Update of the application of an age-structured assessment model to swordfish (*Xiphias gladius*) in the Indian Ocean

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INTRODUCTION

Swordfish in the Indian Ocean (*Xiphias gladius*) was historically taken mainly by Japan and Taiwan, but the catch was low. Since the early 1990s, the catch of swordfish in the Indian Ocean increased substantially owing to the seasonal targeting of the Taiwanese fishery, the targeting of EU longline fisheries from Spain, Portugal and the UK and exploitation of semi-industrial longline and artisanal fisheries (Fig. 1). The catch of swordfish in the Indian Ocean increased from less than 10,000 mt before early 1990's to around 35,000 mt in recent years and the bulk of catch was made in the western Indian Ocean (IOTC, 2008).

Most previous evaluations of swordfish in the Indian Ocean have been based on the trends of catch-per-unit-effort (CPUE) (e.g. Yuji, 1999; Yokawa and Shono, 2000; Chang and Wang, 2004). Recently, applied surplus production models and age-structured production model were applied to the swordfish in the Indian Ocean (Nishida and Shiba. 2006, Nishida and Semba, 2008; Kolody, 2008; Nishida and Wang, 2009).

Since biological parameters (e.g. Poisson et al., 2009; Wang et al. 2010) and historical length-frequency data are available for swordfish in the Indian Ocean, the length-based assessment methods (e.g. Fournier et al., 1998; Methot, 2005; Wang et al., 2005; Wang et al., 2007) can be applied to assess the population status. Therefore, this study is the first attempt to fit an assessment model to all the fishery and biological data to estimate exploitation rates, recruitment, and biomass.

Swordfish in the Indian Ocean are known to be sexually dimorphic (Wang et al., 2010). Wang et al. (2005 and 2007) also showed using simulation and sensitivity analyses that ignoring sex-structure when conducting population model-based stock assessments can lead to biased results while the estimations of relative management quantities remains robust. Owing to the absence of sex-specific data of catch and length-frequency for swordfish in the Indian Ocean, however, we attempt to modify the age-structured assessment model conducted by Wang et al. (2005) and Wang et al. (2007) for applying to the swordfish in the Indian.

MATERIALS AND METHODS

Data used

The definition of fisheries used in this study is listed in Table 1. Except for longline fishery of Australia, all fisheries were divided into four fleets based on four subareas (NW. SE, SW and SE) of the Indian Ocean which have been used for the swordfish assessment since 2008 (IOTC, 2008; Fig. 2). No catch of semi-industrial longline fleets of France-Reunion, France-Mayotte, Madagascar, Mauritius and the Seychelles occurred in the northeastern area (SE).

The historical catches in weight and length-frequency are available for all fisheries and these data were reported to Indian Ocean Tuna Commission (IOTC) by each fishery (Table 1). Generally, the time series of the length-frequency data for these fisheries were shorter than the catch data. All of the length-frequency data were aggregated into 3 cm (lower jaw fork length) interval length-compositions for each fishery.

The relative abundance indices used in this study were based on the standardized CPUE of Taiwanese from 1995 to 2008 and Japanese longline fisheries from 1980 to 2008. The CPUEs were standardized using General Linear Model (GLM) with the assumption that the errors are lognormally distributed (Fig. 3; see Nishida and Wang (2010) and Wang and Nishida (2010) for details).

Biological information

The biological and demographic parameters, including the length-weight relationship, growth and maturity are available for swordfish in the Indian Ocean. The parameters of length-weight relationship and von Bertalanffy growth curve and the Standard deviation of length-at-age were based on the results of age and growth study for swordfish in the Indian Ocean (Wang et al., 2010). Poisson et al. (2009) provided the parameters of logistic maturity curve and also the relationship between sex-ratio and length for swordfish caught by the Reunio-based pelagic longline fishery. The biological parameters used in this study are listed in Table 2.

Assessment model

The population dynamics model developed by Wang et al. (2005) and Wang et al. (2007) was used in this study after eliminating the sex-structured factors from the model. This model considers the lifespan of swordfish from age 0 to 10 (age 10 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. The relationship between sex-ratio and length from Wang et al. (2010) was used to calculate female abundance for estimating spawning biomass (eq. (A.10) in Wang et al. (2007)). The recruitment deviations for the years prior to 1980 are all set to zero due to insufficient length frequency data which could inform year-class strength for these years whereas those for the years after 1980 are treated as parameters of the assessment model with a penalty based on the distributional assumption.

The logistic curve, which assumes that the vulnerability of a fish increases monotonically to an asymptote with increasing length, is commonly used in fisheries stock assessment models to represent selectivity for longline gear. For most fisheries, however, few swordfish with length larger than 200 cm were caught (Fig. 4) and the assumption that selectivity follows a logistic curve might be inadequate. In this study, therefore, the selectivities were assumed to be dome-shaped curve (represented by a normal distribution) for all fleets.

Parameter estimation

The parameters of the model can be divided into those for which auxiliary information is available (Table 2) and those which need to be estimated from the monitoring data (Table 3). 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 0.25 year^{-1} based on Pauly's (1980) empirical equation, h is assumed to be 0.9 (Punt et al., 2001; Wang et al., 2005; Wang et al., 2007), and σ_v is assumed to be 0.4 (Punt et al., 2001).

The objective function was minimized to find the estimates of the estimated parameters of the model. The objective function combines the likelihoods for the CPUE and length-frequency data, and the penalty for the annual recruitment deviates. The model is implemented using AD Model Builder (version 8.0.2) (Otter Research Ltd, 2007). The data available for assessment purposes are the catches and the length–frequencies, and the CPUE-based indices of abundance. Constraints are imposed on the extent to which the number of 0-year-olds can deviate from the underlying stock-recruitment relationship.

Sensitivity analyses

Sensitivity is examined to the value assumed for natural mortality M (0.15 $year^{-1}$ and 0.3 $year^{-1}$), that assumed for the steepness of the stock-recruitment relationship *h* (0.6, 0.8 and 0.95)..

For each scenario, five quantities of management interest, including the maximum sustainable yield (*MSY*), the spawning biomass at which *MSY* is achieved (S_{MSY}), the spawning biomass in 2008 as a ratio of the unexploited spawning biomass (S_{2008} /S_0), the spawning biomass in 2008 as a ratio of S_{MSY} (S_{2008}/S_{MSY}) and the fleet-aggregated fishing intensity (defined as the ratio of total catch to exploitable biomass, see Wang et al. (2005) for details) in 2008 as a ratio of that at which *MSY* is achieved (F_{2008}/F_{MSY}), were examined for sensitivity analyses.

RESULTS AND DISCUSSION

Fig. 3 shows the fits of the model to the observed CPUE data. Based on the results of base-case, the model cannot fitted to the CPUEs for all fleets very well because the CPUEs changed sharply since the mid 1980s and the mid of 1990s they revealed inconsistent patterns among fleets.

The observed and the model estimated length frequencies aggregated across years are shown in Fig. 4. In substance, the model estimated length-frequencies mimics the observed length frequency data well for all fleets. The model estimated selectivites are shown in Fig. 5. The gillnet, trolling, artisanal fleets, EU fleets in the northern areas and semi-industrial longline fleet in the northern west area tend to select smaller fishes than other fleets.

Fig. 6 shows the time trajectories of MPD estimates for S_{2008} /S_0, S_{2008}/S_{MSY} and F_{2008}/F_{MSY} for base-case analysis. The fleet-aggregated fishing intensity substantially increased to more than 50% of 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 years, the estimates of fleet-aggregated fishing intensity increased to about 60-80% of F_{MSY} and the spawning biomass deceased to about 40-50% of S_0 after 2000 while the spawning biomass was still much higher than S_{MSY}.

The estimates of quantities of management interest are listed in Table 4. Based on the different assumptions related to *M* and *h*, the results indicated that current fishing intensity was about 44-77% of F_{MSY} and the spawning biomass maintained at about 40-60% of S_0 and about double of S_{MSY}. The most pessimistic stock status occurred when assuming a relative high value of *M* and the highest fishing intensity was obtained when assuming a relative low value of *h*. Based on the Kobe plot, however, the results of this study indicated that the status of swordfish in the Indian Ocean might not be under an overexploitation condition (Fig. 7). Although the MSY was estimated in this study, it should be noted that ignoring sex-specific information might lead to the bias in some estimates of absolute quantities based on simulation analysis of Wang et al. (2005).

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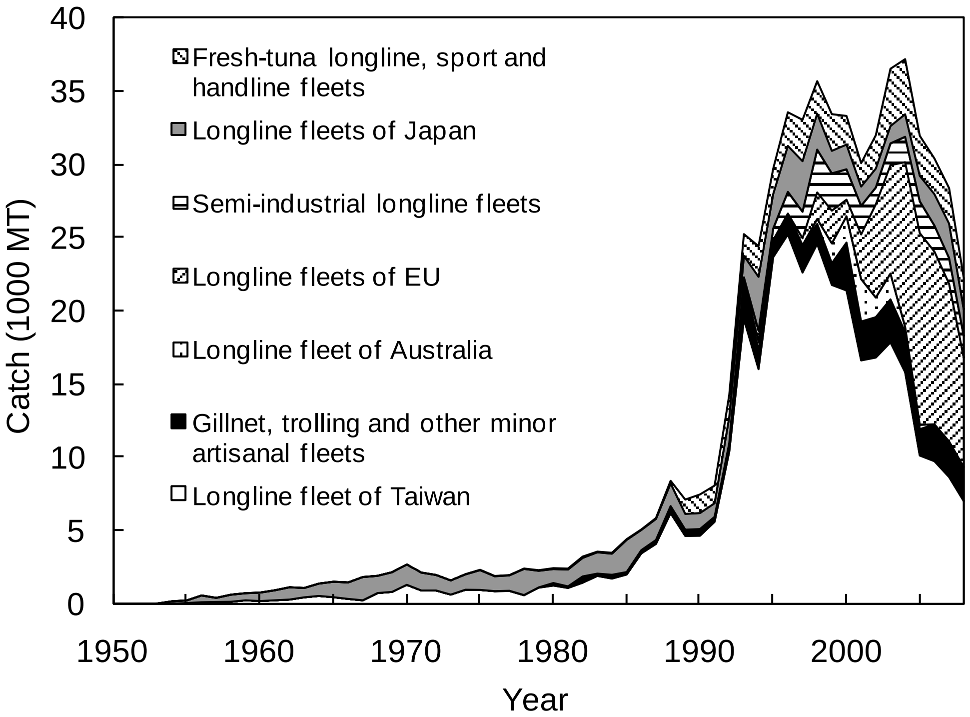

Fig. 1. Annual catches of swordfish in the Indian Ocean from 1952 to 2008.

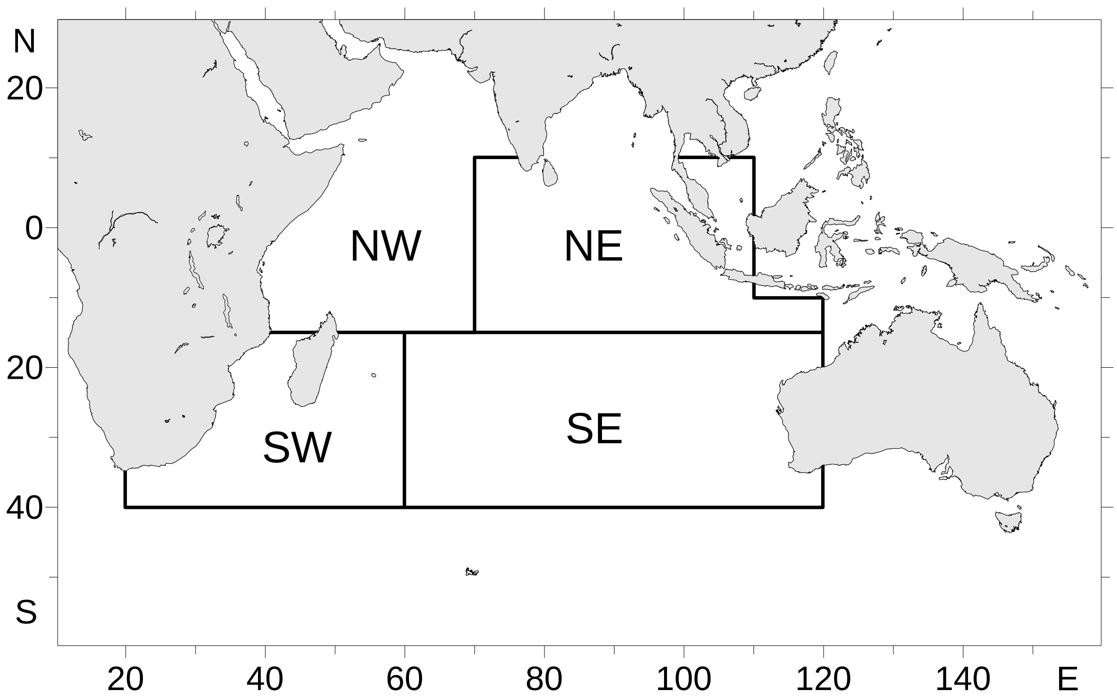

Fig. 2. The definition of areas used in the analyses for swordfish in the Indian Ocean.

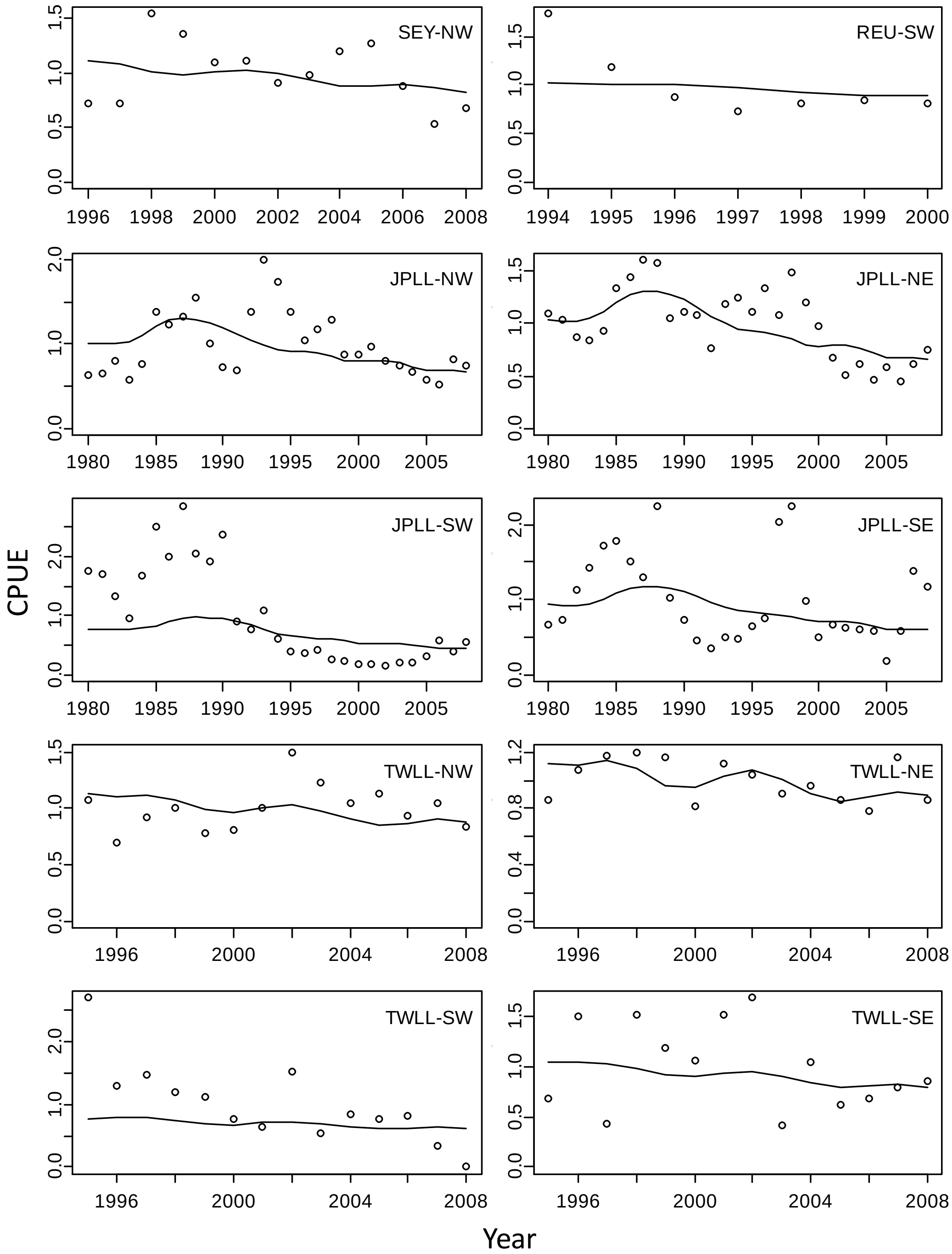

Fig. 3. Standardized observed CPUE (points) and predicted CPUE estimated based on the base-case analysis (solid lines).

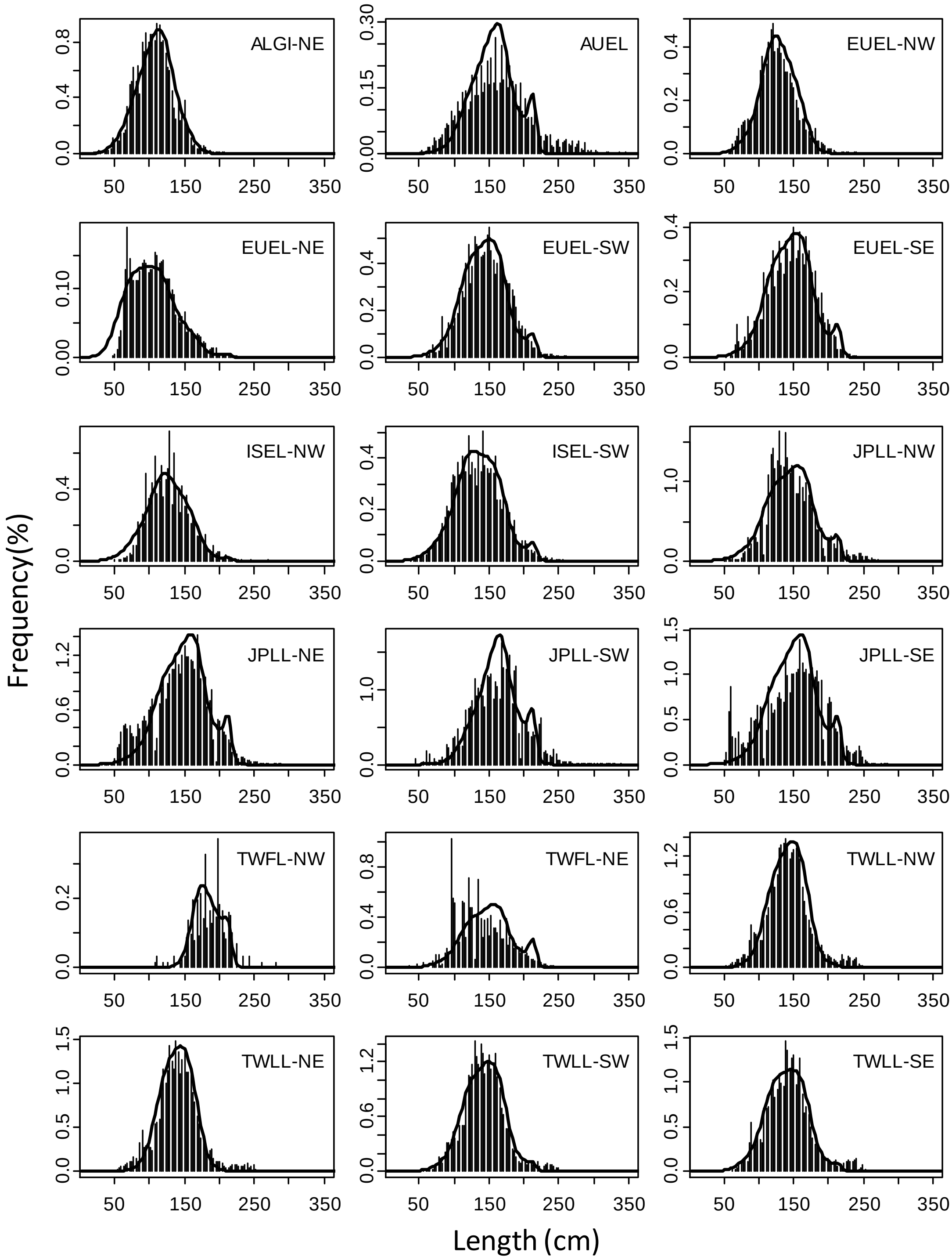

Fig. 4. Observed (histograms) and model-estimated (lines) length-frequencies for the base-case analyses.

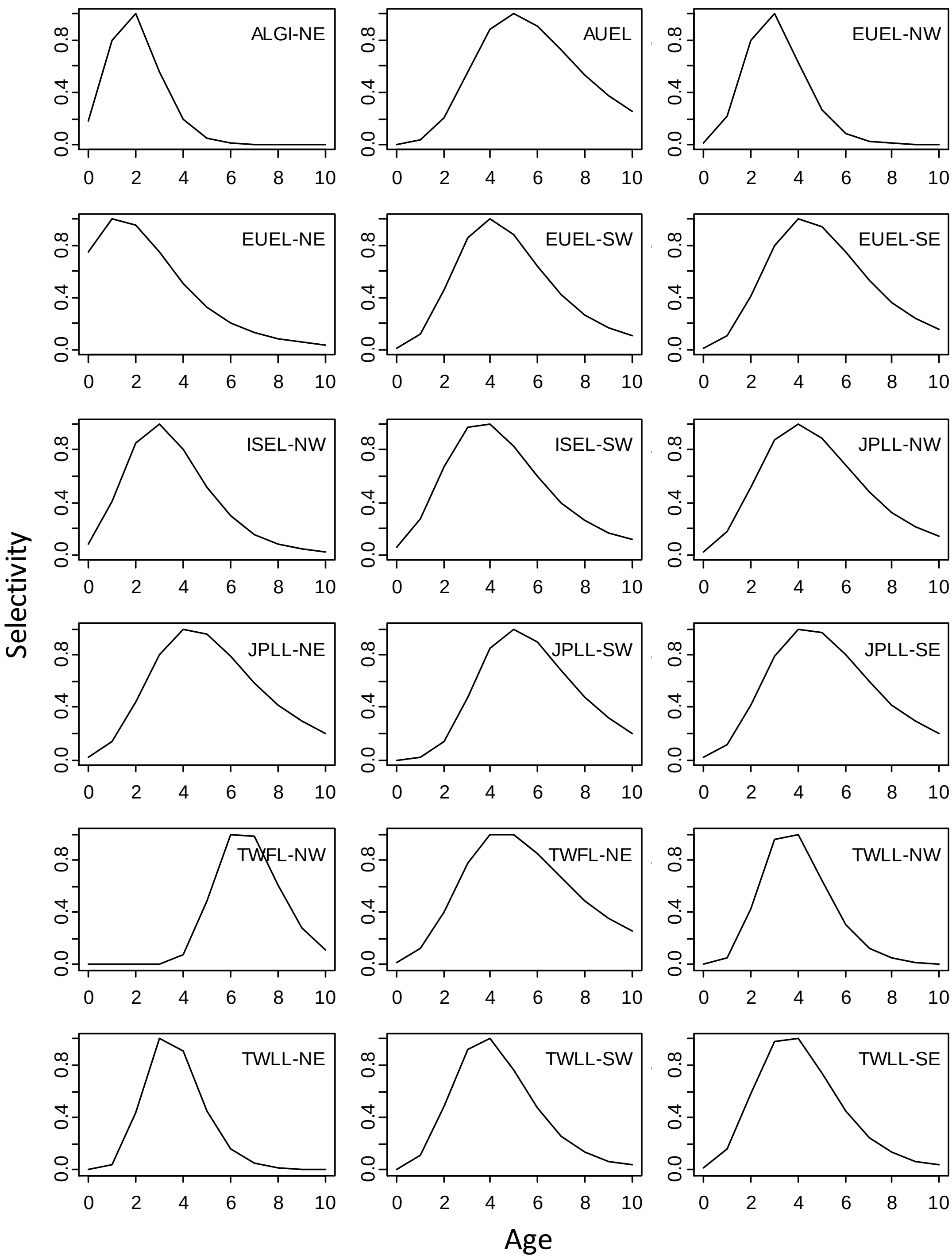

Fig. 5. Model-estimated selectivity curves for the base-case analysis.

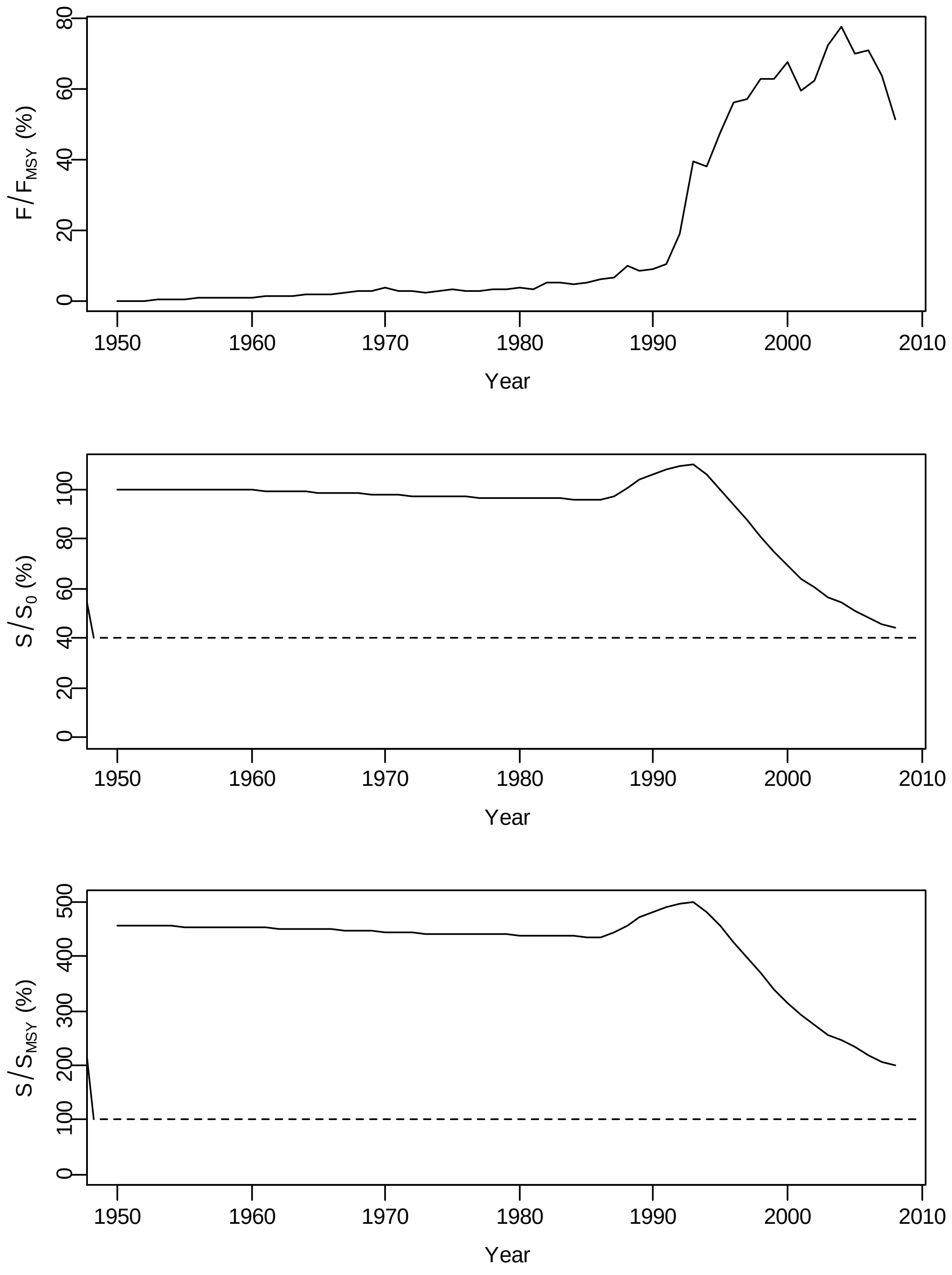

Fig. 6. Time trajectories of MPD estimates for the spawning biomass as a ratio of the unexploited spawning biomass (S_{2008} /S_0), the spawning biomass as a ratio of S_{MSY} (S_{2008}/S_{MSY}) and the fleet-aggregated fishing intensity as a ratio of that at which *MSY* is achieved (F_{2008}/F_{MSY}) for base-case analysis.

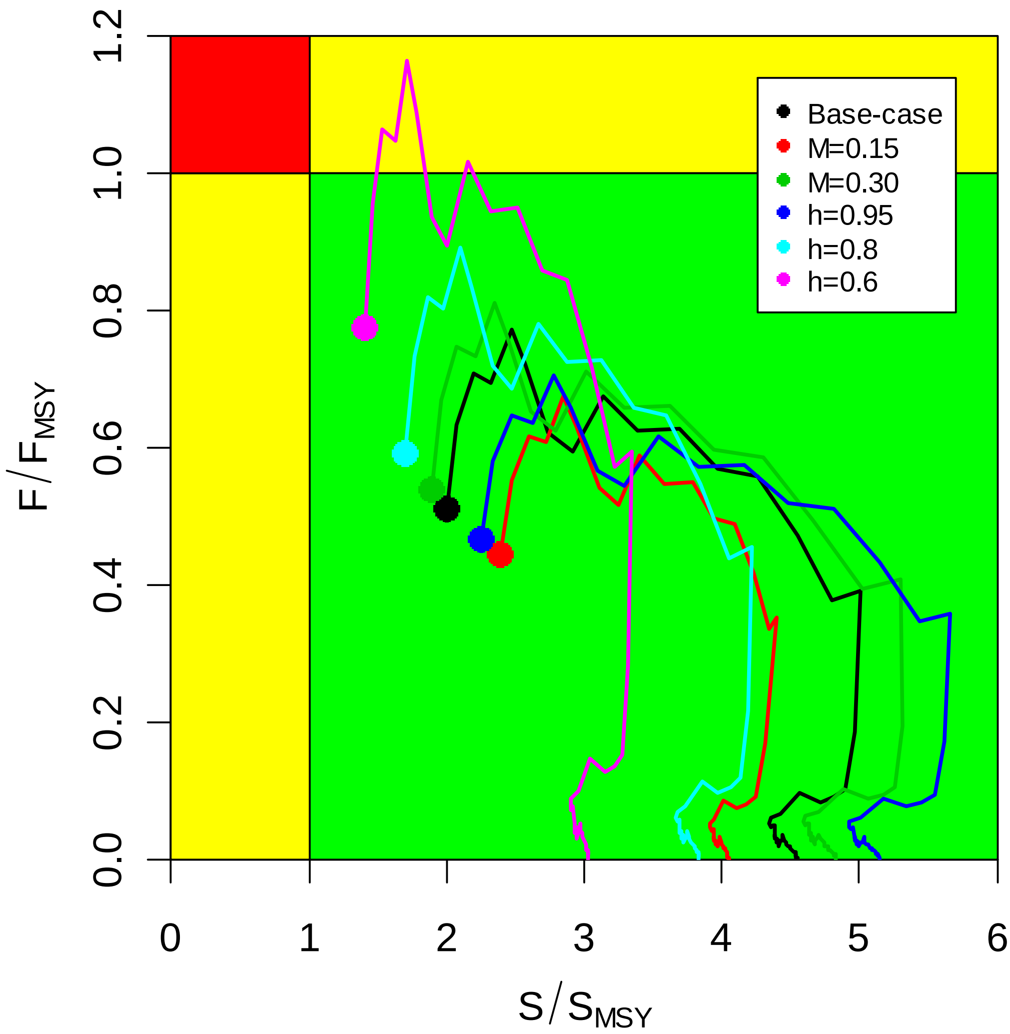

Fig. 7. Kobe plot for swordfish in the Indian Ocean based on different assumptions of natural mortality and stepness of the stock-recruitment relatonship.

Table 1. Definition of the fleets operating in the Indian Ocean and the data availability for each fleet.

Fleet	Fleet Code	Area	Catch data	Length data	CPUE
Gillnet, trolling and other minor artisanal fleets	ALGI	NW	✓	-	-
		NE	✓	✓	-
		SW	✓	-	-
		SE	✓	-	-
Longline fishery of Australia	AUEL	SE	✓	✓	-
Longline fleets of EU (from Spain, Portugal and the UK)	EUEL	NW	✓	✓	-
		NE	✓	✓	-
		SW	✓	✓	-
		SE	✓	✓	-
Semi-industrial longline fleets of France-Reunion, France-Mayotte, Madagascar, Mauritius and the Seychelles	ISEL	NW	✓	✓	✓
		SW	✓	✓	✓
		SE	✓	-	-
Longline fleets of Japan	JPLL	NW	✓	✓	✓
		NE	✓	✓	✓
		SW	✓	✓	✓
		SE	✓	✓	✓
Fresh-tuna longline fleets of Taiwan and Indonesia, and sport and hand line fleets	TWFL	NW	✓	✓	-
		NE	✓	✓	-
		SW	✓	-	-
		SE	✓	-	-
Longline fleet of Taiwan	TWLL	NW	✓	✓	✓
		NE	✓	✓	✓
		SW	✓	✓	✓
		SE	✓	✓	✓

Table 2. The biological parameters of length-weight relationships, von Bertalanffy growth curve, and maturity and age for swordfish in the Indian Ocean.

Parameter	Females	Males
Asymptotic size, L_∞ (cm)	274.86	234.00
Growth parameter, K (year^{-1})	0.1377	0.1694
Age-at-zero-length, t_0 (year)	-1.9975	-2.1809
Length-weight, A	9.133×10^{-6}	9.133×10^{-6}
Length-weight, B	3.012	3.012
Maturity slope, r_m	0.0953	-
Length-at-50%-maturity, L_m (cm)	170.4	-
Maximum age, λ (year)	10	10

Source: Poisson and Fauvel (2009) and Wang et al. (2010).

Table 3. The parameters of the population dynamics model not known from auxiliary Information.

Parameter	No. of parameters
Estimated	
Unfished recruitment, R_0	1
Process errors, v_t	1 per year from 1980 to 2008
Selectivity	
Dome-shaped	
Length-at-mean-selectivity, L^f_{mu}	1 per fleet, expect for the AUEL, JPLL and TWFL
Standard deviation of selectivity, L^f_{sd}	1 per fleet, expect for the AUEL, JPLL and TWFL
Logistic curve	
Length-at-50%-selectivity, L^f_{50}	1 per fleet for the AUEL, JPLL and TWFL
Length-at-95%-selectivity, L^f_{95}	1 per fleet for the AUEL, JPLL and TWFL
Pre-specified	
Natural mortality, M	1
Steepness, h	1
Variation in recruitment, σ_v	1

Table 4. The value of the MPD estimates of the quantities of management interest for the base-case analysis and the sensitivity analyses.

	MSY	S_{MSY}	S_{2008}/S_0	S_{2008}/S_{MSY}	F_{2008}/F_{MSY}
Base-case	34210	72132	0.44	2.00	0.51
M = 0.15	37644	207182	0.59	2.39	0.44
M = 0.30	33025	47616	0.39	1.89	0.54
h = 0.95	35900	63181	0.44	2.25	0.47
h = 0.8	31201	87502	0.44	1.70	0.59
h = 0.6	25442	119343	0.46	1.40	0.77