Ocean were simply aggregated into the 3 fleets (LL1: Japan type; LL2: Taiwan type; OTH: Other fisheries), which are similar to Nishida (2015) (Fig. 1).

Biological information

Since 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 life history parameters used in stock assessment for striped marlin in the Western and Central North Pacific Ocean were adopted in this study (see ISC, 2015 for details). The biological parameters used in this study are listed in Table 1.

Assessment model

The sex-specific age–structured integrated analysis used in this study was based on the population dynamics model developed by Wang et al. (2005, 2007, 2015). This model considers striped marlin from age 0 to 15 (age 15 being treated as a ‘plus group’) (ISC, 2015). The model assumes that recruitment is related to spawning stock biomass according to a Beverton–Holt stock-recruitment relationship and that the deviations about this relationship are log-normally distributed. The recruitment deviations for the years prior to 1975 are set to zero due to lack of information in the length–frequency data about the year-class strength for these years. The recruitment deviations for the years after 1975 are treated as parameters of the assessment model, with a penalty based on the distributional assumption.

The parameters of the model can be divided into those for which auxiliary information is available and are estimated outside the assessment model and those that needed to be estimated by fitting the stock assessment model to the data. The values for the parameters related to natural mortality (M), the steepness of the stock-recruitment relationship (h), and the extent of variation in recruitment (σ_v) cannot be determined from auxiliary information, nor can they be estimated reliably by fitting the model to the data (results not shown) and must therefore be pre-specified. In this study, the base-case value for M is taken to be 0.45 year^{-1}, h is assumed to be 0.86, and σ_v is assumed to be 0.6 (ISC, 2015). Constraints are imposed on the extent to which the number of 0-year-olds can deviate from the underlying stock-recruitment relationship.

The logistic curve is commonly used in fisheries stock assessment models to represent selectivity for longline gears. However, few catches of striped marlin with large body lengths were made by longline fleet and the distributions of length-frequency data obviously concentrated in a relative narrow range (Fig. 2). Therefore, selectivity was assumed to be a dome-shaped curve (represented by a double normal ogive (Bull et al., 2012) for all fleets. Catchability was assumed to be constant over time for all fleets.

The objective function, which is minimized, combines the negative log-likelihoods for the CPUE and length-frequency data, and a penalty for the annual recruitment deviates. The model is implemented using AD Model Builder (Fournier et al., 2012). The Markov Chain Monte Carlo (MCMC) method is used to develop Bayesian posterior distributions for the parameters of the model and the key quantities of management interest. The posterior distributions are constructed based on samples generated by conducting 1,020,000 cycles of the MCMC algorithm, ignoring the first 20,000 cycles as the burn in” period, and selecting every 1000th parameter vector thereafter. The median with 80% C.I. (the 10th and 90th percentiles) of posterior of model estimates are used to evaluate the stock status of striped marlin in the Indian Ocean.

RESULTS AND DISCUSSION

The observed and the model estimated length frequencies aggregated across years are shown in Fig. 2. Generally, the model estimated length-frequencies mimics the observed length frequency data well for longline fleets (LL1 and LL2). However, the model cannot fit to the length-frequency data for other fisheries (OTH) and due to few samples were available. The model estimated selectivites for females and males are shown in Fig. 3. Longline fisheries (LL1 and LL2) tended to select smaller fishes, while other fisheries (OTH) tended to selected both small and large fishes, especially for fishes with ages 3-7.

Fig. 4 shows the fits of the model to the observed CPUE data. The model cannot fit to CPUE series very well for LL1 because it sharply decreased in the early years but catchability was assumed to be constant over time.

Fig. 5 shows the trajectories of median of posterior distribution for SB_{2014} /SB_0, SB_{2014}/SB_{MSY} and F_{2014}/F_{MSY} for base-case analysis. The fleet-aggregated fishing intensity substantially increased to more than F_{MSY} since the early1990s due to the increasing of catch (Fig. 1) and this leaded to the obvious decreasing of spawning biomass. In recent three years, the estimates of fleet-aggregated fishing intensity was about 83% of F_{MSY} and the spawning biomass decreased to about 78% of SB_{MSY}, while the depletion of spawning biomass (SB_{2014} /SB_0) was still under a very low level of about 22% of SB_0.

Based on the Kobe plot, the results of this study indicate that the status of striped marlin in the Indian Ocean might be overfished but not be overfishing (Fig. 6). The estimates of quantities of management interest based on the base-case are summarized in Table 2.

Table 3 shows the Kobe II Strategy Matrix, which represents probability (percentage) of violating the MSY-based reference points for nine constant catch projections (average catch level from 2012–14 (4,049 t), ± 10%, ± 20%, ± 30% and ± 40%) projected for 3 and 10 years. The results indicate that there is low risk of fishing intensity exceeding the MSY level if future catch will be maintained at or lower than current level. To reduce the risk of spawning biomass dropping MSY level, however, decrease in catch might be necessary in the future. In addition, any increase in future catch would lead to obvious risk for both of spawning biomass and fishing intensity.

The stock status evaluated using the age-structured integrated approach adopted in this study is much more optimistic than those derived from surplus production models (IOTC, 2015; Nishida, 2015). However, the assessment results of this study might be highly uncertain because life history parameters are not available for striped marlin in the Indian Ocean and length-frequency data are also sparse for most fisheries other than Taiwanese and Japanese longline fisheries.

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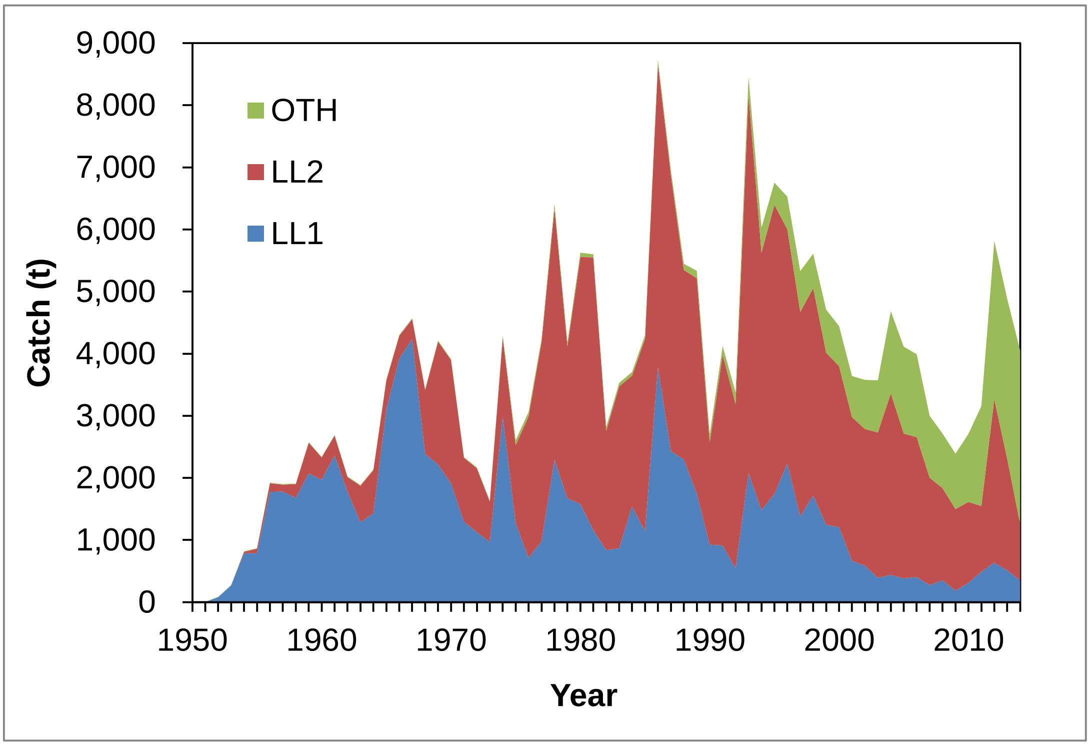

Fig. 1. Annual nominal catches (NC) of striped marlin in the Indian Ocean from 1950 to 2014.

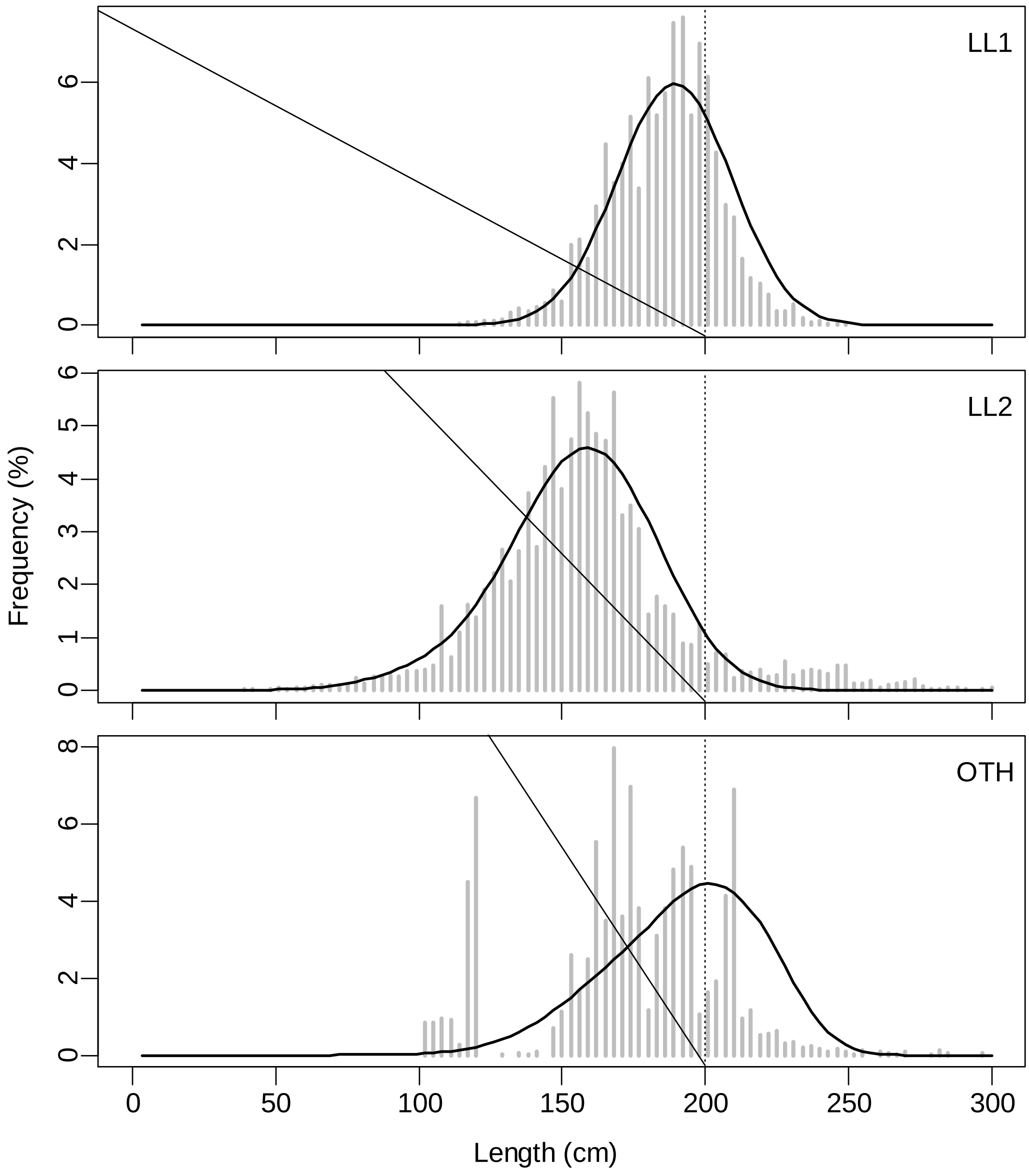

Fig. 2. Observed (histograms) and model-estimated (lines) length-frequencies of striped marlin in the Indian Ocean.

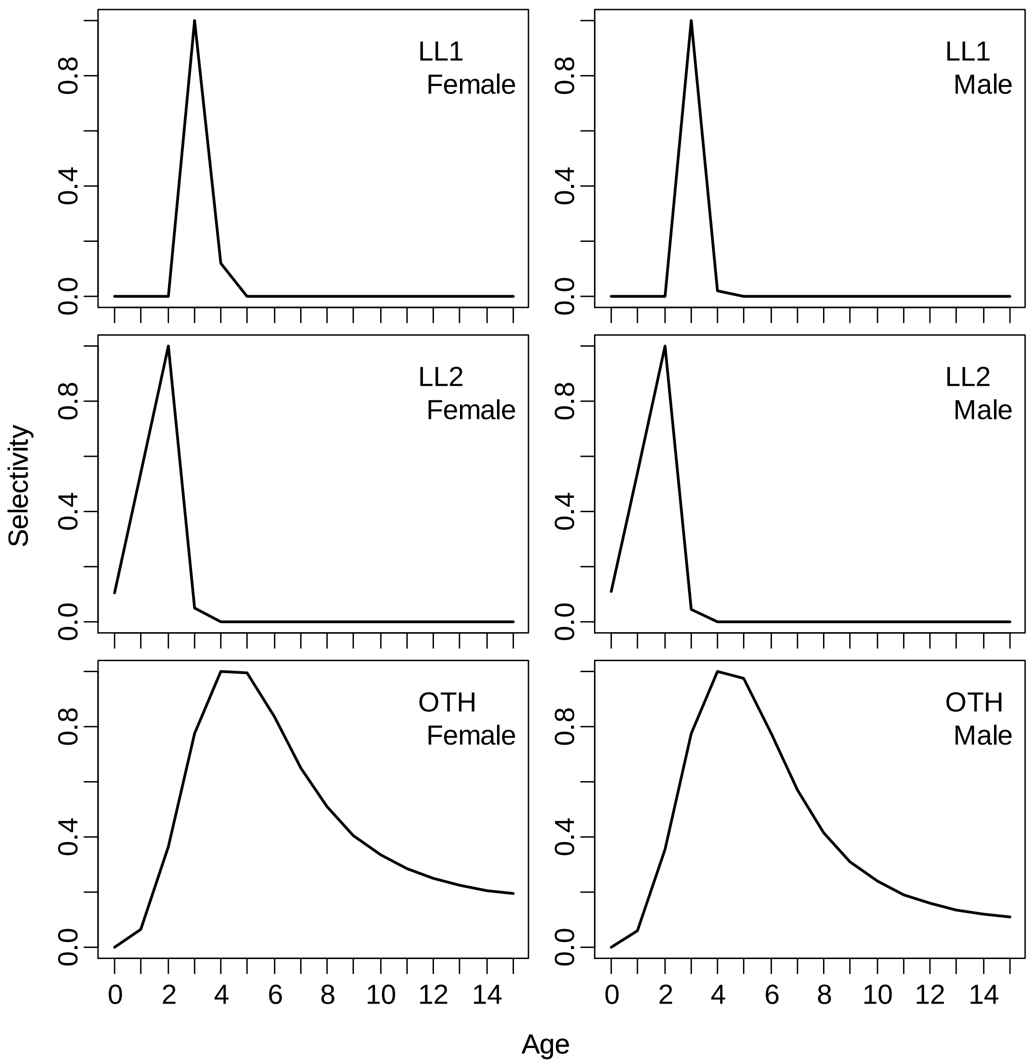

Fig. 3. Model-estimated selectivity curves for striped marlin in the Indian Ocean.

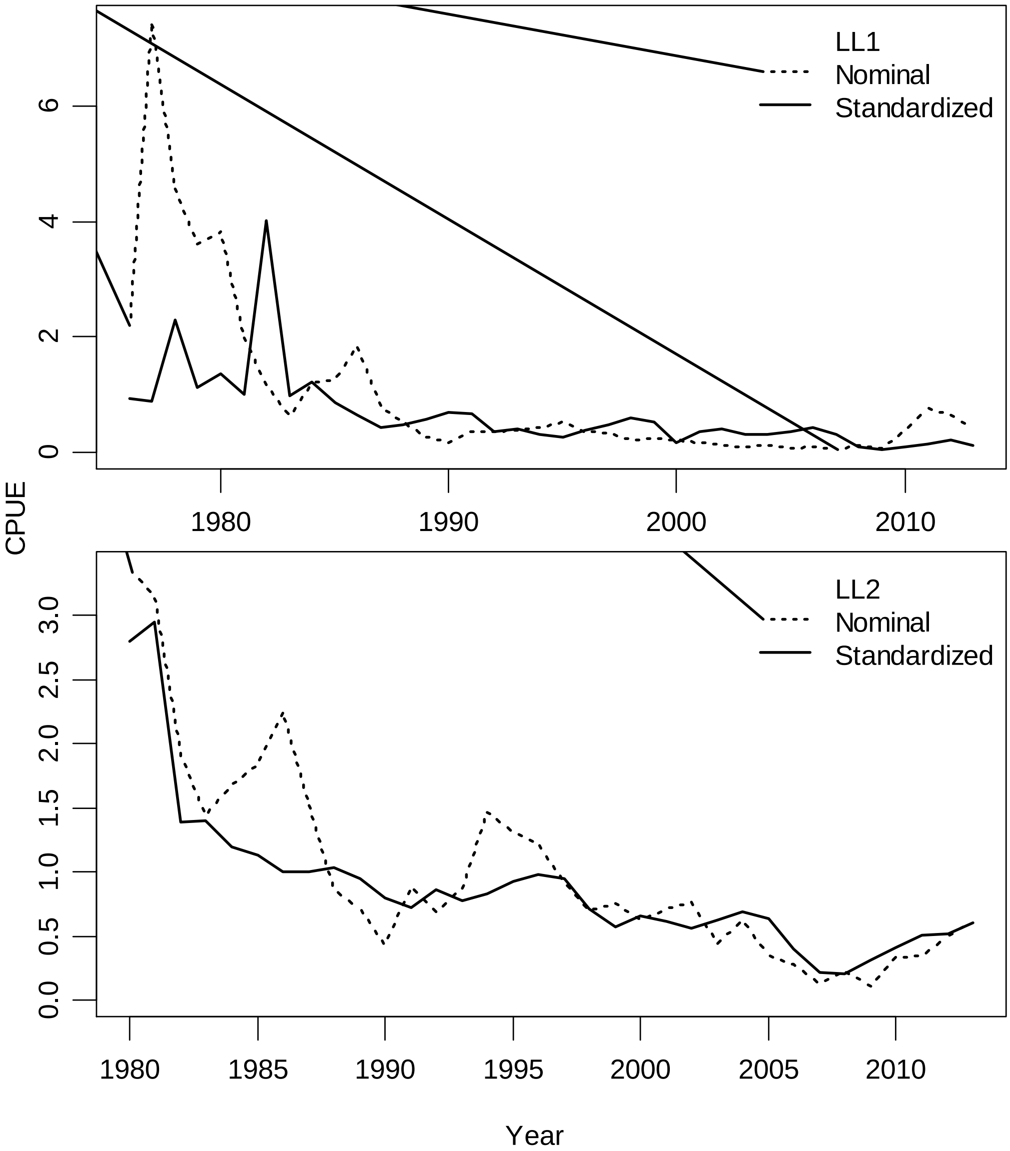

Fig. 4. Standardized observed CPUE (dot lines) and model-estimated CPUE (solid lines) of striped marlin in the Indian Ocean.

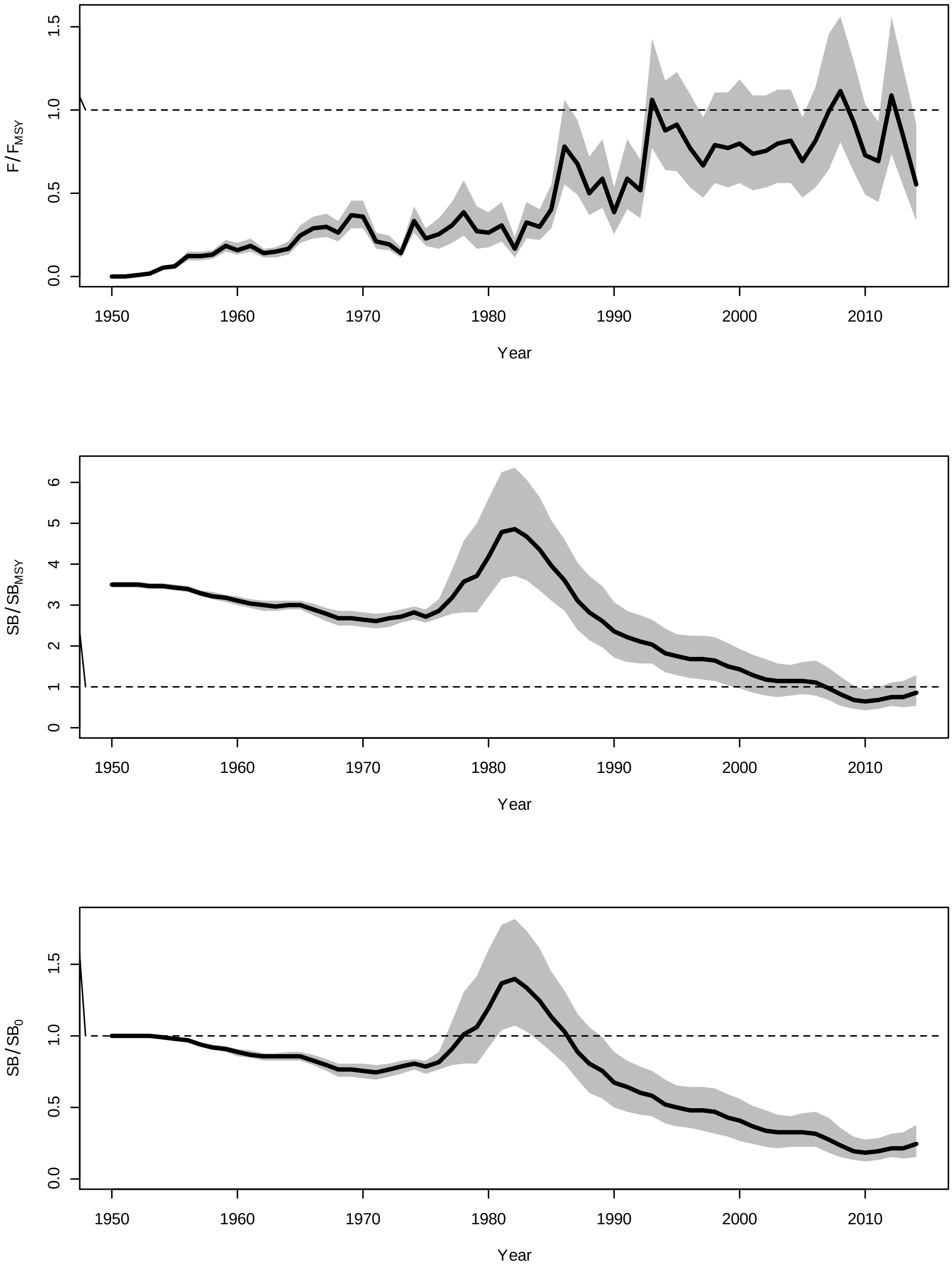

Fig. 5. Time trajectories of median of posterior distribution for the spawning biomass as a ratio of the unexploited spawning biomass (SB_{2014}/SB_0), the spawning biomass as a ratio of SB_{MSY} (SB_{2014}/S_{MSY}) and the fleet-aggregated fishing intensity as a ratio of that at which MSY is achieved (F_{2014}/F_{MSY}) for striped marlin in the Indian Ocean. Grey areas represent the 80% confidence intervals.

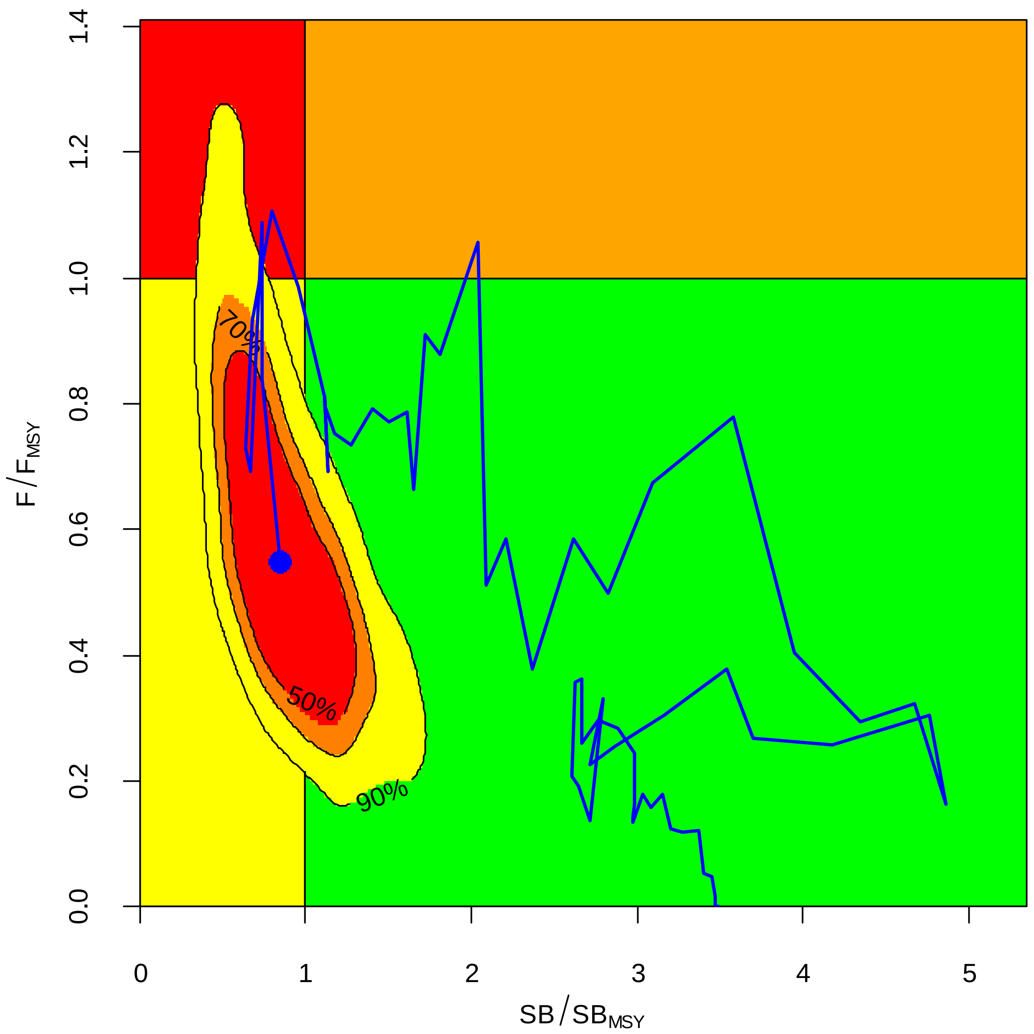

Fig. 6. Kobe plot for striped marlin in the Indian Ocean. The trajectory (blue line) was calculated based on the median of 1000 re-samplings of Bayesian posterior distribution. Blue circle indicate the estimate for 2014. Concentric ellipses represent 50%, 70% and 90% confidence surface of the estimate for 2014.

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)	15	15

Table 2. Key management quantities from the ASIA assessment, for the Indian Ocean.

Management Quantity	**Aggregate Indian Ocean**
2014 catch estimate	4,049
Mean catch from 2010–2014	4,122
MSY (1000 t) (80% CI)	6.40 (5.25–7.85)
Data period (catch)	1950–2014
F_{MSY} (80% CI)	0.73 (0.71–0.75)
SB_{MSY} (1,000 t) (80% CI)	6.95 (5.73–8.50)
F_{2014}/F_{MSY} (80% CI)	0.55 (0.33–0.91)
SB_{2014}/SB_{MSY} (80% CI)	0.85 (0.53–1.29).
SB_{2014}/SB_{1950} (80% CI)	0.24 (0.15–0.37)

Table 3. Kobe II Strategy Matrix for striped marlin in the Indian Ocean based on an age-structured integrated approach. Values represent probability (percentage) of violating the MSY-based reference points for nine constant catch projections (average catch level from 2012–14 (4,049 t), ± 10%, ± 20%, ± 30% and ± 40%) projected for 3 and 10 years.

Reference point and projection timeframe	**Alternative catch projections (relative to the average catch level from 2012–14) and probability (%) of violating MSY-based target reference points ($SB_{targ} = SB_{MSY}$; $F_{targ} = F_{MSY}$)**								
	60%	**70%**	**80%**	**90%**	**100%**	**110%**	**120%**	**130%**	**140%**
$SB_{2017} < SB_{MSY}$	6.6	7.2	10.3	14.5	18	21.8	24.7	27.9	32.2
$F_{2017} > F_{MSY}$	0	0	0.1	0.8	6.6	15.3	35.4	56	75.7
$SB_{2024} < SB_{MSY}$	2.4	3.3	5.1	10.6	26	46.5	77.1	90.6	96.2
$F_{2024} > F_{MSY}$	0	0	0	0	5.6	69.3	99.1	100	100