CPUE standardization of swordfish (*Xiphias gladius*) caught by Taiwanese longline fishery in the Indian Ocean during 1995-2008

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INTRODUCTION

Taiwanese longline fishery in the Indian Ocean commenced in mid-1950s and targeted on yellowfin tuna in the beginning. Following the development of the fishery, two different operation patterns were currently established: the first targets on albacore for canning and the other on tropical tuna species (bigeye tuna and yellowfin tuna) for sashimi market. Since 1990's, however, swordfish has become a seasonal target species to some of the fleets.

Most of swordfish catch in the Indian Ocean was made by lognline fisheries especially for Taiwanese longline fishery (seasonal targeting fishery) and Japanese longline fishery (exploited as bycatch), which have the longest period of catch data series. Furthermore, Taiwanese longline fishery made highest proportion of swordfish (about 50-70%) than other fisheries since 1970's although the proportion (about 40-55%) decreased during recent decades.

The characters of fishing operation, such as number of hooks between float (NHBF), material of line, bait and etc., are known to be informative to describe the change in target species. The number of hooks between float were available since 1995. In this paper, therefore, we attempted to the standardize CPUE of swordfish caught by Taiwanese longline fisheries in the Indian Ocean for the period of 1995 to 2008.

MATERIAL AND METHODS

Catch and Effort data

In this study, daily set-by-set catch and effort data (logbook) with 1x1 degree longitude and latitude data of Taiwanese longline fishery during 1995-2008 were provided by Oversea Fisheries Development Council of Taiwan (OFDC). The core fishing areas for swordfish in the Indian Ocean were defined based on the high frequency of swordfish catch occurrence of Taiwanese and Japanese longline fisheries (Nishida and Wang, 2010) (Fig. 1). The data in the core fishing areas were extracted for CPUE standardization.

Environmental data

The details of environmental data used in this study were described in the paper of Nishida and Wang (2009).

GLM Model

In this study, GLM is used to model the logarithm of the nominal CPUE (defined as the number of fish per 3,000 hooks). The main effects considered in this analysis are year, quarter, area, NHBF and vessel. The environmental effects included in the GLM are Indian Oscillation Index (IOI), temperature gradient (TG), salinity gradient (SG), moon phase (MP), dipole index (DPI), temperature at 45 m depth (T45) and salinity at 45 m depth (S45). Hinton and Maunder (2004) indicated that interactions with the year effect would invalidate the year effect as an index of abundance. In addition, high autocorrelation would occur among environmental effects. For the interactions between effects, therefore, the interactions between the effects of year and area and between effects of temperature gradient and area were considered in the GLM. The effects of year, quarter and were treated as category variables and others were treated as continuous variables. Seven models with different combination of effect were considered:

$$\text{Model 1}: \log(CPUE + c) = \mu + Y + Q + A + Y \times A$$
$$\text{Model 2}: \log(CPUE + c) = \mu + Y + Q + A + Y \times A + NHBF$$
$$\text{Model 3}: \log(CPUE + c) = \mu + Y + Q + A + Y \times A + NFBF + V$$
$$\text{Model 4}: \log(CPUE + c) = \mu + Y + Q + A + Y \times A + ENV$$
$$\text{Model 5}: \log(CPUE + c) = \mu + Y + Q + A + Y \times A + NHBF + ENV$$
$$\text{Model 6}: \log(CPUE + c) = \mu + Y + Q + A + Y \times A + NHBF + ENV + V$$
$$\text{Model 7}: \log(CPUE + c) = \mu + Y + Q + A + Y \times A + NHBF + ENV + V + TG \times A$$

where $CPUE$ is the nominal CPUE of swordfish (catch in number/3000 hooks),

c is the constant value (i.e. 10% of the average nominal CPUE),

μ is the intercept,

Y is the effect of year,

Q	is the effect of quarter,
A	is the effect of fishing area,
HHBF	is the effect of number of hooks between float,
V	is the effect of vessel,
ENV	is all of the environmental effects described above,
ε	is the error term, $\varepsilon \sim N(0, \sigma^2)$.

Adjustment by area size

The estimation of annual nominal and standardized CPUE is calculated from the weighted average of the area indices (Punt et al., 2000).

$$U_y = \sum_a S_a U_{y,a}$$

Where	U_y	is CPUE for year *y*,
	$U_{y,a}$	is CPUE for year *y* and area *a*,
	S_a	is the relative size of the area *a* to the four new areas.

The relative sizes of nine IOTC statistics areas for swordfish in the Indian Ocean (Nishida and Wang et al., 2006) were used to be aggregated into four areas used in this study.

RESULTS AND DISCUSSION

Based on the values of BIC and R^2 (Table 1), the model with all main effects and interaction of TG×A (Model 7) would be selected as the best model but the proportion of explained variances (R^2) was not obviously improved than that of the model without interaction of TG×A (Model 6). Among effects, including the vessel effect has the most significant improvement for BIC and R^2 but this increased large amount of estimated parameters in the model (Table 2).

The quarter effect was the most explainable variable for the model and the effect of salinity at 45 m depth and area would be the second and third one (Table 2). It is surprised that the explanation ability of NHBF effect was not very significant. This might be because Taiwanese longline vessels changed the fishing area in different season but the NHBFs in different fishing areas was not significantly changed over time although they slightly increased since 1995 (Fig. 2).

The area-specific standardized CPUEs are shown in Fig. 3. The results of seven models reveal similar trends for each fishing area although model 6 and 7 reveal relatively smooth trends in area NE. Except for area SE, standardized CPUEs reveal continuously decreasing trends for recent years, especially for area SW where the CPUE sharply decreased since 1995. Fig. 4 shows the standardized CPUE area-aggregated by area size. Although there was an obvious peak in 2002, the standardized CPUE reveals gradually decreasing pattern since 1995.

Acknowledgement

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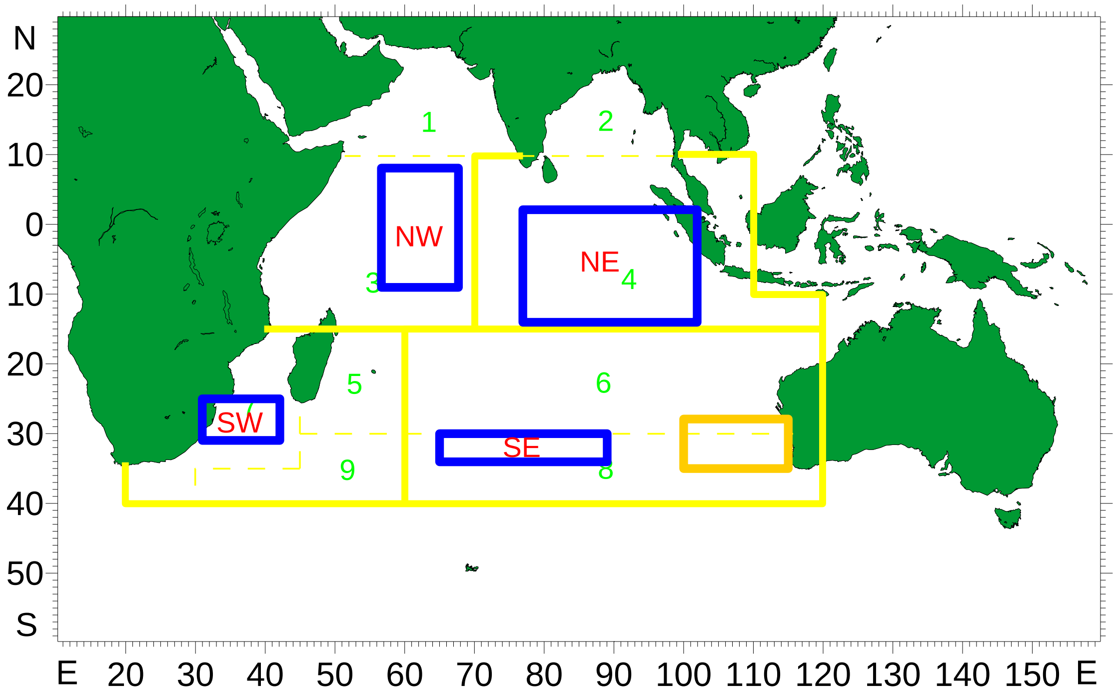

Fig. 1. Core fishing areas (squares in blue) for swordfish caught by Taiwanese longline fishery in the Indian Ocean (square in orange is the SE area for Japanese longline fishery).

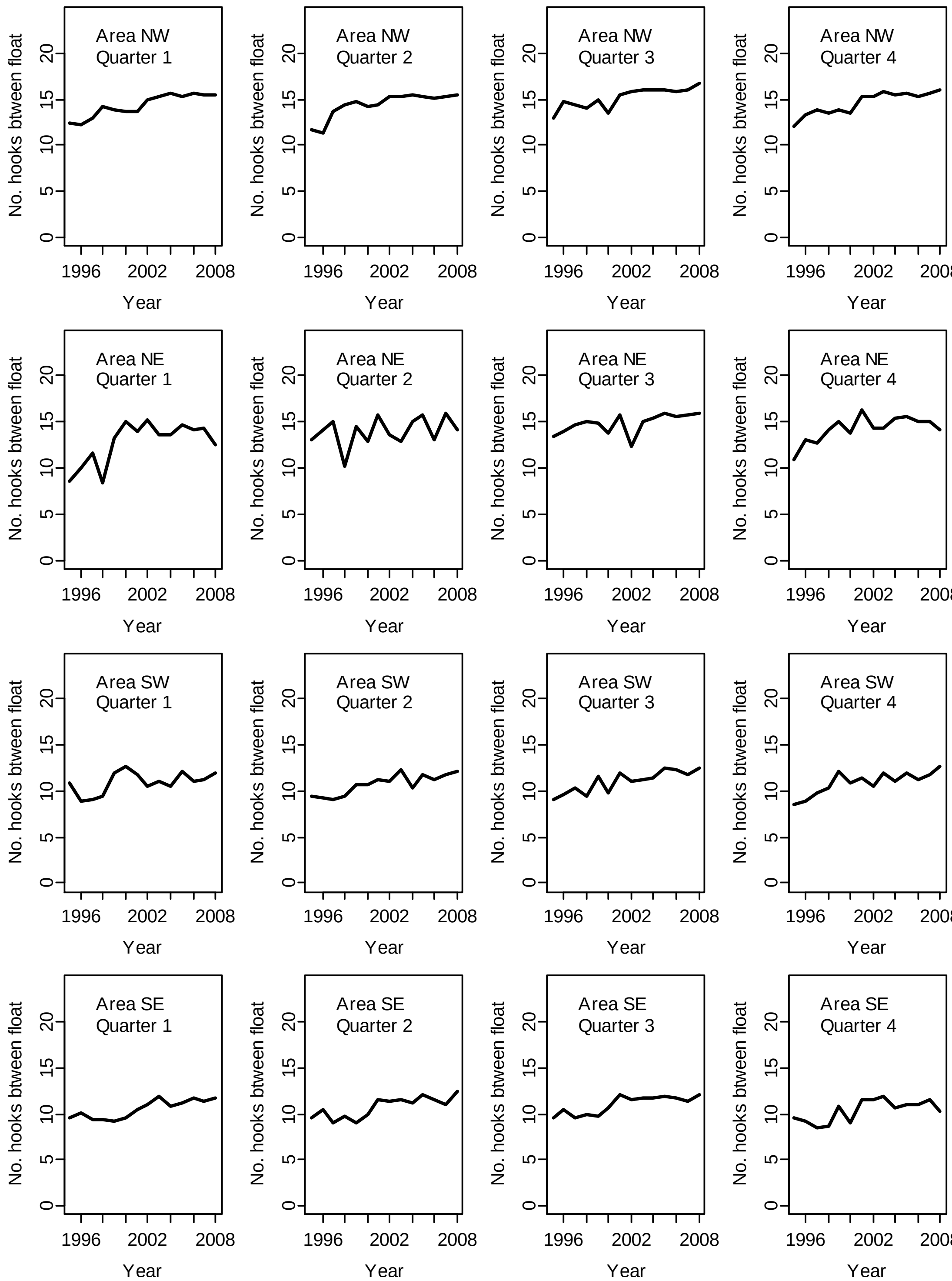

Fig. 2. The mean number of hooks between float of Taiwanese longline fishery in the Indian Ocean.

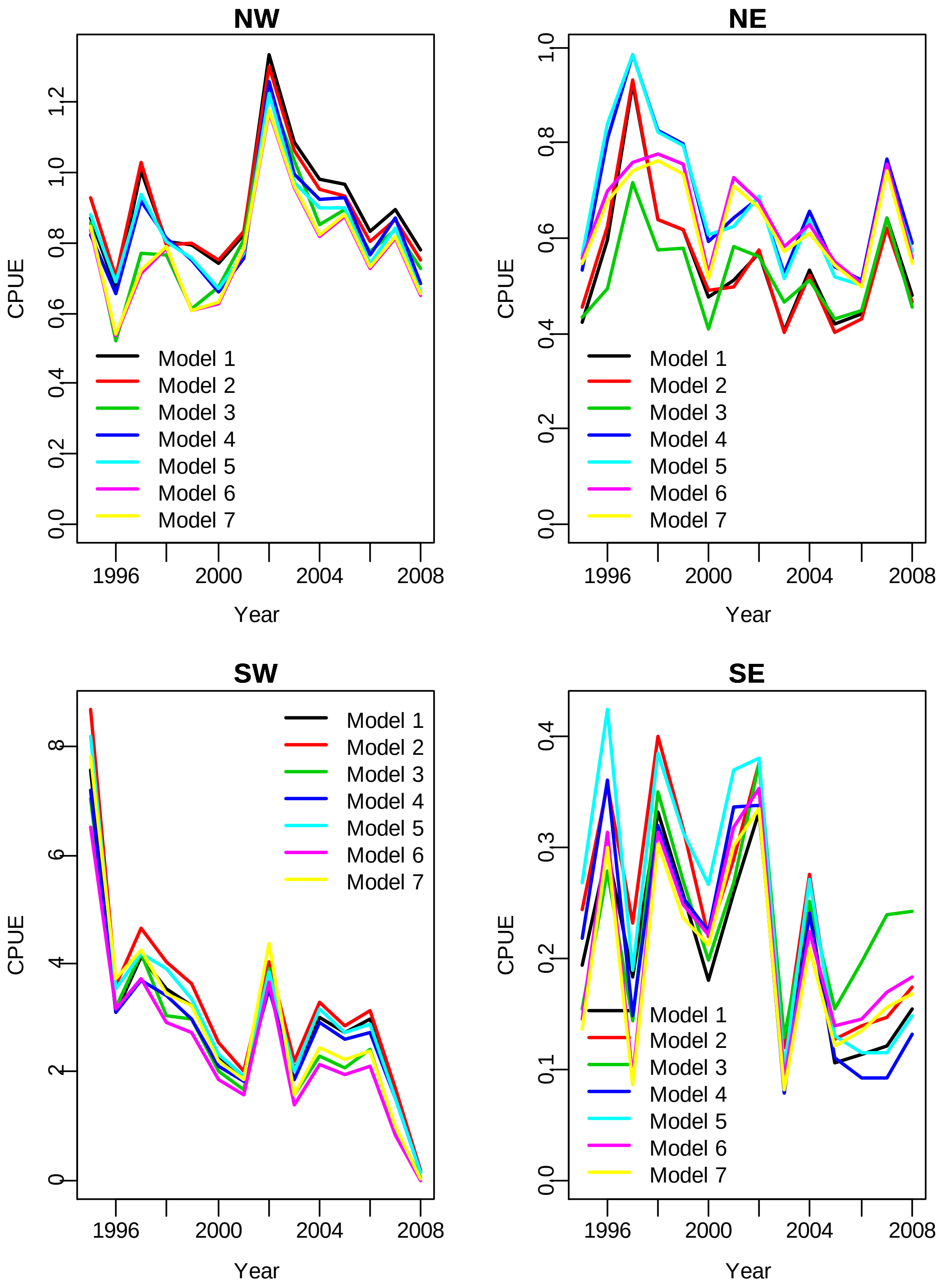

Fig. 3. Area-specific standardized CPUE of swordfish caught by Taiwanese longline fishery in the Indian Ocean.

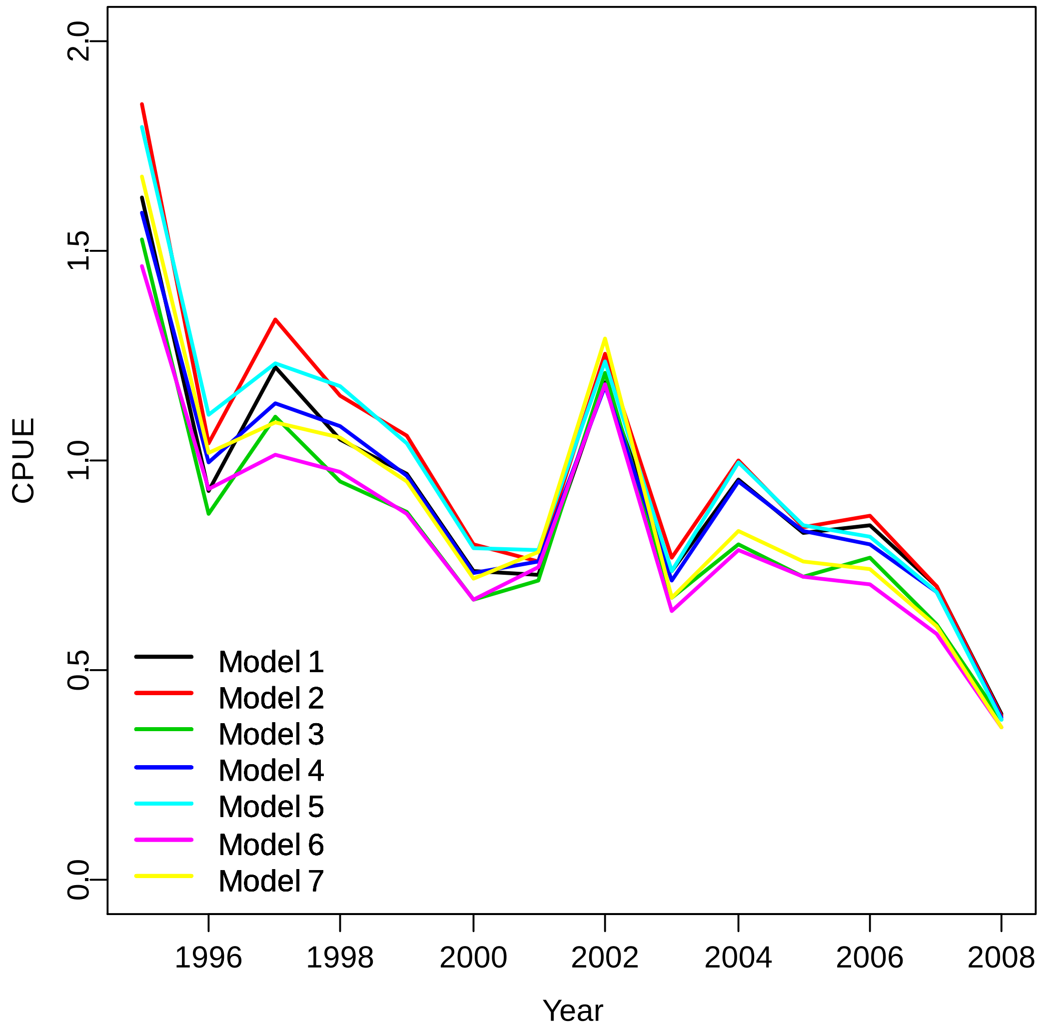

Fig. 4. Area-aggregated standardized CPUE of swordfish caught by Taiwanese longline fishery in the Indian Ocean.

Table 1. The values of BIC and R^2 for seven models.

sn	MODEL	BIC	△BIC	R^2 (%)
1	Y+Q+A+Y×A	596847	-	11.94
2	Y+Q+A+Y×A+NHBF	596620	-226	12.06
3	Y+Q+A+Y×A+NHBF+V	579945	-16901	20.23
4	Y+Q+A+Y×A+ENV	596137	-710	12.30
5	Y+Q+A+Y×A+NHBF+ENV	595939	-908	12.41
6	Y+Q+A+Y×A+NHBF+ENV+V	579315	-17531	20.52
7	Y+Q+A+Y×A+NHBF+ENV+V+TG×A	579272	-17575	20.54

Table 2. ANOVA table of Model 7.

Source	DF	Type III SS	Mean Square	F Value	Pr > F
Y	13	1191.73	91.67	57.04	<.0001
Q	3	5016.57	1672.19	1040.49	<.0001
A	3	867.67	289.22	179.96	<.0001
Y*A	39	2439.77	62.56	38.93	<.0001
NHBF	1	58.30	58.30	36.27	<.0001
S45	1	741.96	741.96	461.67	<.0001
T45	1	8.41	8.41	5.23	0.0222
TG	1	24.18	24.18	15.05	0.0001
SG	1	40.50	40.50	25.20	<.0001
IOI	1	37.47	37.47	23.31	<.0001
DPI	1	106.15	106.15	66.05	<.0001
MP	1	38.15	38.15	23.74	<.0001
V	374	28596.99	76.46	47.58	<.0001
TG*A	3	76.83	25.61	15.94	<.0001