Preliminary 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, Nishida and Shiba (2006), Nishida and Semba (2008) and Dale (2008) applied surplus production models to the swordfish in the Indian Ocean and their results suggested that current biomass was not below the level corresponding to MSY, but the estimate of fishing mortality varied depending on the assumptions (IOTC, 2008).

Since biological parameters (e.g. Young and Drake, 2004; Ariz et al., 2006; Poisson et al., 2009) 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 are known to be sexually dimorphic (Young and Drake, 2004). 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 (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 and Japanese longline fisheries from 1980 to 2007. The CPUEs were standardized using General Linear Model (GLM) with the assumption that the errors are lognormally distributed (Fig. 3; see Nishida and Wang (2009) and Wang and Nishida (2009) 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 were based on the sampling of the Spanish observer program for swordfish in the south western Indian Ocean (Ariz et al., 2006). The parameters of 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 western waters around Australia (Young and Drake, 2004). 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 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. The relationship between sex-ratio and length from Ariz et al. (2006) 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. Except for Japanese, Australian and fresh tuna longline fleets (JPLL, AUEL and TWFL), 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 for other longline fisheries. In this study, therefore, the selectivities were assumed to be logistic for longline JPLL, AUEL and TWFL and a dome-shaped curve (represented by a normal distribution) was used for the other 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 0.2 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

The CPUEs of Japanese longline fleets revealed significantly different trends for different periods. The CPUEs of Japanese longline around the early 1990s were much higher than those after the early 1990s (Fig. 3). Therefore, CPUEs of Japanese longline fleets were separated into two periods (1980-1992 and 1993-2007 for JPLL-NW, JPLL-NE and JPLL-SW, and 1980-1988 and 1989-2007 for JPLL-SE) for examining the influences of changes in catchability on the estimations of the model. The CPUEs of Taiwanese longline fleets in the southern subareas also revealed different pattern around the early 1990s (Fig. 3). Therefore, the CPUEs of Taiwanese longline fleets in the southern subareas were also separated into two periods (1980-1992 and 1993-2007 for TWLL-SW, and 1980-1997 and 1998-2007 for TWLL-SE) for examining the change in fishing configuration since the early 1990s when they began to seasonally target on swordfish.

In addition, the model estimations were examined based on the assumption that selectivities were assumed to be logistic curves for all longline fisheries and a dome-shaped curve for the gillnet fishery.

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 2007 as a ratio of the unexploited spawning biomass (S_{2007} /S_0), the spawning biomass in 2007 as a ratio of S_{MSY} (S_{2007}/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 2007 as a ratio of that at which *MSY* is achieved (F_{2007}/F_{MSY}), were examined for sensitivity analyses. The values of likelihood were also used to examine the fits of model to the length-frequency and CPUE data.

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 generally fitted to the CPUEs of Taiwanese longline fleets well except for the CPUEs of fleets in the southern subareas between the mid 1980s and the mid of 1990s when the CPUEs reveled obvious increasing patterns. For the base-case, however, the model can not adequately fit to the CPUEs of Japanese longline fleets. Separating the CPUEs of Japanese longline fleets into two time periods substantially improves the model fits to the CPUEs of Japanese longline fleets but the improvement in model fits was not perceptible when separating the CPUEs of Taiwan longline fleets into two time periods (Fig. 3 and Table 4).

Fits

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. However, the model fits obviously degraded when assuming that the selectivities for all of longline fleets are logistic curves (Table 4). The model estimated selectivites are shown in Fig. 5. Fishes with age larger than about 5 years would be almost selected by fishing gear when assuming that the selectivities for all of longline fleets are logistic curves.

Fig. 6 shows the time trajectories of MPD estimates for S_{2007}/S_0, S_{2007}/S_{MSY} and F_{2007}/F_{MSY} for base-case analysis. The fleet-aggregated fishing intensity substantially increased to about 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. The spawning biomass deceased to about 70% of S_0 after 2000 but 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 assumption that selectivies of longline fleets are dome-shaped except for JPLL, AUEL andTWFL, the estimates slightly varied for different assumptions of separated time periods for CPUEs of Japanese and Taiwanese longline fleets The results indicated that current fishing intensity was about 30-50% of F_{MSY} and the spawning biomass maintained at about 67-87% of S_0 and more than triple of S_{MSY}. However, assuming that all selectivities of longline fleets are logistic curve can result in obviously dissimilar estimates, that the estimates of MSY and spawning biomass were only one third of those from other cases, the spawning biomass decreased to 29% of S_0 and close to S_{MSY}, and current fishing intensity also exceed F_{MSY}. In addition, not only the fits of the length frequency data but also the fits of CPUEs obviously degraded when assuming all selectivities of longline fleets are logistic curve (Table 4).

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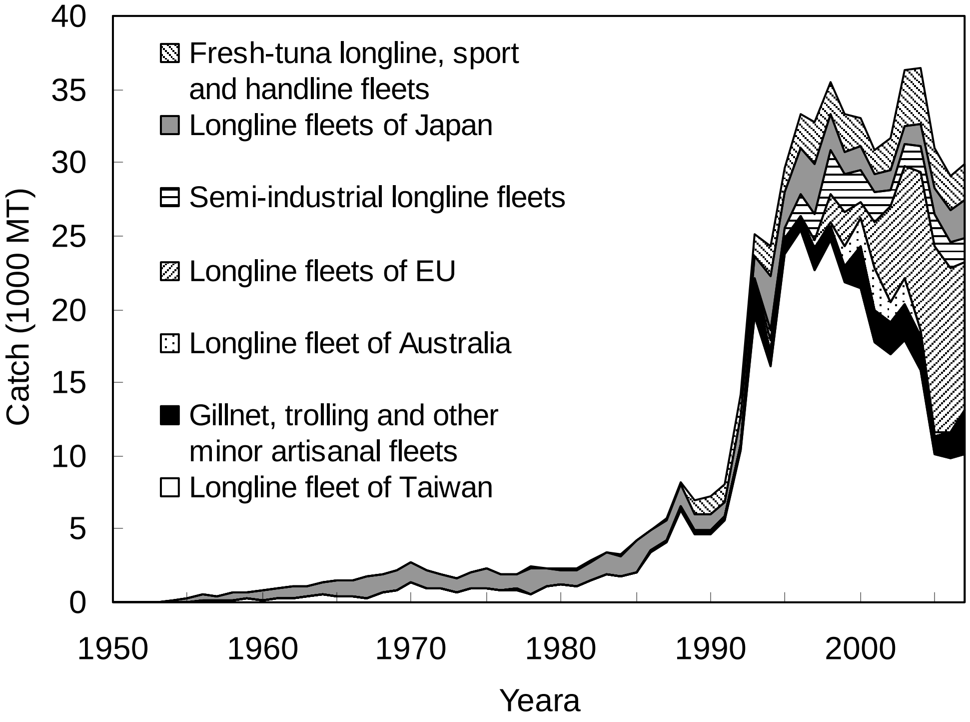

Fig. 1. Annual catches of swordfish in the Indian Ocean from 1952 to 2006.

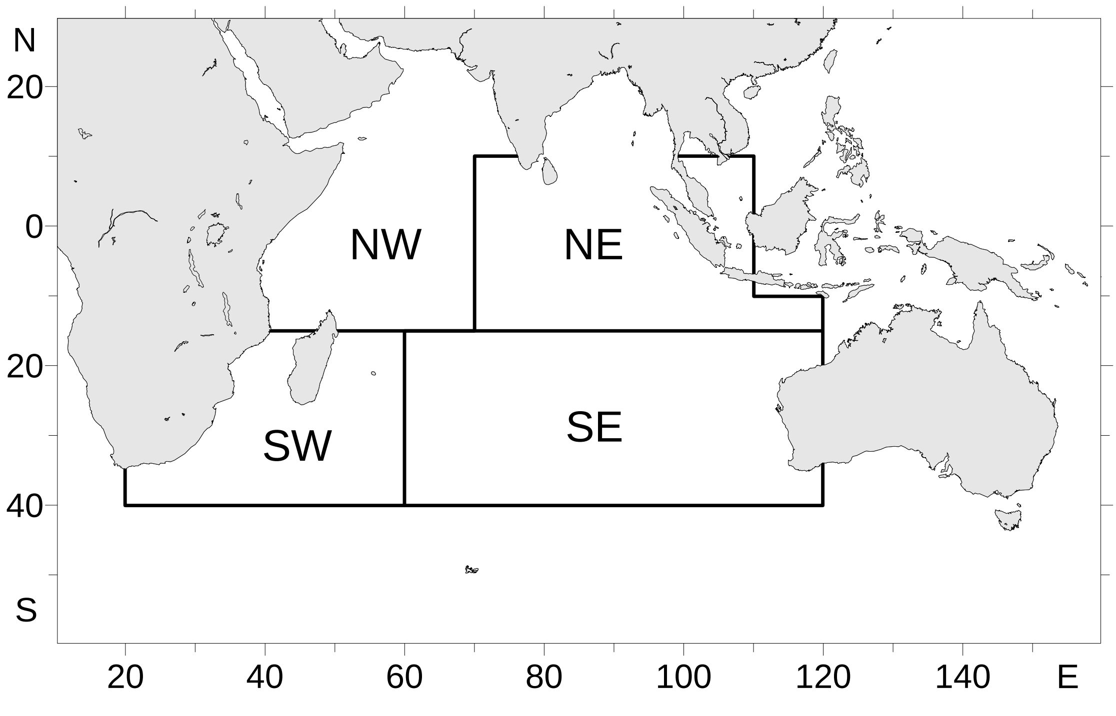

Fig. 2. The definition of areas used in the analyses for swordfish in the Indian Ocean.

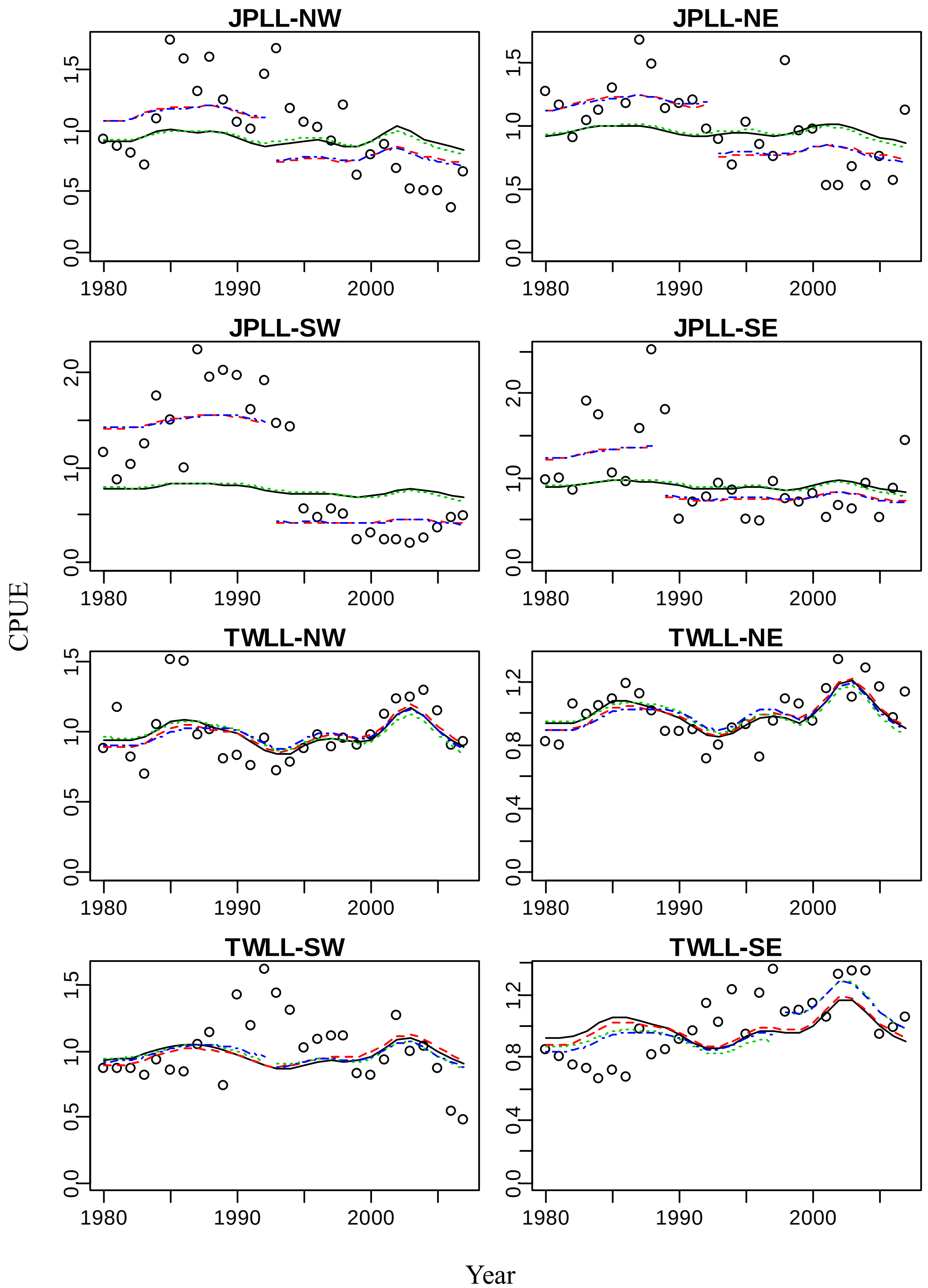

Fig. 3. Standardized observed CPUE (points) and predicted CPUE estimated based on the base-case analysis (solid lines) and based on separating CPUEs of JPLL and TWLL-SW, TWLL-SE into two periods (dashed lines).

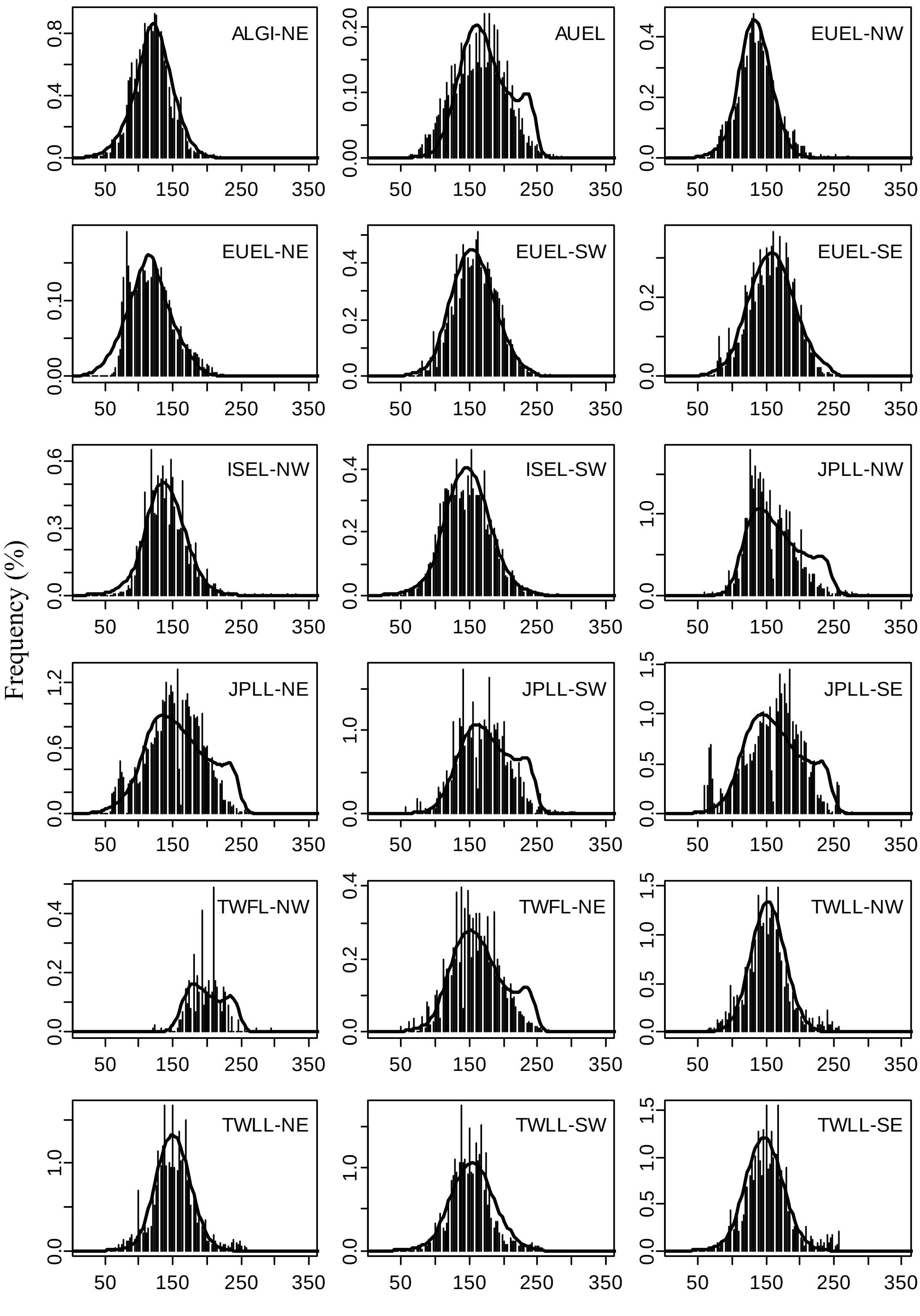

Fig. 4. Observed (histograms) and model-estimated (lines) length-frequencies for the base-case analyses.

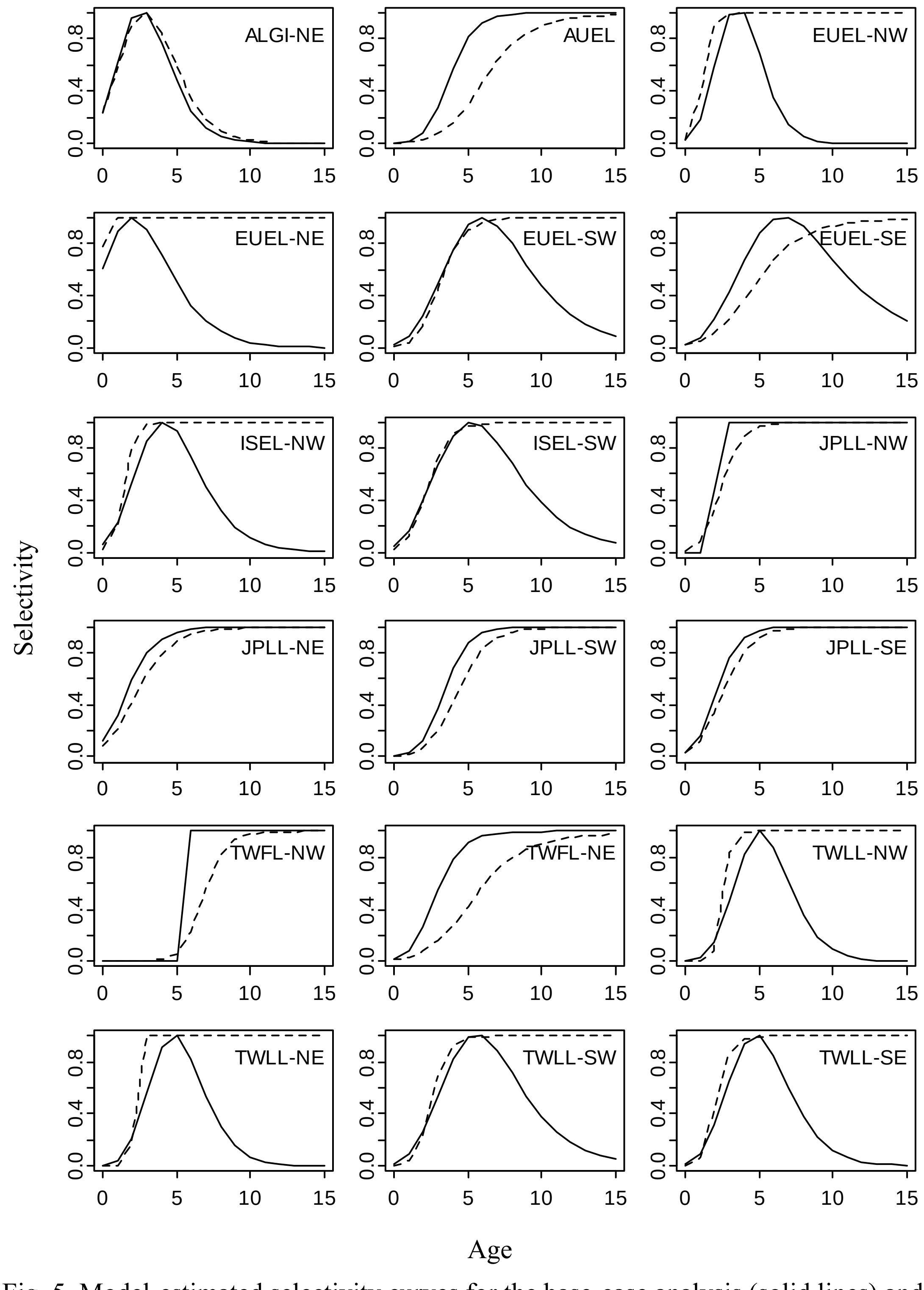

Fig. 5. Model-estimated selectivity curves for the base-case analysis (solid lines) and the case that assumed logistic curve for longline fleets and dome-shaped curve for gillnet fleet (dashed lines).

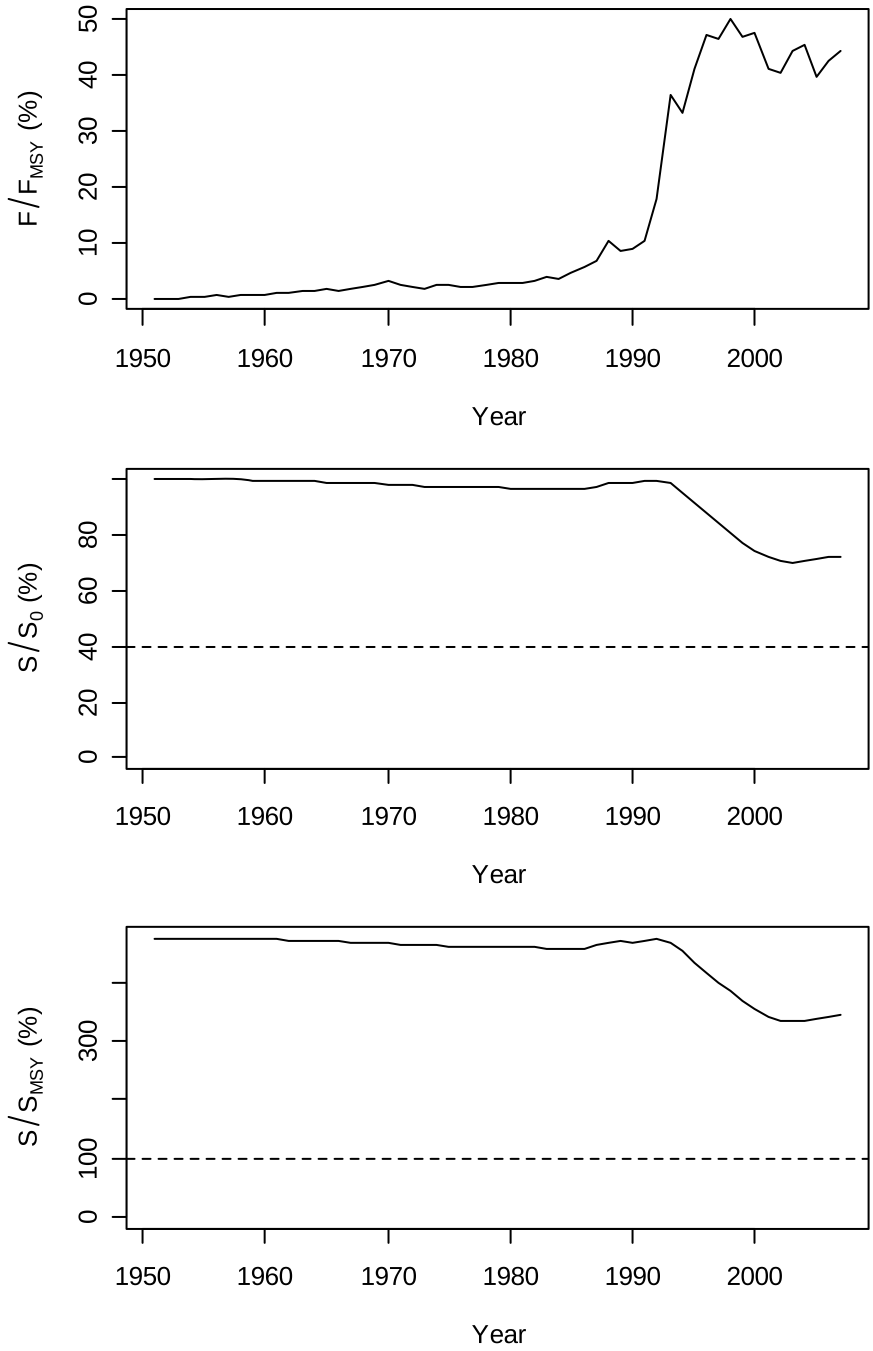

Fig. 6. Time trajectories of MPD estimates for the spawning biomass as a ratio of the unexploited spawning biomass (S_{2007} /S_0), the spawning biomass as a ratio of S_{MSY} (S_{2007}/S_{MSY}) and the fleet-aggregated fishing intensity as a ratio of that at which *MSY* is achieved (F_{2007}/F_{MSY}) for base-case analysis.

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

Fleet	Fleet Code	Area	Catch data	Length data	CPUE
Gillnet, trolling and other minor artisanal fleets	ALGI	NW	1957-2007	-	-
		NE	1951-2007	1988-2006	-
		SW	1988-2006	-	-
		SE	1986-1992	-	-
Longline fishery of Australia	AUEL	SE	1989-2005	2001-2005	-
Longline fleets of EU (from Spain, Portugal and the UK)	EUEL	NW	1980-2007	1993-2006	-
		NE	1980-2007	1999-2006	-
		SW	1980-2007	1994-2007	-
		SE	1980-2007	1999-2007	-
Semi-industrial longline fleets of France-Reunion, France-Mayotte, Madagascar, Mauritius and the Seychelles	ISEL	NW	1995-2007	1995-2007	-
		SW	1991-2007	1997-2007	-
		SE	1995-2007	-	-
Longline fleets of Japan	JPLL	NW	1952-2007	1970-2007	1980-2007
		NE	1952-2007	1970-2007	1980-2007
		SW	1952-2007	1970-2007	1980-2007
		SE	1952-2007	1970-2007	1980-2007
Fresh-tuna longline fleets of Taiwan and Indonesia, and sport and hand line fleets	TWFL	NW	1997-2007	2000-2003	-
		NE	1974-2007	1998-2006	-
		SW	1984-2007	-	-
		SE	2001-2007	-	-
Longline fleet of Taiwan	TWLL	NW	1954-2007	1980-2007	1980-2007
		NE	1954-2007	1980-2007	1980-2007
		SW	1954-2007	1980-2007	1980-2007
		SE	1954-2007	1980-2007	1980-2007

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)	323.4	260.47
Growth parameter, K (year^{-1})	0.08148	0.1096
Age-at-zero-length, t_0 (year)	-3.413	-3.3808
Length-weight, A	$1.839\text{x}10^{-6}$	$1.839\text{x}10^{-6}$
Length-weight, B	3.3921	3.3921
Maturity slope, r_m	0.0953	-
Length-at-50%-maturity, L_m (cm)	170.4	-
Maximum age, λ (year)	15	15

Source: Poisson and Fauvel (2009), Young and Drake (2004) and Ariz et al. (2006).

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 2007
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 and the values of likelihood for length-frequency and CPUE data for the base-case analysis and the sensitivity analyses.

	MSY	S_{MSY}	S_{2007}/S_0	S_{2007}/S_{MSY}	F_{2007}/F_{MSY}	The value of likelihood for	
						length-frequency	CPUE
Base-case	33423	107083	0.72	3.43	0.44	488.85	-170.63
Two time periods for CPUEs of JPLL	43197	140623	0.87	4.13	0.31	487.16	-199.51
Two time periods for CPUEs of TWSW and TWSE	30649	97665	0.67	3.16	0.52	488.01	-171.74
Two time periods for CPUEs of JPLL, TWLL-SW and TWLL-SE	38748	125605	0.83	3.94	0.36	486.62	-200.86
Logistic selectivity for longline and dome-shaped selectivity for gill net	12779	36490	0.29	1.40	1.67	519.56	-158.66