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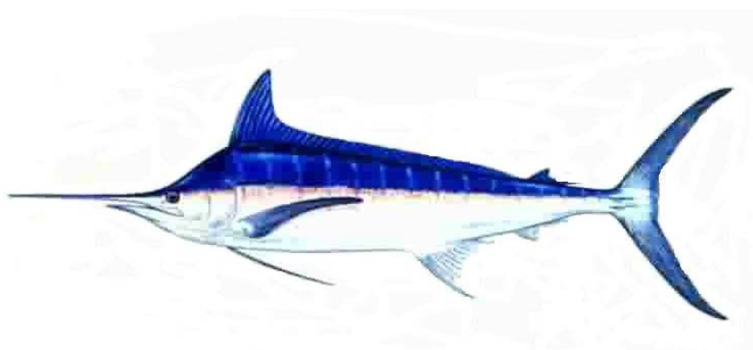

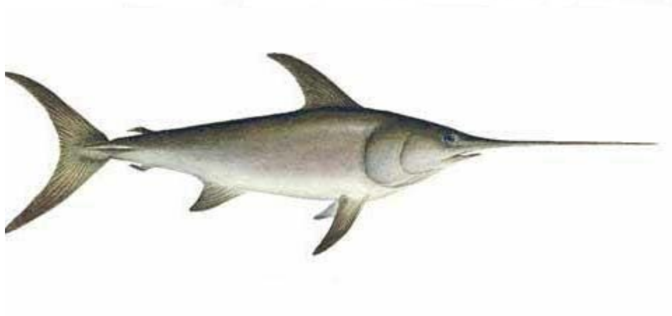

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Stock assessment of striped marlin (*Kajikia audax*) in the western and central North Pacific Ocean using an age-structured model*

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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_{2009}) was at a low fraction of its unfished level and below the MSY level, and that the current fishing intensity (F_{2009}) exceeded the level to maintain MSY. However, there was considerable uncertainty regarding the assessment results because of the conflict between the CPUE series and size-composition data when fitting the model with all available data.

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). Striped marlin is an apex predator in the open ocean and valuable in commercial longline and recreational fisheries throughout its distribution (Bromhead et al., 2004). They are important catches to recreational fisheries around the Pacific Ocean, such as in Hawaii, New Zealand, Australia, Southern California, and Mexico (Kopf et al., 2011). However, this species is generally considered as a bycatch species in the Japanese, Taiwanese, and Hawaiian commercial longline fisheries and the coastal and driftnet fisheries in Japan, with smaller targeted fisheries in several locations (Dalzell and Boggs, 2003; Kopf et al., 2011).

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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 (i.e., the WCPO and EPO stocks separated at 140°W) scenarios 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). The results showed that the striped marlin abundance has declined 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 assessment data used, biological parameters, or stock structures.

The objective of this study is 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).

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 (1952-2009) for the WCPO stock were available from ISC Billfish Working Group (Fig. 1), as well as the time-series of standardized catch-rates and length data for the Japanese, Taiwanese, and Hawaiian longline fisheries, and used for the assessments (ISC, 2011). Sex-aggregated length-frequency data of striped marlin are treated as input data by 5-cm length bin to fit a sex-pooled model for this 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 for the 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.

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 (σ_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

The 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_{2009}, the current spawning stock biomass in 2009; (3) F_{2009}, the current fishing mortality aggregated over fleets in 2009; (4) S_{MSY}, the spawning stock biomass at which MSY is achieved; and (5) F_{MSY}, the exploitation rate at which MSY is achieved. The current status of this stock is examined using the "Kobe plot".

3. Results and discussion

The observed and model-predicted length-frequencies of striped marlin for the Japanese, Taiwanese, and Hawaiian fisheries are illustrated in Fig. 2. Results are aggregated across years for ease of presentation. The model-predicted values of length frequencies generally follow the distribution of sampled length frequencies (Fig. 2).

To assess the model fits, the model-estimated catch-rates of the seven fleets from the Japanese, Taiwanese and Hawaiian fisheries are shown in Fig. 3, 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 (Fig. 3). We tried to fit the model using separated catch-rate series of Japanese distant-water longline fishery for 1975-1986, 1987-1999, and 2000-2009. However, the model cannot converge with realistic assessment results.

Figure 4 shows the time trajectory of the ratio of the spawning stock biomass to its MSY level (S_{MSY}) and the ratio of exploitation rates relative to F_{MSY} for the base-case scenario (M = 0.38 yr^{-1}, h = 0.87, and σ_v = 0.4). Generally, the exploitation rates for the WCPO stock of striped marlin in the North Pacific Ocean are 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).

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. 4). 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, but they began from the late 1980s (Fig. 3).

Figure 5 shows the "Kobe Plots" for the WCPO stock of striped marlin in the North Pacific Ocean. Current spawning stock biomass of this population is estimated to be lower than the MSY level (S_{2009}/S_{MSY} = 0.54), with current fishing mortality exceeding the level to maintain MSY (F_{2009}/F_{MSY} = 1.10) (Fig. 5). The population status still remains at an over-fished state, although 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 a MSY estimated at 2,430 mt ranging from 1,696 to 2,851 mt. The population was observed in a low fraction of its initial biomass. However, there was considerable uncertainty regarding the stock assessment results because of the conflict between the CPUE series and size-composition data when fitting the model with all available data.

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Table 1. The values assumed for the parameters of the 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_∞ (cm)	246.60
Growth parameter, k (yr^{-1})	0.26
Age-at-zero-length, t_0 (yr)	–2.55
Length-weight, A	4.68×10^{-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, λ (yr)	15

Table 2. The parameters of the population dynamics model not known from auxiliary information.

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, σ_v	1

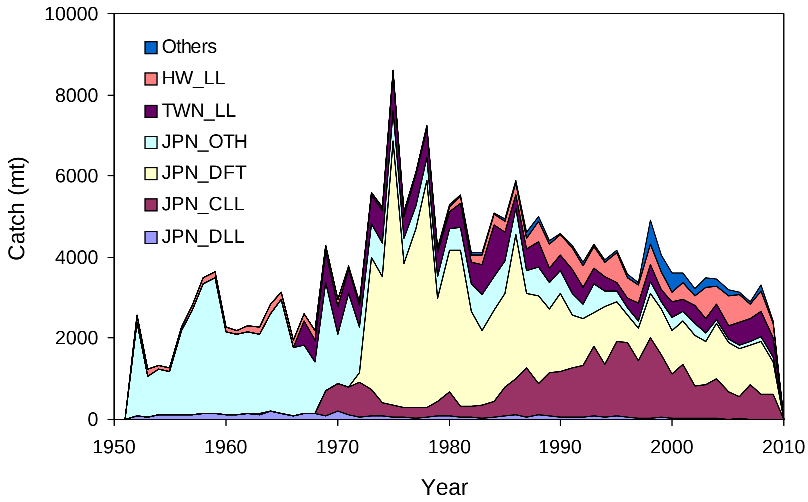

Fig. 1. Annual catches (1952-2009) of striped marlin by fleet for the WCPO stock in the North Pacific Ocean. JPN_DLL: Japanese distant-water longline; JPN_CLL: Japanese coastal longline; JPN_DFT: Japanese driftnet; JPN_OTH: Japanese other; TWN_LL: Taiwanese longline; HW_LL: Hawaiian longline; Others: other fisheries.

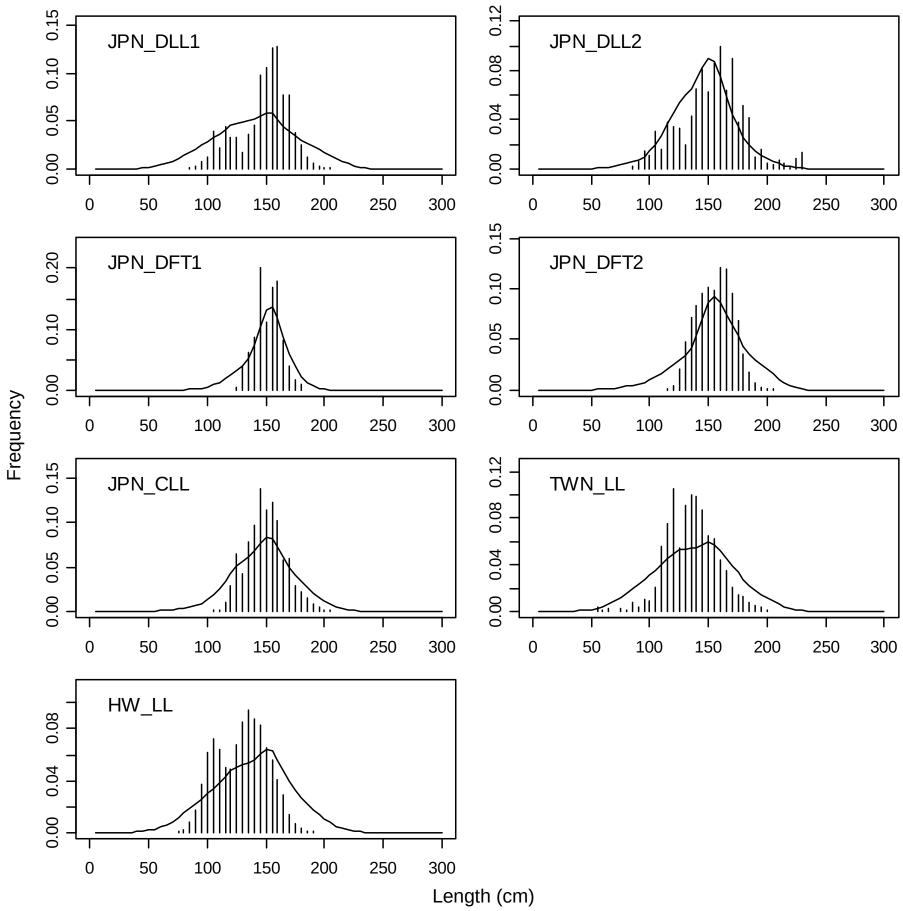

Fig. 2. Observed (histograms) and model-predicted (lines) length-frequencies of striped marlin by fleet for the WCPO stock in the North Pacific Ocean.

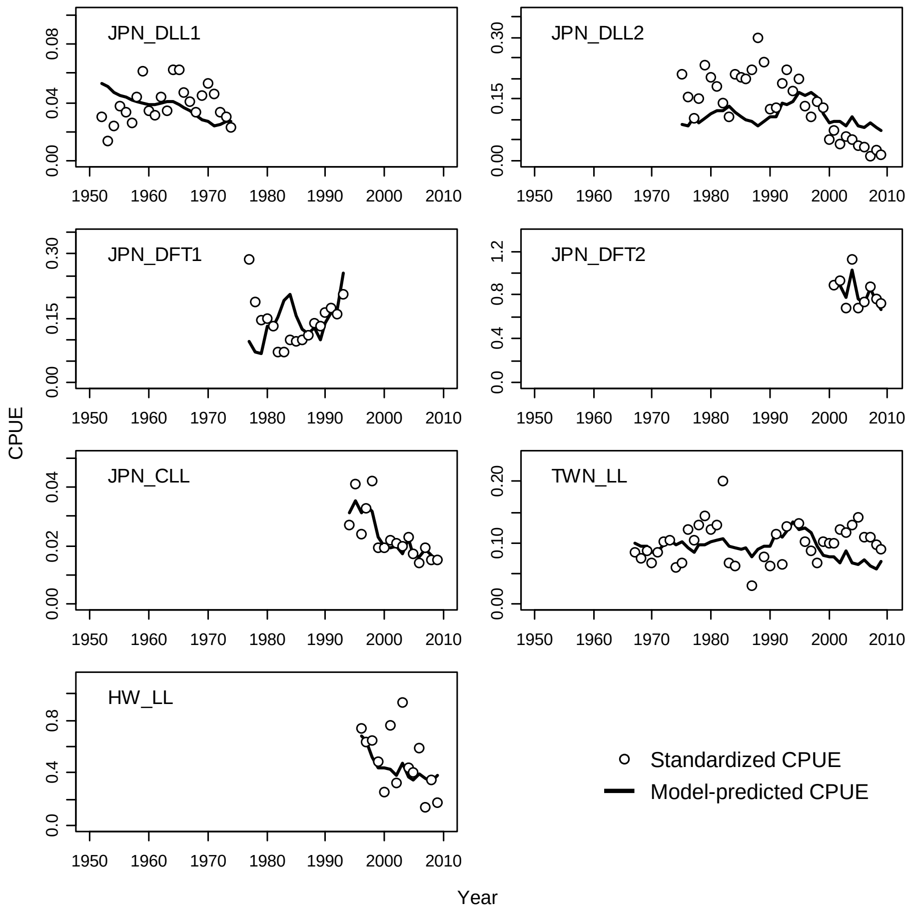

Fig. 3. Observed (standardized) and model-predicted (lines) CPUEs of striped marlin by fleet for the WCPO stock in the North Pacific Ocean.

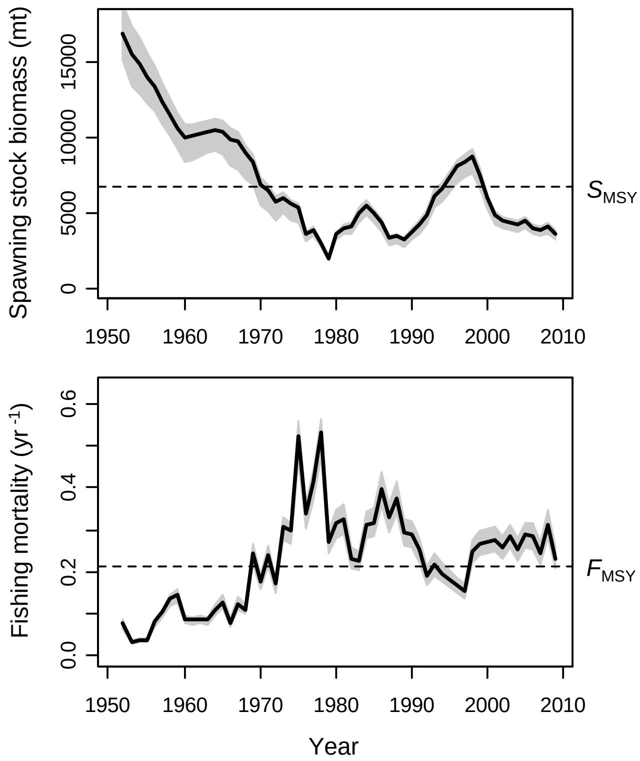

Fig. 4. Time trajectories of the spawning stock biomass relative to the MSY level (S/S_{MSY}) and the fishing mortality relative to that at MSY (F/F_{MSY}) for the WCPO stock of striped marlin in the North Pacific Ocean.

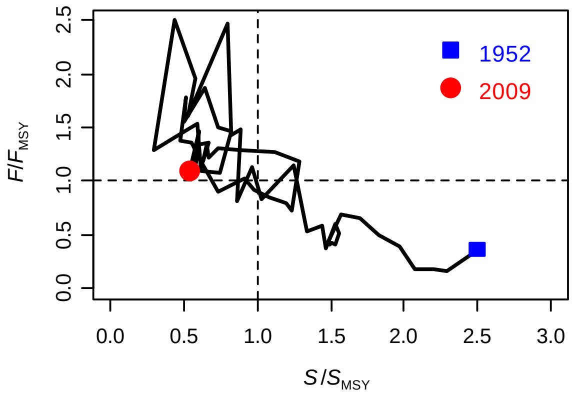

Fig. 5. The estimated spawning stock biomass relative to that supports MSY (S/S_{MSY}) versus the estimated fishing mortality relative to that at MSY (F/F_{MSY}) for the WCPO stock of striped marlin in the North Pacific Ocean.