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Stock assessment of swordfish, Xiphias gladius, in the North Pacific Ocean using an age-structured population dynamics model

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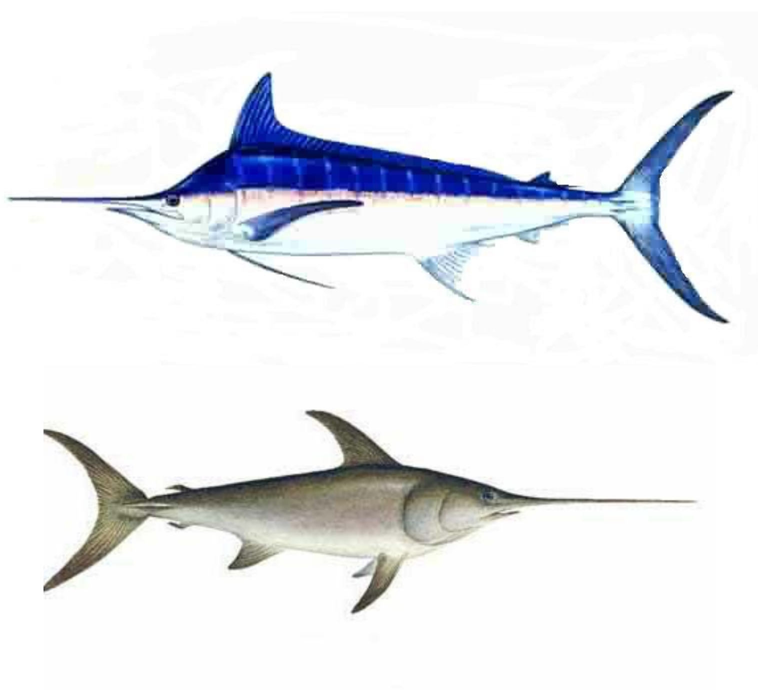

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Stock assessment of swordfish, *Xiphias gladius*, in the North Pacific Ocean using an age-structured population dynamics model*

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Abstract

Based on the two scenarios of spatial structure for swordfish stock in the North Pacific Ocean, an age-structured population dynamics model was fitted to catch, catch-rate, and length-frequency data for the main swordfish fisheries (Japanese, Taiwanese, and Hawaiian longline fleets) to examine the current status of the swordfish population in the North Pacific Ocean. Results indicate that the current spawning stock biomass (2006) was at a high fraction of its unfished level and that the current fishing intensity (2006) was less than F_{MSY} for different scenarios of stock structure of swordfish. Therefore, the swordfish stock in the North Pacific Ocean appears to be relatively stable at the current level of exploitation.

1. Introduction

Swordfish (*Xiphias gladius*, Linnaeus 1758) is a cosmopolitan species distributed in tropical, subtropical, temperate, and sometimes cold waters of all oceans and adjacent seas (Nakamura, 1985). In the North Pacific Ocean (Fig. 1), the bulk of the swordfish catch has been taken by Japan, the United States, Taiwan and Mexico, with very small catches by Korea and China, whose swordfish catch is estimated to be less than 4% of the total swordfish catch in the North Pacific Ocean (Wang et al., 2007).

Most previous assessments of swordfish in the North Pacific Ocean have been based on trends in catch-rates (i.e. catch-per-unit-effort, CPUE) (e.g. DiNardo and Kwok, 1998; Kleiber and Bartoo, 1998; Nakano, 1998; Uosaki, 1998). Wang et al. (2005; 2007) applied a sex-specific age-structured assessment method to catch, effort and sex-specific length-frequency data collected from Japanese and Hawaiian vessels to assess the status of swordfish in the North Pacific Ocean. All of these analyses

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indicate that the swordfish stock in the North Pacific Ocean is not over-exploited, and that it has been relatively stable at current levels of exploitation.

The objective of this study is to assess the current status of the swordfish population in the North Pacific Ocean using an age-structured population dynamics model based on the two scenarios of the spatial structure of swordfish stock (single stock or two stocks in the North Pacific Ocean) proposed by Ichinokawa and Brodziak (2008).

2. Materials and methods

2.1. Data used

Based on the two scenarios (single-stock or two-stock) of the spatial structure of swordfish stock in the North Pacific, the boundaries of three areas (North Pacific area for single stock scenario, and sub-areas 1 and 2 for two stock scenario) were established (Fig. 1) and the catch and effort data of various fisheries were compiled separately for each of the three areas for the stock assessments.

For single stock scenario, the longline swordfish catch data (Japan, 1952-2006; Taiwan, 1959-2006; Hawaii, 1970-2006; Fig. 2) and standardized catch-rate series (Japan, 1952-2006; Taiwan, 1995-2006; Hawaii, 1995-2006) were included for the assessment. For the two stock scenario, Japanese, Taiwanese and Hawaii-based longline catch data and standardized catch-rates were used for the assessments for subarea-1, however, only the Japanese (1952-2006) and Taiwanese (1995-2006) longline catch and effort data were considered for the assessments because the fishing ground of Hawaii-based longline is distributed mainly in the central North Pacific Ocean.

Sex-aggregated length-frequency data of swordfish are available only for the Japanese longline fisheries since 1970 which were treated as input to fit a sex-pooled model for the assessments in the North Pacific Ocean.

The time-series of historical catches (Fig. 2) and standardized catch-rates for the Japanese, Taiwanese, and Hawaiian longline fisheries used in the assessment were from reports to the ISC Billfish Working Group (BILL-WG 2009).

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”). 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. Owing to lack of length-frequency data before 1971, the recruitment deviations prior to 1971 and those thereafter are treated differently. The recruitment deviations for the years prior to 1971 are all set to zero because there are no data which could inform year-class strength for these years whereas those for the years after 1970 are treated as free parameters 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 selectivity for longline gears (e.g. Erzini et al., 1998; Sousa et al., 1999). The assumption that selectivity-at-length follows a logistic curve might be adequate to mimic the length-frequency data for the longline fleets. However, owing to lack of length-frequency data for the Taiwanese and Hawaiian longline fleets and for the Japanese longline fleet under the assumption of two-stock scenario, the selectivity ogives for the fleets without length-frequency samples are assumed to be the same with the Japanese longline fleet under the assumption of single stock scenario.

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 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, three values of M are examined for the sensitivity analysis, whereas h is assumed to be 0.9 and σ_{v} to be 0.4 following Wang et al. (2007).

The objective function minimized to find the estimates of the ‘free’ parameters of the model includes two components (the data available for assessment purposes and the constraints based on *a priori* assumptions). The data available for assessment purposes are: (1) the catches (assumed known without error), (2) the annual length-frequencies (pooled across sex to fit a sex-pooled model), and (3) the standardized catch-rate indices by fleet. Constraints are imposed on the extent to which the number of 0-year-olds can deviate from the underlying stock-recruitment relationship.

The model outputs examined are the key quantities of management interest as follows, (1) S_0, the spawning stock biomass at unfished equilibrium; (2) MSY, the Maximum Sustainable Yield; (3) S_{MSY}, the spawning stock biomass at which MSY is achieved; (4) F_{MSY}, the exploitation rate at which MSY is achieved.

3. Results and discussion

Figure 3 shows the age-specific selectivity ogives for the Japanese longline fleet for each stock in different scenarios, assumed to be the same between sexes. The selectivity patterns for the Taiwanese and Hawaiian longline fleets used in the assessment model are assumed to be the same with the Japanese longline fleet because of no length-frequency data available for these fleets. The observed and model-predicted length-frequencies for the Japanese longline fleet are illustrated in Fig. 4. Results are aggregated across years for ease of presentation. To assess the model fitting, the model-estimated catch-rates for Japanese, Taiwanese and Hawaiian longline are shown in Fig. 5, which all generally follow the trends of standardized catch-rate indices.

Figure 6 shows the model-estimates of the exploitation rates for the fleets included in the analysis. The exploitation rates for the Japanese fleets were relatively high before the early 1960s, declined substantially thereafter as a result of reduced catches, and have stabilized since the early 1960s. The exploitation rates for the Taiwanese longline fleet show a continuing increasing trend since the fishery was introduced, especially after 1990 with extremely increasing trend. The exploitation rates by the Hawaii-based fleets decreased after mid-1990s when the catches by these fleets dropped. However, it is noted that although the exploitation rates by the Taiwanese and Hawaii-based longline fleet increased rapidly in 1990s, the level of exploitation is well below that of the Japanese longline fleet (Fig. 6).

Figure 7 shows the time trajectory of model-estimates for the ratio of yield to MSY, the ratio of exploitation rates relative to F_{MSY}, and the ratio of the spawning stock biomass to its unfished level (S_0) for different values assumed for the natural mortality (M). The exploitation rates of swordfish population in the North Pacific Ocean are lower than that at MSY level, although the catch levels approach that to maintain MSY, except for the stock in sub-area 2 of which the catch level seems somewhat higher than the MSY level (Fig. 7). However, the spawning stock biomass of swordfish is considered stable for all scenarios, although declined due to the high catches from 1952 until the early 1960s when it was about 40% of S_0, but recovered in 1970s and maintained at a stable level during recent years (Fig. 7).

Even assuming a lower level of natural mortality, the results of “Kobe Plots” still suggest that the spawning stock biomass of swordfish in the North Pacific is currently at a fairly high fraction of its initial level and that the exploitation rates are lower than that corresponding to the MSY level for both scenarios of swordfish stock spatial structure (Fig. 8).

It is recommended to include more fisheries (e.g. Mexican and Korean longline) to the sensitivity analysis, although the impacts of these fisheries may be ignored because of the relative small amount of catch. In addition, care should be taken in evaluating the assessment results for sub-area 2 because the information used for the assessments in this area is quite limited (i.e. biological parameters and selectivity ogives are assumed to be the same as those used for other scenarios) although results seem not sensitive to different growth curves and maturity ogives when comparing with those estimated by Wang et al. (2007). Finally, it is important to collect sex-specific length-frequency data to estimate sex-specific selectivity patterns and attempt a sex-specific population dynamics model which are known to improve the assessment results for swordfish in the North Pacific Ocean (Wang et al., 2007).

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Table 1. The values assumed for the parameters of the relationships between length and weight, length and age, and maturity and age.

Parameter	Value
Asymptotic length, L_∞ (cm)	220.0
Growth parameter, k (yr^{-1})	0.258
Age-at-zero-length, t_0 (yr)	–1.30
Length-weight, A	1.3528×10^{-6}
Length-weight, B	3.4297
Length-at-50%-maturity, L_m (cm)	143.68
Maturity slope, r_m	–0.1034
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

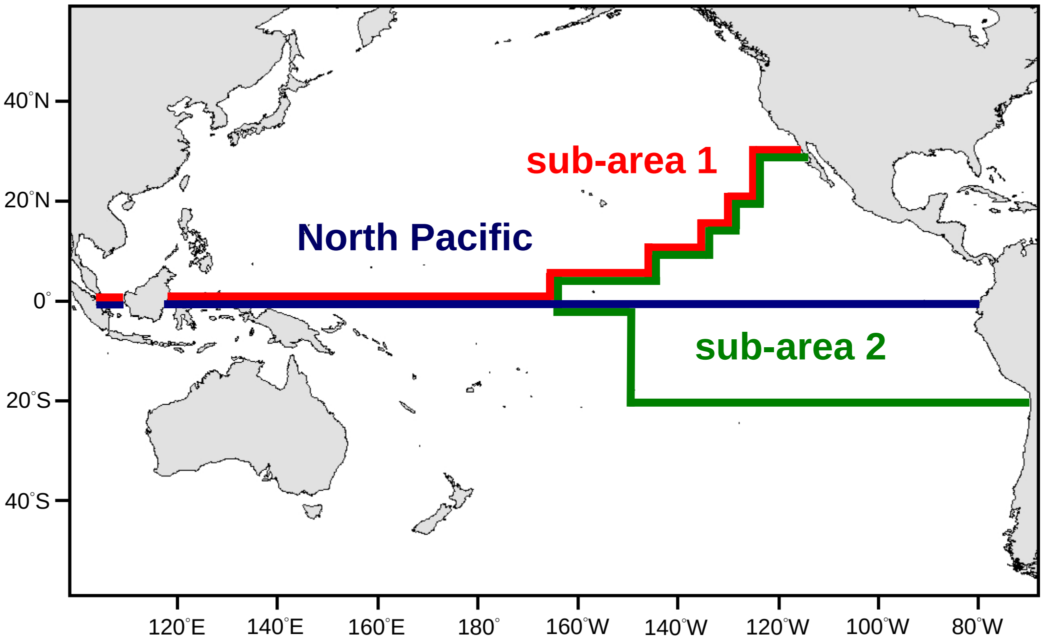

Fig. 1. Boundaries for the single stock (North Pacific, blue line) and the two stock (sub-area 1 red lines and sub-area 2 green lines) scenarios of swordfish spatial structure in the North Pacific.

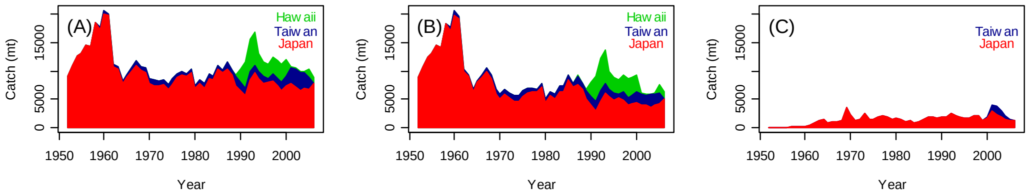

Fig. 2. Annual catches of swordfish by fleet reported to the ISC Billfish Working Group (BILL-WG 2009) (1952–2006) for the two scenarios (single or two stocks) of swordfish spatial structure (A) North Pacific; (B) sub-area 1 and (C) sub-area 2.

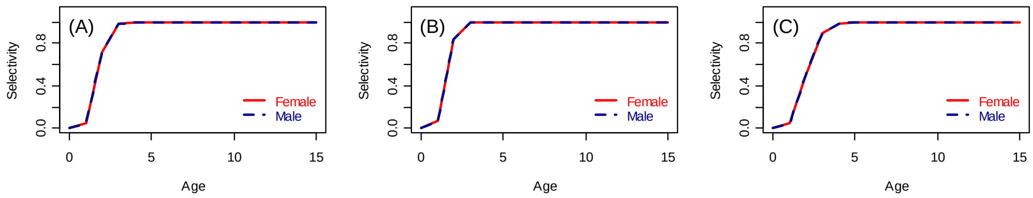

Fig. 3. Estimated selectivity ogives by age class for swordfish in the North Pacific Ocean for the Japanese longline fleet for the two scenarios (single or two stocks) of swordfish spatial structure (A) North Pacific; (B) sub-area 1 and (C) sub-area 2.

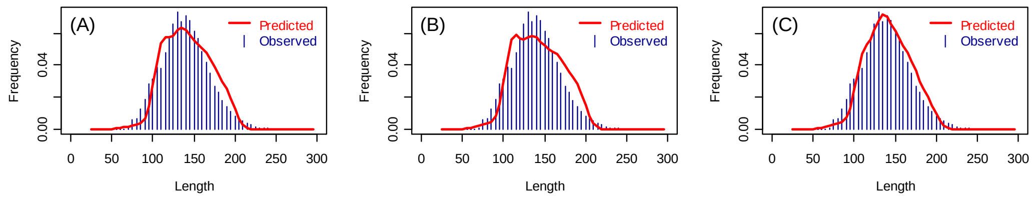

Fig. 4. Observed (histograms) and model-predicted (lines) length-frequencies of swordfish estimated for the Japanese longline fleet for the two scenarios (single or two stocks) of swordfish spatial structure (A) North Pacific; (B) sub-area 1 and (C) sub-area 2.

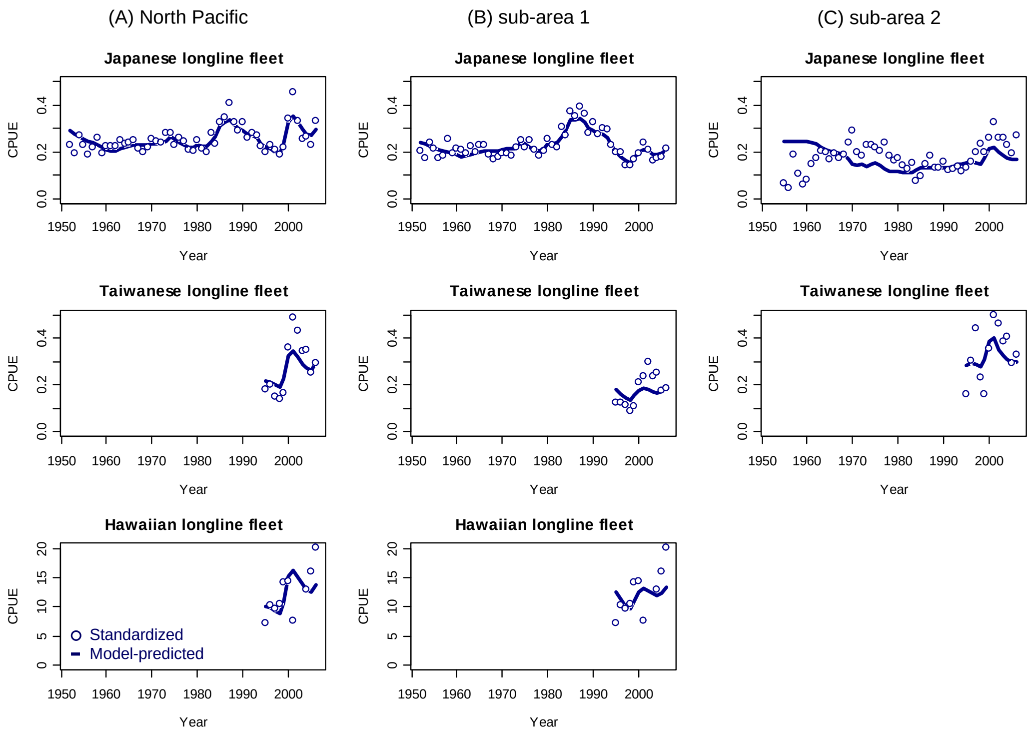

Fig. 5. Annual catch-rate indices (standardized and model-predicted) of swordfish for the Japanese, Taiwanese, and Hawaiian longline fleets for the two scenarios (single or two stocks) of swordfish spatial structure (A) North Pacific; (B) sub-area 1 and (C) sub-area 2.

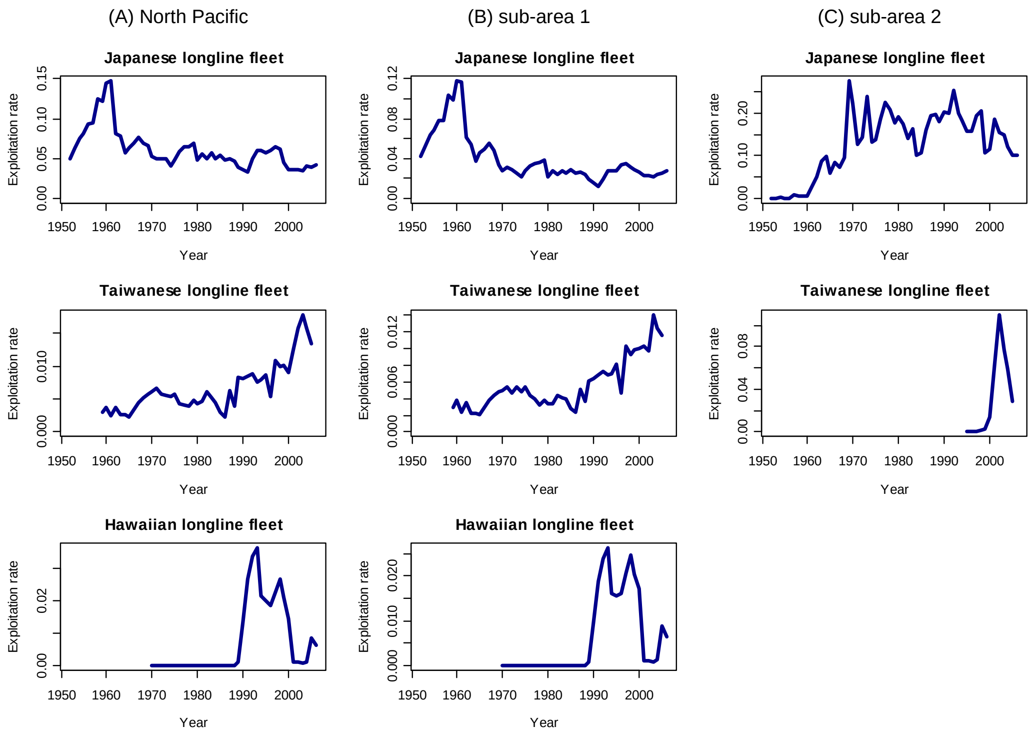

Fig. 6. Time trajectories of the exploitation rate for the Japanese, Taiwanese, and Hawaiian longline fleets for the two scenarios (single or two stocks) of swordfish spatial structure (A) North Pacific; (B) sub-area 1 and (C) sub-area 2.

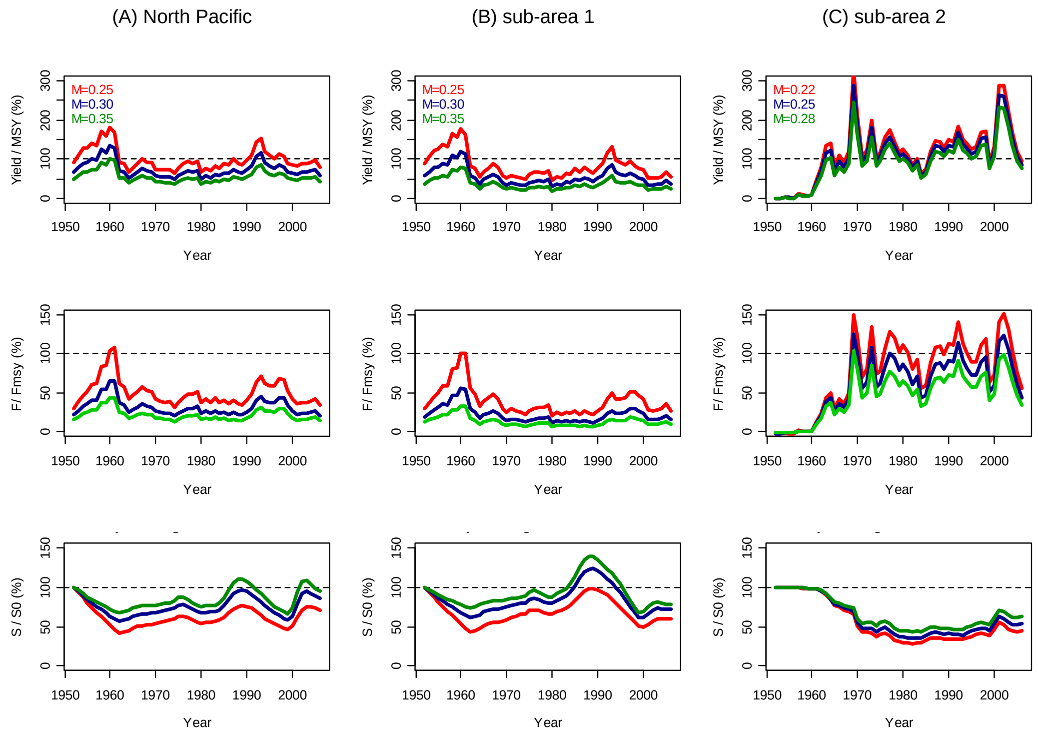

Fig. 7. Time trajectories of the yield relative to MSY, the exploitation rate relative to that at MSY (F/F_{MSY}), the spawning stock biomass relative to its unfished level (S/S_0) for the two scenarios (single or two stocks) of swordfish spatial structure (A) North Pacific; (B) sub-area 1 and (C) sub-area 2.

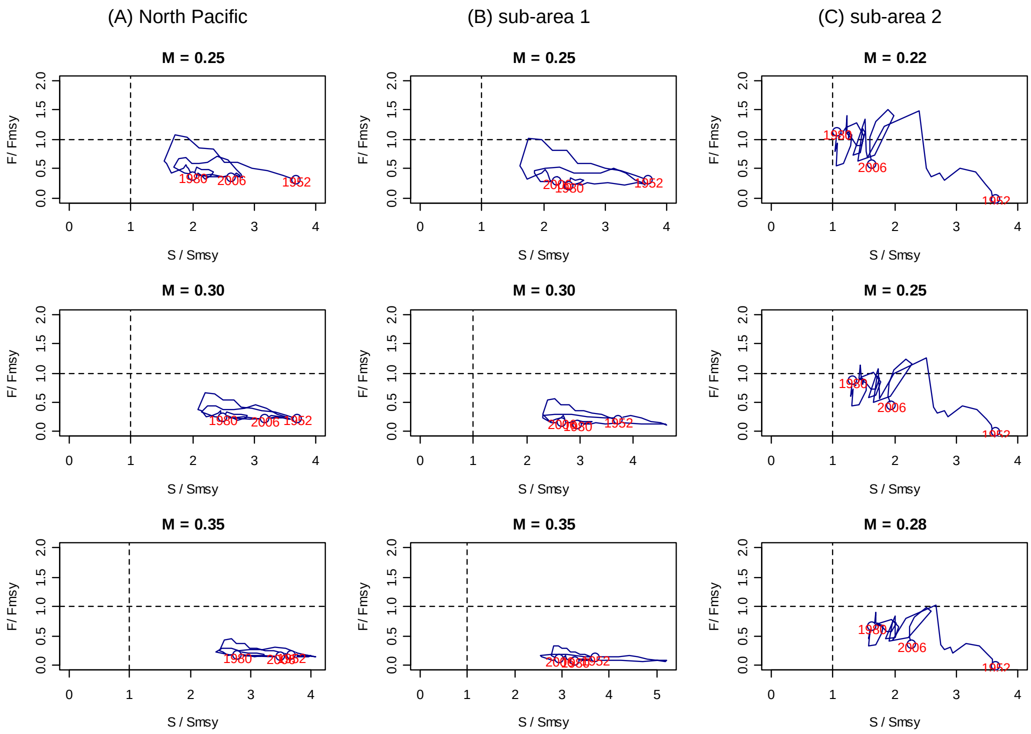

Fig. 8. The "Kobe Plots" showing the model-estimated exploitation rates relative to that at MSY (F/F_{MSY}) versus the estimated spawning stock biomass relative to that supports MSY for different levels of natural mortality for the two scenarios (single or two stocks) of swordfish spatial structure (A) North Pacific; (B) sub-area 1 and (C) sub-area 2.