# Stock assessment of striped marlin (*Kajikia audax*) in the western and central North Pacific Ocean using an age-structured model: Updated to 2013*

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## Abstract

Based on the two-stock scenario of population structure, an age-structured population dynamics model was fitted to catch, catch-rate, and length-frequency data for the WCPO stock of striped marlin in the North Pacific Ocean to examine the current status of this population. Catch-rate and length-frequency data of striped marlin for Japanese, Taiwanese, and Hawaiian fisheries were included in the analyses. Results indicate that the current spawning stock biomass ($S_{2013}$) has increased to near but below the MSY level, and that the current fishing mortality ($F_{2013}$) has decreased to below the level to maintain MSY since 2010.

**Keywords:** striped marlin, stock assessment, age-structured model

## 1. Introduction

Striped marlin (*Kajikia audax*) is a highly migratory species and is broadly distributed across tropical, subtropical, and temperate oceanic waters in the Pacific and Indian Oceans, considered the most widely distributed billfish (Nakamura, 1985). They are an apex predator in the open ocean and valuable in commercial longline and recreational fisheries throughout their spatial distribution (Bromhead et al., 2004). This species is important to recreational fisheries around the Pacific Ocean, such as in Hawaii, New Zealand, Australia, Southern California, and Mexico (Kopf et al., 2011). However, striped marlin are generally considered as a bycatch species in the Japanese, Taiwanese, and Hawaiian commercial longline fisheries and the coastal and driftnet fisheries in Japan, while they are targeted by several small fisheries in various areas

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(Dalzell and Boggs, 2003; Kopf et al., 2011).

Several (semi-independent) stocks of striped marlin in the Pacific Ocean have been proposed based on differences in genetic population structure, body size, movement pattern, and spawning dynamics (McDowell and Graves, 2008; Purcell and Edmands, 2011). Single-stock or two-stock scenarios (i.e., the WCPO and EPO stocks separated at 140°W) for the stock structure of striped marlin in the north Pacific Ocean were assumed for stock assessments (ISC, 2007; 2011). Previous assessment of striped marlin in the North Pacific Ocean was conducted based on a single-stock scenario (ISC, 2007; 2011). The results showed that the striped marlin abundance has declined to a low fraction of its unfished level since the 1970s. However, the actual magnitude of abundance decline may be under-estimated or over-estimated given the substantial uncertainties in the assessments such as biological parameters, stock structures, or the data used in the assessment.

The objective of this study was to assess the current status of the striped marlin population in the western and central North Pacific Ocean (the WCPO stock) using an age-structured population dynamics model based on the two-stock scenario of striped marlin stock structure assumed by ISC (ISC, 2011). Fishery data are available up to 2013 (Figs. 1 and 2) and were used to update the assessment of Sun et al. (2011c).

## 2. Materials and methods

2.1. Data used

For the WCPO stock of striped marlin population in the North Pacific Ocean, the catch and effort data of various fisheries were compiled for stock assessments. Catch data of striped marlin (1952-2013) for the WCPO stock (Fig. 1), as well as the time-series of standardized CPUE for the Japanese, Taiwanese, and Hawaiian fisheries (Fig. 2), available from ISC Billfish Working Group (ISC, 2015), were used in this assessment. However, updated length composition data were not available from the Working Group, and thus sex-aggregated length-frequency data of striped marlin, available from the last assessment in 2011 (Sun et al. 2011c), were used and treated as input data by 5-cm length bin to fit a sex-pooled model for this updated assessment of striped marlin WCPO stock in the North Pacific Ocean.

2.2. The population dynamics model

The population dynamics model that forms the basis of this assessment is an age-structured model modified from Wang et al. (2007), and considers pooled sexes from age 0 to 15 (age 15 being treated as a "plus group", Table 1). 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 assessment period are treated as free parameters to be estimated to inform year-class strength for the years of the assessment model.

The logistic curve, which assumes that the vulnerability of a fish increases monotonically to an asymptote with increasing length, is used most commonly in fisheries stock assessment models to represent gear selectivity. The assumption that selectivity-at-age follows a logistic curve might be an adequate function to mimic the length-frequency data. However, owing to lack of length-frequency data for the other fleets, the selectivity ogives for these fleets are assumed to be the same with the Japanese driftnet fishery. Because length composition data are not available for recent years, the length data set, same in the last assessment, was used to fit the model.

### 2.3. Parameter estimation

The parameters of the model can be divided into those for which auxiliary information is available (Table 1) and those which need to be estimated from the monitoring data (Table 2). The biological parameters of striped marlin for the WCPO stock in the North Pacific Ocean refer to the age and growth and reproductive studies of Sun et al. (2011a, 2011b).

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 ($\sigma_v$) cannot be determined from auxiliary information, nor can they be estimated reliably by fitting the model to the data and must therefore be pre-specified. In this study, the value of $M$ is assumed to be 0.38 according to Piner and Lee (2011) and $h$ is assumed to be 0.87 following Brodziak (2011). The variation in recruitment is assumed to be 0.4 ranging between 0.3 and 0.5.

### 2.4. Model outputs

Model outputs are examined using several key quantities of management interest as follows: (1) $S_0$, the spawning stock biomass at unfished equilibrium; (2) $S_{2013}$, the current spawning stock biomass in 2013; (3) $F_{2013}$, the current fishing mortality aggregated over fleets in 2013; (4) $S_{MSY}$, the spawning stock biomass at which MSY is achieved; and (5) $F_{MSY}$, the exploitation rate at which MSY is achieved.

## 3. Results and discussion

Catch and CPUE data of striped marlin for the WCPO stock updated to 2013 were used in this assessment. Total catches over fleet are continuously decreasing from 2010-2013 (Fig. 1). However, updated standardized CPUE of striped marlin showed a slightly increasing trend since 2010 for the Japanese distant-water longline and driftnet fisheries, Taiwanese distant-water longline fishery, and US Hawaiian longline fishery (Fig. 2).

The model-estimated catch-rates of fleets from the Japanese, Taiwanese and Hawaiian fisheries are shown in Fig. 3 to assess the model fits, which all generally follow the trends of standardized catch-rate indices, except for the early Japanese distant-water longline fishery before 1975. The observed (standardized) catch-rates for this fleet showed an increasing trend, while the model-predicted abundance indices seem to decline when the fishery began from 1952. We thus fitted the model using separated catch-rate series of different periods for the Japanese distant-water longline fishery (Fig. 3). Two separate CPUE series for the Taiwanese distant-water obtained from Sun et al. (2015) were used in the assessment.

The observed and model-predicted length-frequencies of striped marlin for fleets of the Japanese, Taiwanese, and Hawaiian fisheries are illustrated in Fig. 4. Results are aggregated across years for ease of presentation. The model-predicted values of length frequencies generally follow the distribution of sampled length frequencies.

Figure 5 shows the time trajectory of the ratio of the spawning stock biomass to its MSY level ($S_{\mathrm{MSY}}$) and the ratio of exploitation rates relative to $F_{\mathrm{MSY}}$ for the base-case scenario ($M$ = 0.38 yr$^{-1}$, $h$ = 0.87, and $\sigma_{\mathrm{V}}$ = 0.4). The spawning stock biomass showed a decreasing trend since the early years. However, the population abundance seemed to recover from 1980 but continued to decline after the late 1990s (Fig. 5). This recovery of striped marlin population during 1980s probably results from the increasing CPUE trend for the Japanese driftnet and distant-water fisheries (Fig. 3), as well as the reduced catches of striped marlin since 1980 (Fig. 1). In addition, the abundance indices from the Taiwanese tuna longline fleets showed an increasing trend beginning from the late 1980s (Fig. 3).

This population seems to recover to near but below the MSY level, which reflects to lower fishing pressure in recent years from 2010 to 2013 (Fig. 1) and increasing abundance index trends since 2010 (see updated CPUE by fleet in Fig. 2).

In general, the exploitation rates for the WCPO stock of striped marlin in the North Pacific Ocean were higher than MSY level after 1970. This can correspond to the highest catches of striped marlin caught by the Japanese driftnet fishery during the 1970s (Fig. 1). However, the fishing mortality of striped marlin has been below the MSY level since 2010, which corresponds well to the historically lower level of catch since 1975 (2,274 mt in average over 2010-2013).

The current stock status of this population was examined using the "Kobe plot". Current spawning stock biomass of this population was estimated to be near but lower than the MSY level ($S_{2013}/S_{MSY}$ = 0.95), with current fishing mortality below the level to maintain MSY ($F_{2013}/F_{MSY}$ = 0.52) (Fig. 6). The population status still remains at an overfished state, but the stock has not experiencing overfishing. The results are sensitive to the values assumed for natural mortality ($M$ = 0.30-0.45 $yr^{-1}$) and steepness ($h$ = 0.80-0.95) but insensitive to recruitment variations, with the MSY estimated to be 3,549 mt. Compared with the last assessment (Sun et al. 2011c), the population was observed in a low fraction of its initial biomass ($S_{2009}/S_{MSY}$ = 0.54 and $F_{2009}/F_{MSY}$ = 1.10), while this stock seems to recover since 2010 due to relatively low fishing pressure in recent years (Figs. 1, 5, and 6). However, there was considerable uncertainty regarding the assessment results because CPUE and size composition data are not available from the other fisheries such as China and Korea (ISC, 2015) to this updated assessment.

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Table 1. Values assumed for the parameters of relationships between length and age, length and weight, and length and maturity, based on age and growth and reproductive biology studies of striped marlin from Sun et al. (2011a; 2011b).

| Parameter | Value |
|---|---|
| Asymptotic length, $L_{\infty}$ (cm) | 246.60 |
| Growth parameter, $k$ (yr$^{-1}$) | 0.26 |
| Age-at-zero-length, $t_0$ (yr) | –2.55 |
| Length-weight, $A$ | $4.68 \times 10^{-6}$ |
| Length-weight, $B$ | 3.16 |
| Length-at-50%-maturity, $L_{m50\%}$ (cm) | 178.98 |
| Length-at-95%-maturity, $L_{m95\%}$ (cm) | 235.96 |
| Maximum age, $\lambda$ (yr) | 15 |

Table 2. Parameters estimated or pre-specified in the population dynamics model.

| Parameter | Number of parameters |
|---|---|
| Estimated | |
| Unfished recruitment, $R_0$ | 1 |
| Process errors, $v_t$ | 1 per year |
| Length-at-50%-selectivity, $L_{50}$ | 1 per fleet |
| Length-at-95%-selectivity, $L_{95}$ | 1 per fleet |
| Pre-specified | |
| Natural mortality, $M$ | 1 |
| Steepness, $h$ | 1 |
| Variation in recruitment, $\sigma_v$ | 1 |

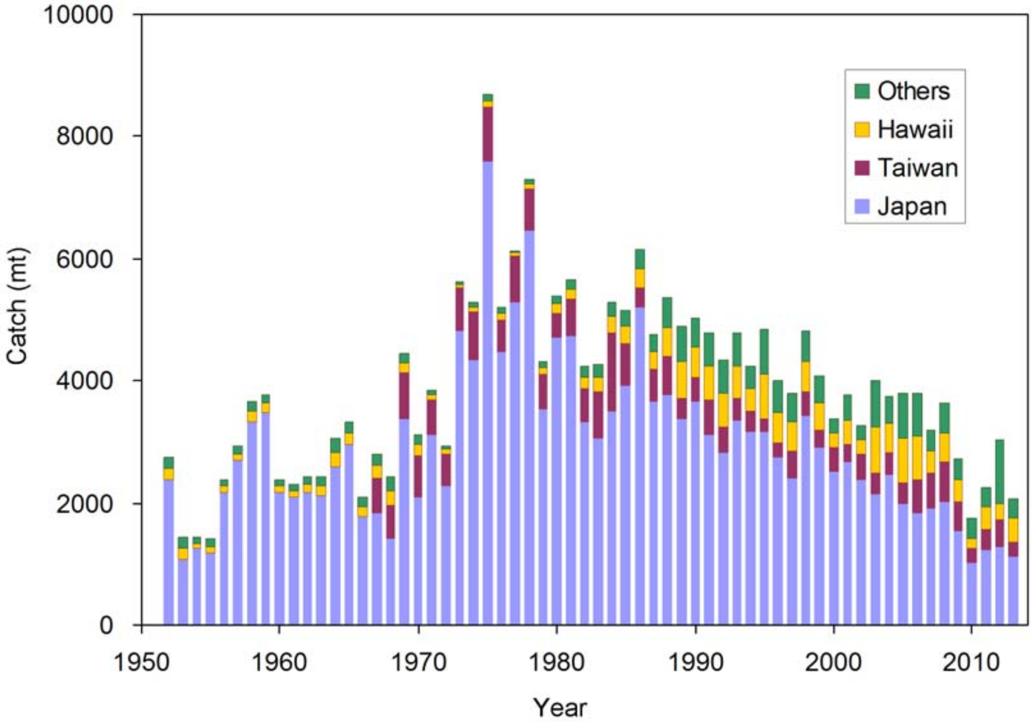


Fig. 1. Annual catches (1952-2013) of striped marlin for the WCPO stock in the North Pacific Ocean. Data source: ISC/15/BILLWG-1/WP5.

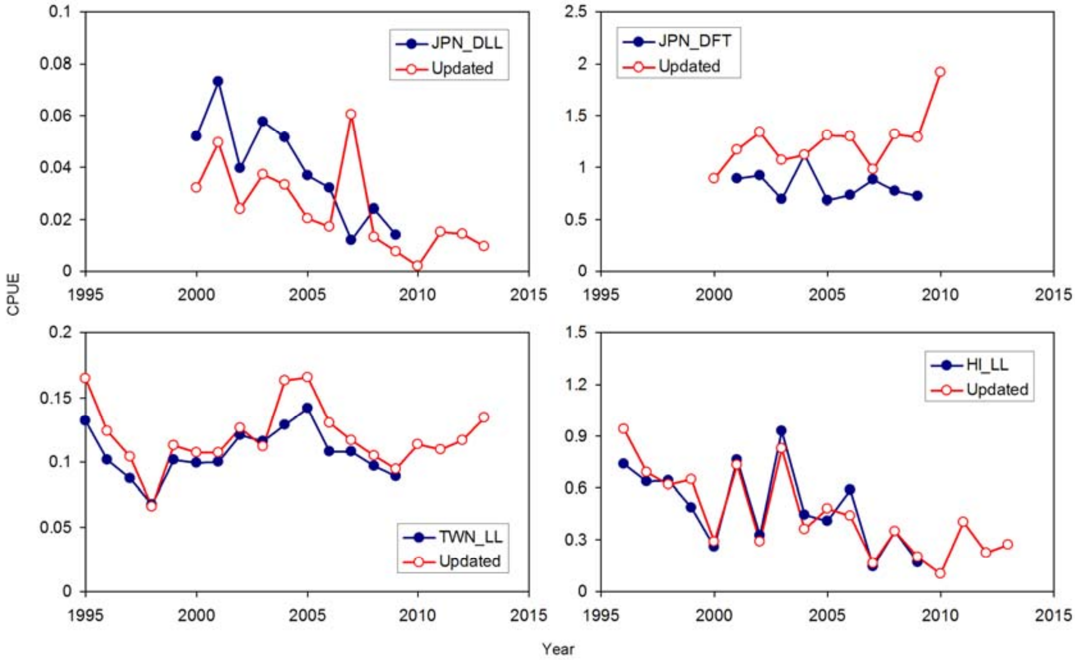


Fig. 2. Standardized CPUE of striped marlin and those updated to 2013 for the WCPO stock in the North Pacific Ocean. JPN_DLL: Japanese distant-water longline; JPN_DFT: Japanese driftnet; TWN_LL: Taiwanese longline; HI_LL: Hawaiian longline. Data are sourced from the billfish working group meeting of ISC (ISC/15/BILLWG-1, working papers WP3, WP7, WP9, and WP10).

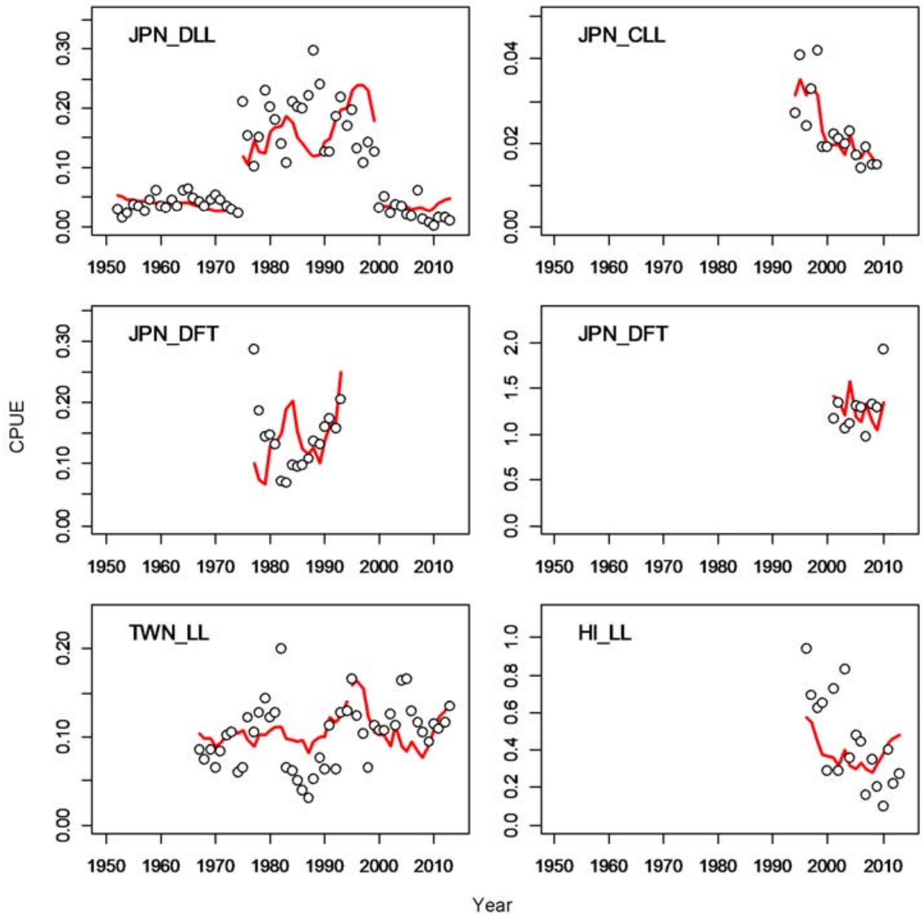


Fig. 3. Standardized (circles) and model-predicted (lines) CPUE of striped marlin for the WCPO stock in the North Pacific Ocean. JPN_DLL: Japanese distant-water longline; JPN_CLL: Japanese coastal longline; JPN_DFT: Japanese driftnet; TWN_LL: Taiwanese longline; HI_LL: Hawaiian longline.

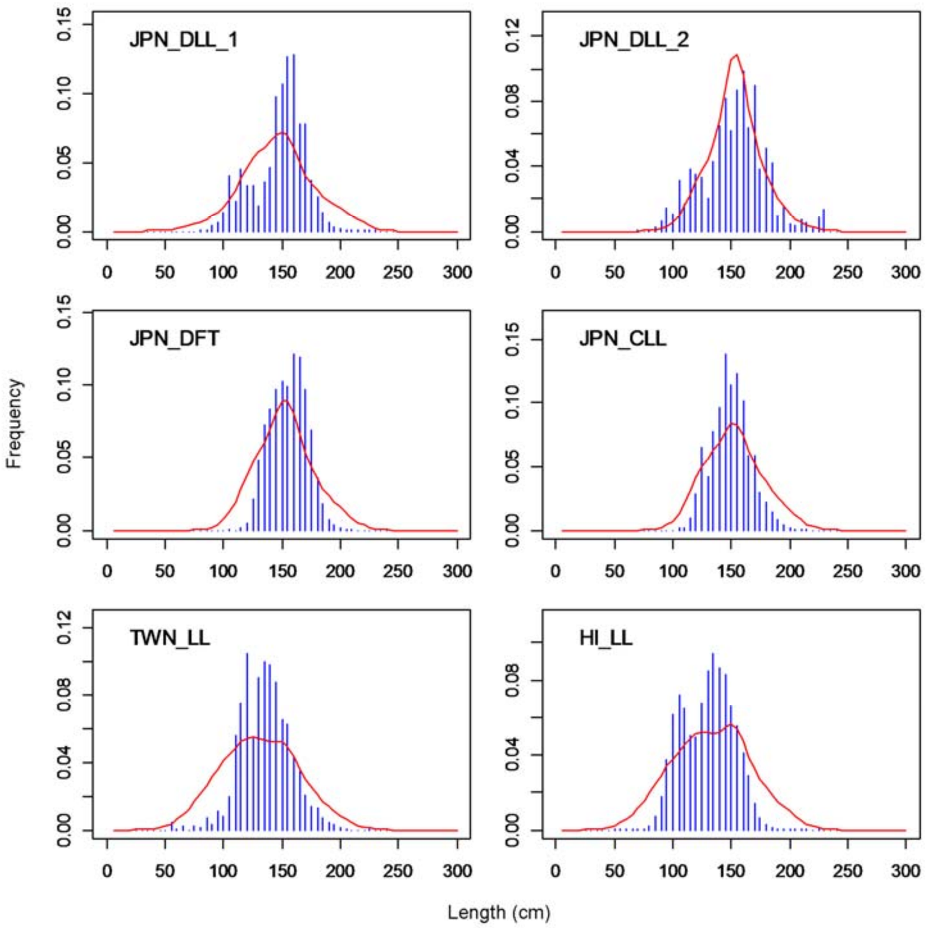


Fig. 4. Observed (histograms) and model-predicted (lines) length-frequencies of striped marlin for the WCPO stock in the North Pacific Ocean. JPN_DLL: Japanese distant-water longline; JPN_CLL: Japanese coastal longline; JPN_DFT: Japanese driftnet; TWN_LL: Taiwanese longline; HI_LL: Hawaiian longline.

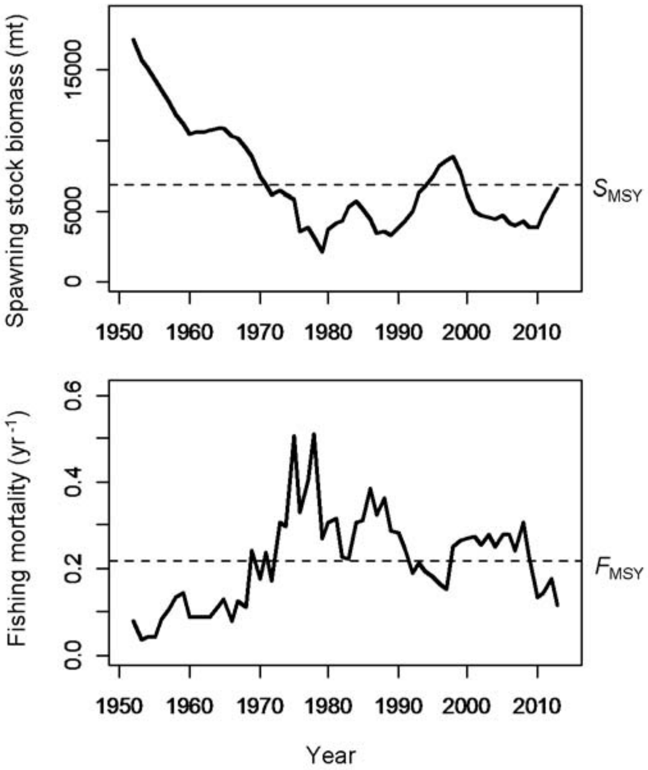


Fig. 5. Time trajectories of the spawning stock biomass relative to the MSY level ($S/S_{MSY}$) and the fishing mortality relative to that at MSY ($F/F_{MSY}$) for the WCPO stock of striped marlin in the North Pacific Ocean.

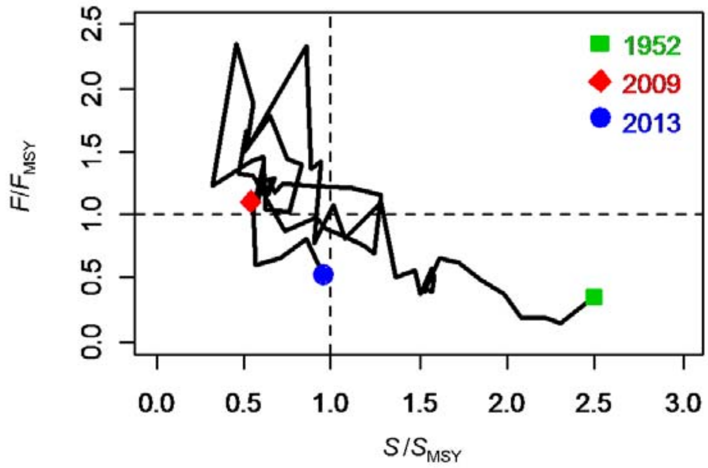


Fig. 6. The estimated spawning stock biomass relative to that supports MSY ($S/S_{MSY}$) versus the estimated fishing mortality relative to that at MSY ($F/F_{MSY}$) for the WCPO stock of striped marlin in the North Pacific Ocean. The point for 2009 was based on the last assessment results conducted in 2011 (Sun et al. 2011c).