Received: 7 July, 2011

IOTC–2011–WPB09–16 Rev1

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

Sheng-Ping Wang[1] and Tom Nishida[2]

[1] Department of Environmental Biology and Fisheries Science, National Taiwan Ocean University, Keelung, Taiwan.
[2] National Research Institute of Far Seas Fisheries, Fisheries Research Agency, Shimizu, Shizuoka, Japan.

ABSTRACT

This study carried out the CPUE standardization of swordfish caught by Taiwanese longline fishery in the Indian Ocean for 1995-2009 using generalized linear model (GLM) and generalized additive model (GAM). Including the effect of vessel and the effect of NHBF treated as continuous variable obviously improved the values of R^2, AIC and BIC. Although there was an obvious peak in 2002, the area-specified and area-aggregated standardized CPUEs all reveal gradually decreasing patterns since 1995. The trends of CPUEs standardized by GAM are similar to those standardized by GLM but reveal much smoother patterns. This study also performed GLM by incorporating the effects of longitude and latitude and the results are also similar to other cases.

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 2009.

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 1995-2009 were provided by Oversea Fisheries Development Council of Taiwan (OFDC). Fishing areas used in this study were redefined by four areas based on the IOTC statistics areas for swordfish in the Indian Ocean (Fig. 1)

Environmental data

The details of environmental data used in this study were described in the paper of Nishida et al. (2011).

GLM analysis

In this study, General Linear Model (GLM is used to model the logarithm of the nominal CPUE (defined as the number of fish per 1,000 hooks). The main effects considered in this analysis are year, quarter, area, NHBF and vessel. The environmental effects included in the model are Indian Oscillation Index (IOI), Dipole Mode Index (DMI), moon phase (MP), sheer currents (SC), (amplitude of the shear current (AM), thermocline depth (TD) and temperature gradient (TG). 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 the effects of quarter, area and NHBF are considered in the GLM.

The effects of year, quarter and vessel are treated as category variables. Two types of the effect of NHBF are used in this study, one was treated NHBF as continuous variable and the other on was treated NHBF as three categories (regular: <9 hooks; deep: 10-14 hooks; ultra deep: >15 hooks). All of environmental effects are treated as continuous variables. Nine models with different combination of effect were considered:

$$\text{Model 1}: \log(CPUE + c) = \mu + Y + Q + A + Y \times A + \varepsilon$$
$$\text{Model 2}: \log(CPUE + c) = \mu + Y + Q + A + Y \times A + V + \varepsilon$$
$$\text{Model 3}: \log(CPUE + c) = \mu + Y + Q + A + Y \times A + NHBF + \varepsilon$$
$$\text{Model 4}: \log(CPUE + c) = \mu + Y + Q + A + Y \times A + NHBF2 + \varepsilon$$
$$\text{Model 5}: \log(CPUE + c) = \mu + Y + Q + A + Y \times A + V + NHBF2 + ENV1 + \varepsilon$$
$$\text{Model 6}: \log(CPUE + c) = \mu + Y + Q + A + Y \times A + V + NHBF2 + ENV1 + ENV2 + \varepsilon$$
$$\text{Model 7}: \log(CPUE + c) = \mu + Y + Q + A + Y \times A + V + NHBF2 + ENV1 + ENV2\_A + \varepsilon$$
$$\text{Model 8}: \log(CPUE + c) = \mu + Y + Q + A + Y \times A + V + NHBF2 + ENV1 + ENV2 + Q \times A + Q \times NHBF2 + A \times NHBF2 + \varepsilon$$
$$\text{Model 9}: \log(CPUE + c) = \mu + Y + Q + A + Y \times A + V + NHBF2 + ENV1 + ENV2 + \text{interactions} + \varepsilon$$

where	*CPUE*	is the nominal CPUE of swordfish (catch in number/1,000 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,
	V	is the effect of vessel,
	NHBF	is the effect of NHBF treated as continuous variable,
	NHBF2	is the effect of three categories of NHBF,
	ENV1	are the environmental effects of IOI, DMI and MP,
	ENV2	are the environmental effects related to oceanographic conditions (SC, AM, TD and TG),
	ENV2_A	are the environmental effects related to anomalies of oceanographic conditions (anomalies of SC, AM, TD, TG),
	ε	is the error term, $\varepsilon \sim N(0, \sigma^2)$.

As the suggestion of the working party, this study also exams the GLM analysis by incorporating the effects of longitude and latitude. For this analysis, the effect of area is not considered because the effect of area might be highly correlated to the effect of longitude and latitude. Therefore, the CPUE standardization is carried out for each area separately.

The model selection is based on the values of the coefficient of determination

(R^2), Akaike information criterion (AIC) and Bayesian information criterion (BIC). The standardized CPUE are calculated based on the estimates of least square means of the interaction between the effects of year and area.

GAM analysis

In addition, this study also attempts to standardize CPUE by using General Additive Model (GAM; Hastie and Tibshirani, 1990). This study simply conducts the GAM based on the additive smoother function of the effects and do not consider the interactions between effects.

$$\log(CPUE + c) = s(Y) + s(Q) + s(A) + s(A) + s(V) \\ + s(NHBF2) + s(ENV1) + s(ENV2) + \varepsilon$$

where $s(x)$ is the spline smoother function of the effects with model calculated degree or freedom,

ε is the error term, $\varepsilon \sim N(0, \sigma^2)$.

The GAMs are performed for each area, separately. The standardized CPUE are calculated based on the partial estimates of the effect of year.

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

Table 1 shows the values of R^2, AIC and BIC for nine models. The results indicate that including the effect of vessel obviously improved the proportion of explained variances (R^2), AIC and BIC. Comparing to the effect of NHBF treated as continuous variable, the values of AIC and BIC significantly decreased when including (Model 3 and 4). Including the environmental effects related to anomalies of oceanographic conditions not only decreased R2 but also increased AIC and BIC (model 6 and 7). In addition, this study also attempted to include the interactions between every two effects (model 9). Although including the interactions much improved R^2 and AIC, BIC was not significantly improved because large amount of estimated parameters were needed in this model. Therefore, Model 8 was the final model selected in this study and the ANOVA table is shown in Table 2.

Based on the GAM analysis for each area, all effects were statistically significant and thus all effects were included in the model (Table 3).

The area-specific nominal and standardized CPUEs are shown in Fig. 2. The trends of CPUEs standardized by GLM and GAM were similar but the trends of CPUE standardized by GAM were much smoother than those standardized by GLM. The results of GLM and GAM both revealed different CPUE trends in western and eastern areas. Standardized CPUEs in areas NE and SE increased during 1995-1997, decreased until 2005, and slight increased thereafter. Standardized CPUEs in areas NW and SW revealed decreasing trends since 1995, especially for area SW.

Fig. 4 shows the standardized CPUE area-aggregated by area size. Although the CPUE standardized by GLM slight fluctuated, the CPUEs standardized by GLM and GAM both reveals gradually decreasing trends since 1995.

Figs. 5 and 6 show the area-specific and area-aggregated standardized CPUE by incorporating the effect of longitude and latitude. The results of this case show very similar CPUE trends with the results form Model 8.

REFERENCE

Hastie, T.J., Tibshirani, R.J., 1990. Generalized Additive Models. Chapman and Hall, New York.

Hinton, M. G., and M. N. Maunder, 2004. Methods for standardizing CPUE and how to select among them. Col. Vol. Sci. Pap. ICCAT, 56: 169-177.

Nishida, T., and S. P. Wang, 2006. Standardization of swordfish (*Xiphias gladius*) CPUE of the Japanese tuna longline fisheries in the Indian Ocean (1975-2004). The fifth session of the IOTC Working Party on Billfish (WPB), Indian Ocean

Tuna Commission (IOTC), March 27–31, 2006. Colombo, Sri Lanka. IOTC-2006-WPB-07, 10 pp.

Nishida, T., T. Kitakado, and S. P. Wang, 2011. Estimation of the Abundance Index (AI) of swordfish (*Xiphias gladius*) in the Indian Ocean (IO) based on the fine scale catch and effort data of the Japanese tuna longline fisheries (1980-2010). The ninth session of the IOTC Working Party on Billfish (WPB), Indian Ocean Tuna Commission (IOTC), July 4-8, 2011. Victoria, Seychelles. IOTC-2011-WPB09-14.

Punt, A. E., T. I. Walker, B. L. Taylor, and F. Pribac, 2000. Standardization of catch and effort data in a spatially-structured shark fishery. Fish. Res. 45: 129-145.

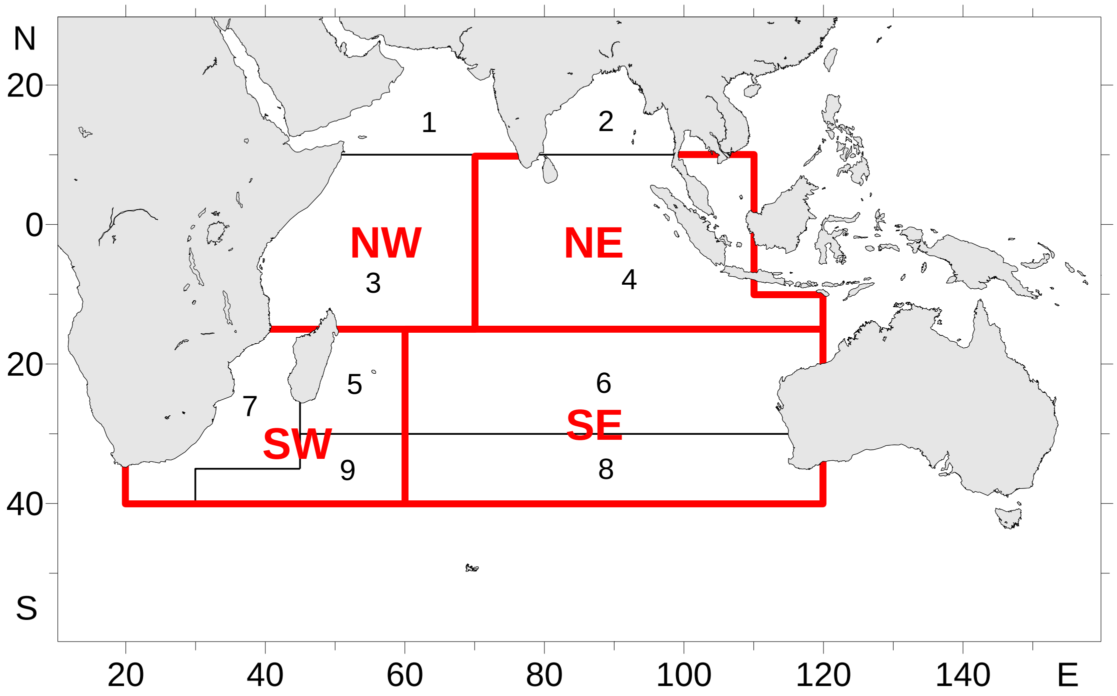


Fig. 1. Area stratification for swordfish in the Indian Ocean.

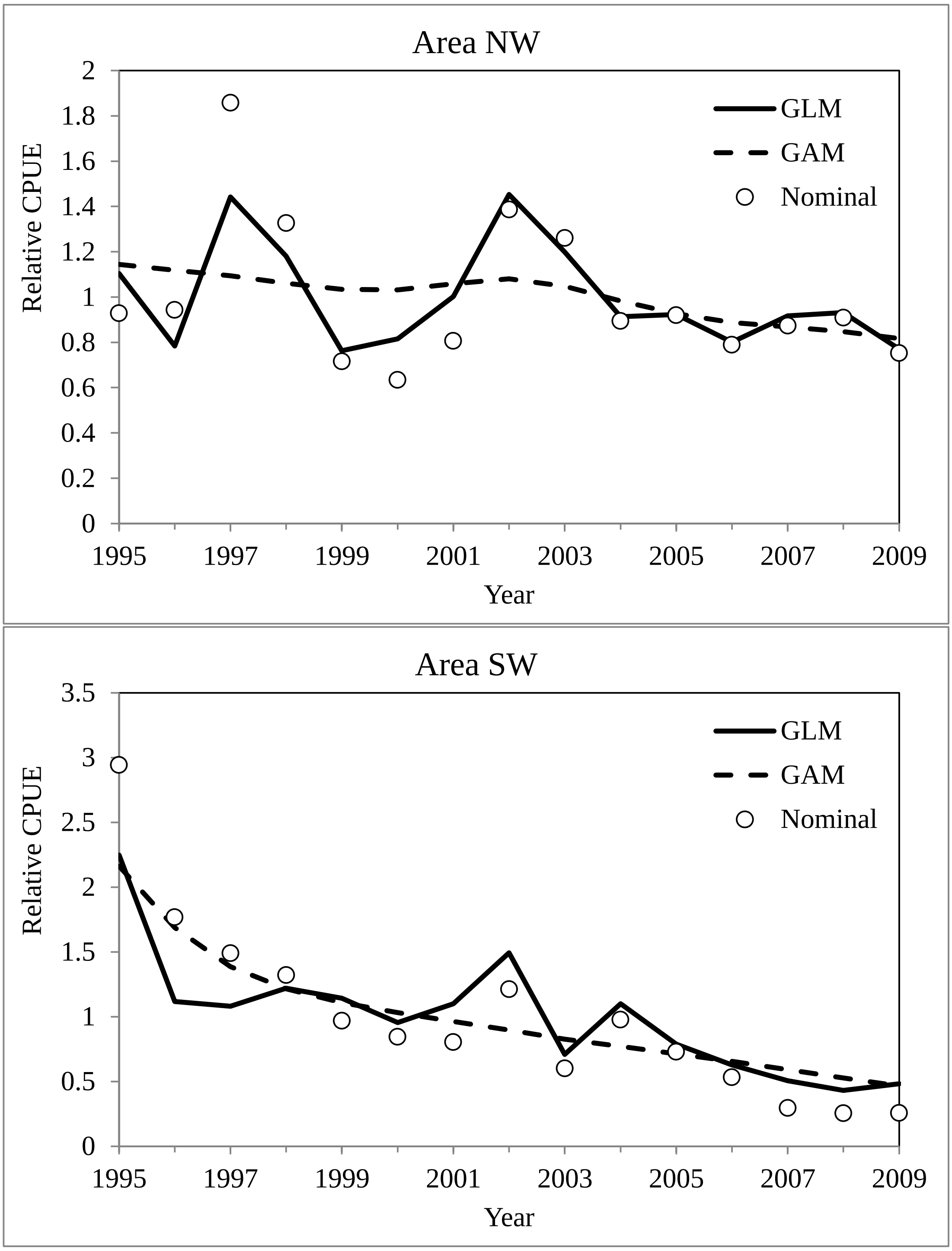
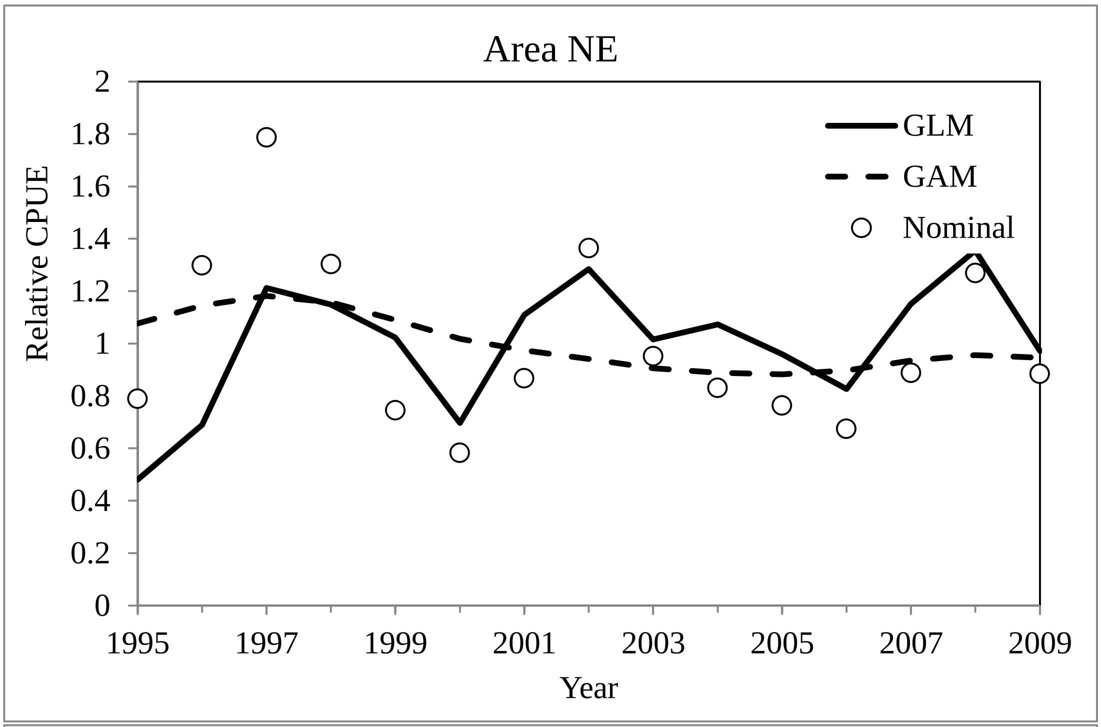


Fig. 3. Area-specific standardized CPUE of swordfish caught by Taiwanese longline fishery in the Indian Ocean.



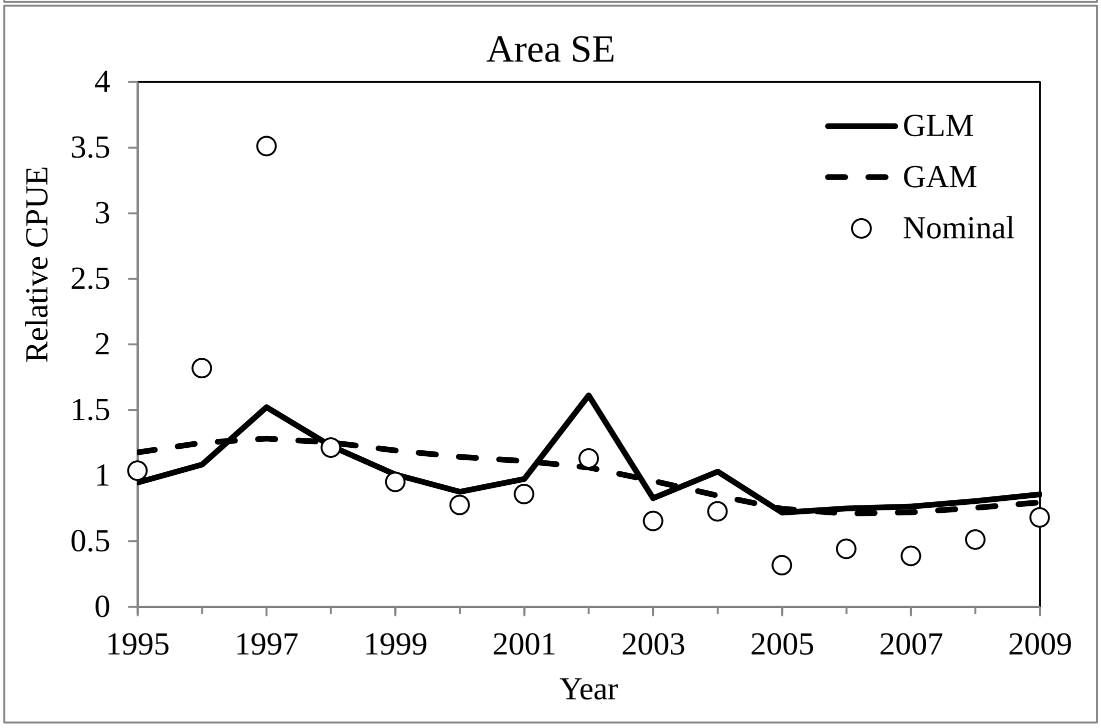


Fig. 3. (Continued).

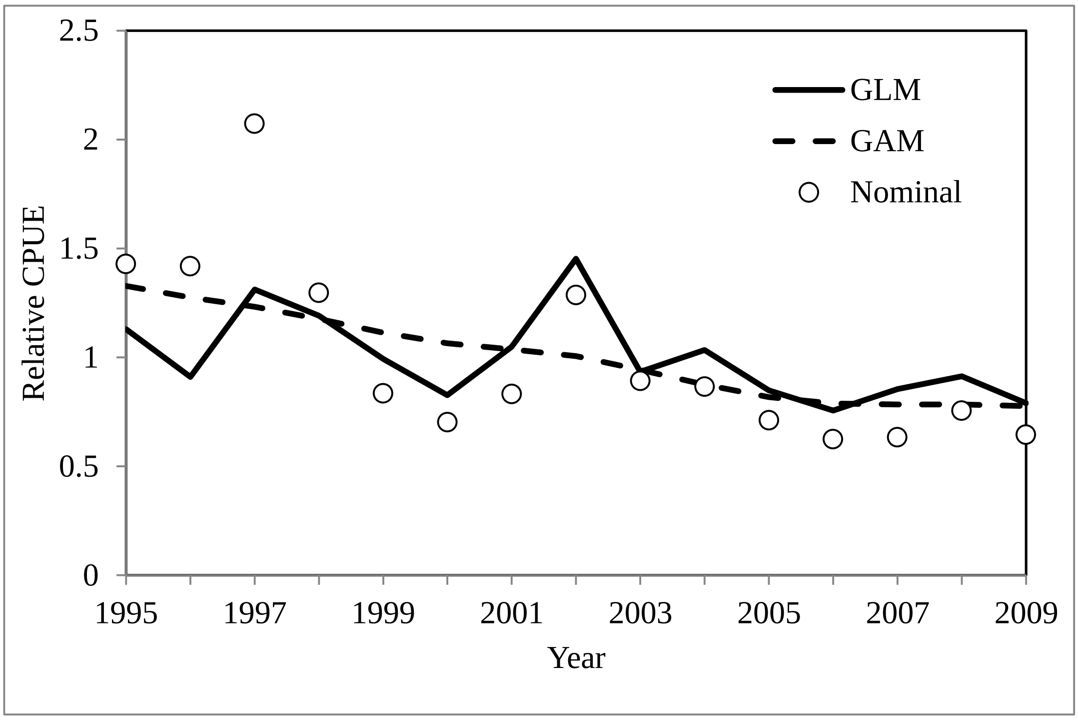
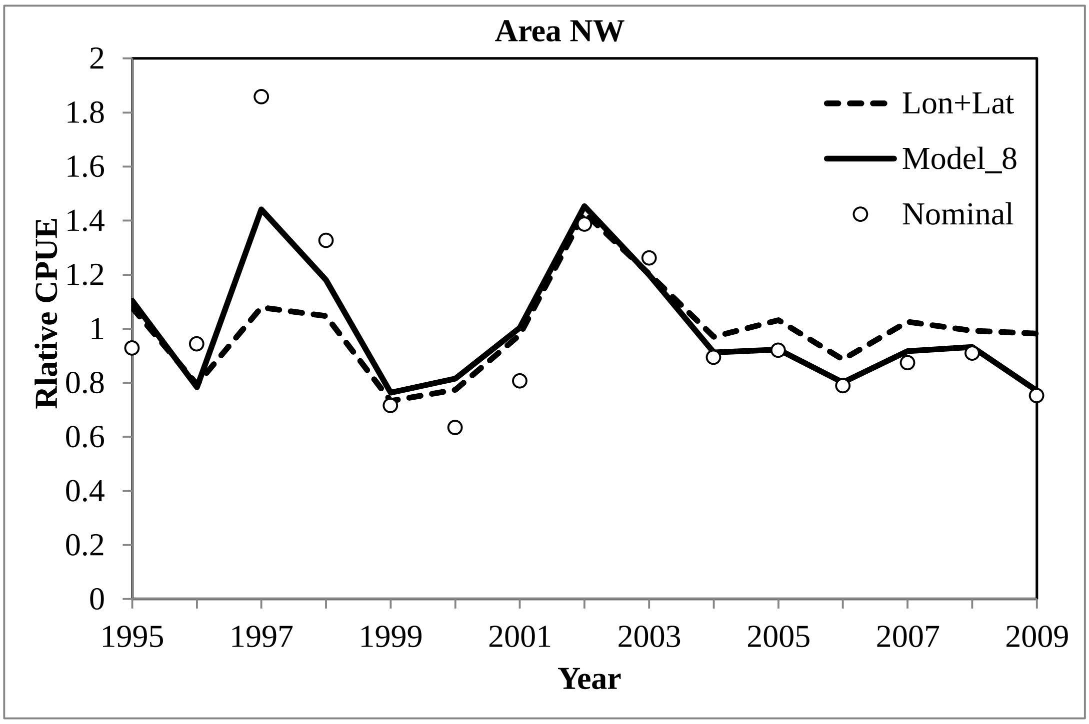


Fig. 4. Area-aggregated standardized CPUE of swordfish caught by Taiwanese longline fishery in the Indian Ocean.



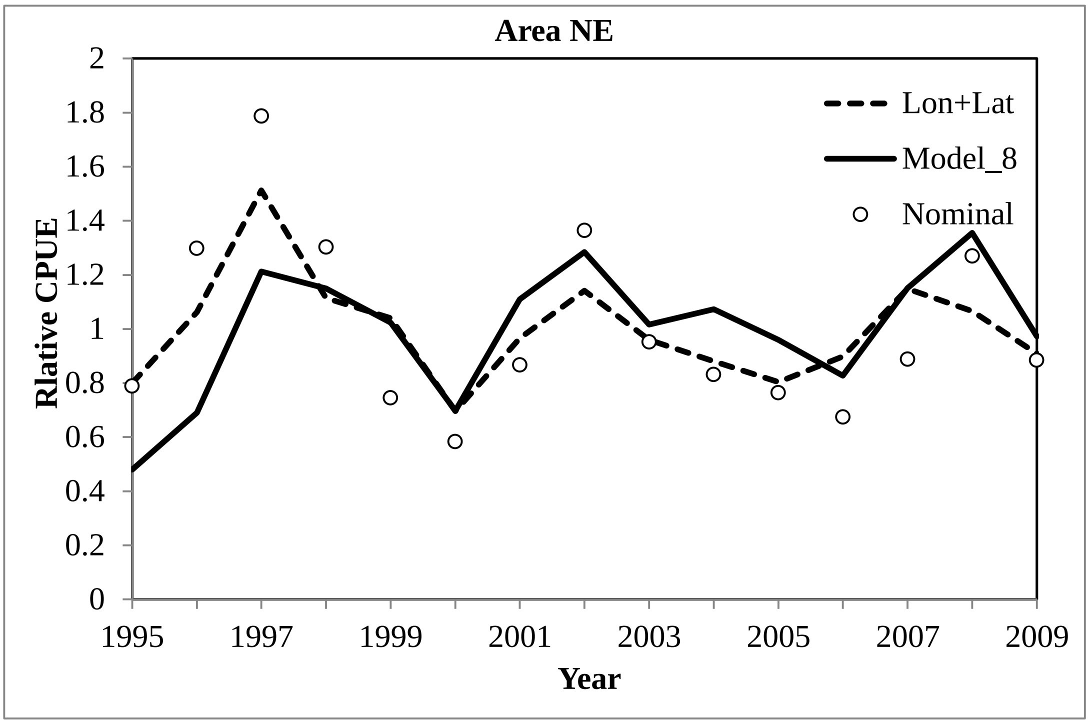
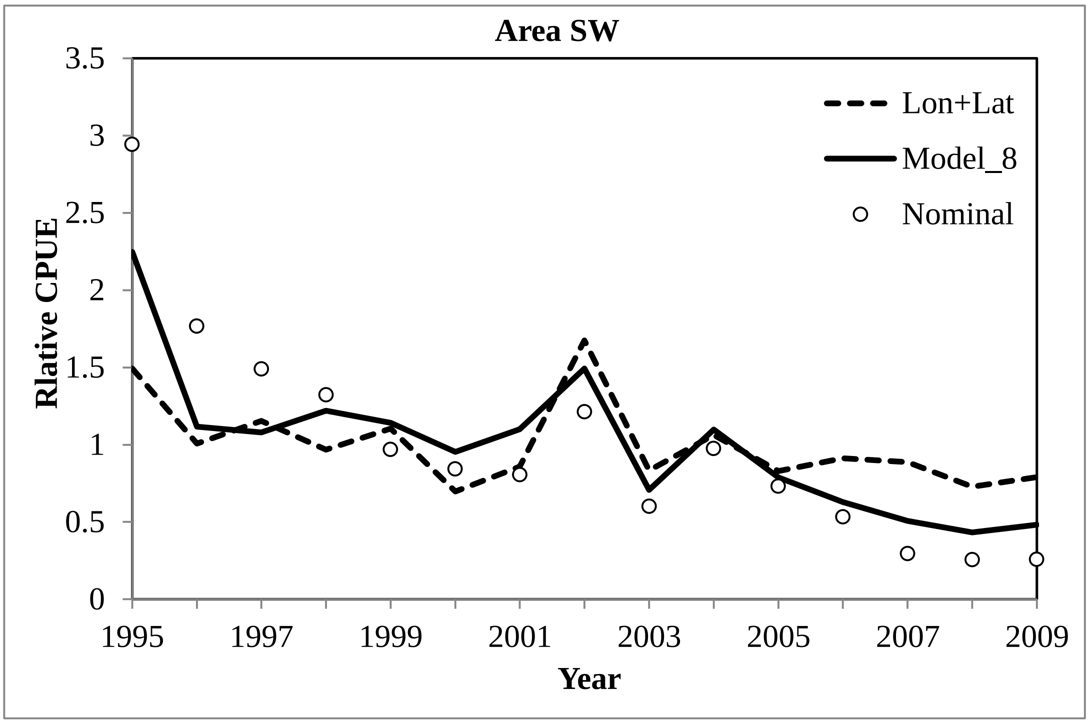


Fig. 5. Area-specific standardized CPUE of swordfish caught by Taiwanese longline fishery in the Indian Ocean based on the model incorporated the effect of longitude and latitude.



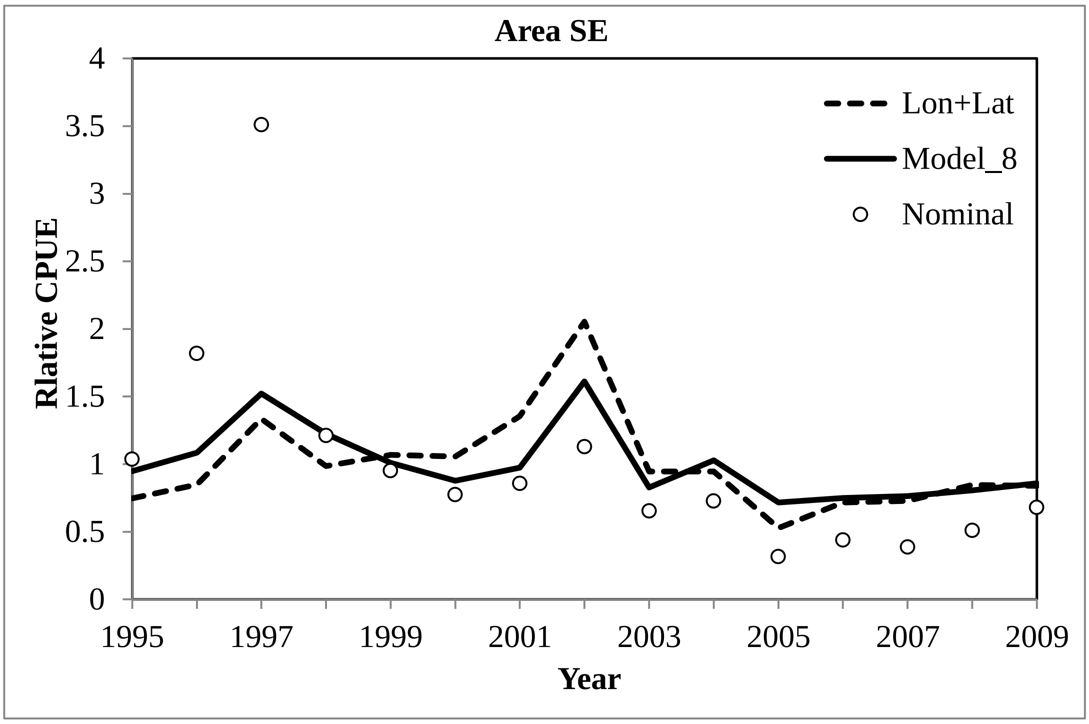


Fig. 5. (Continued).

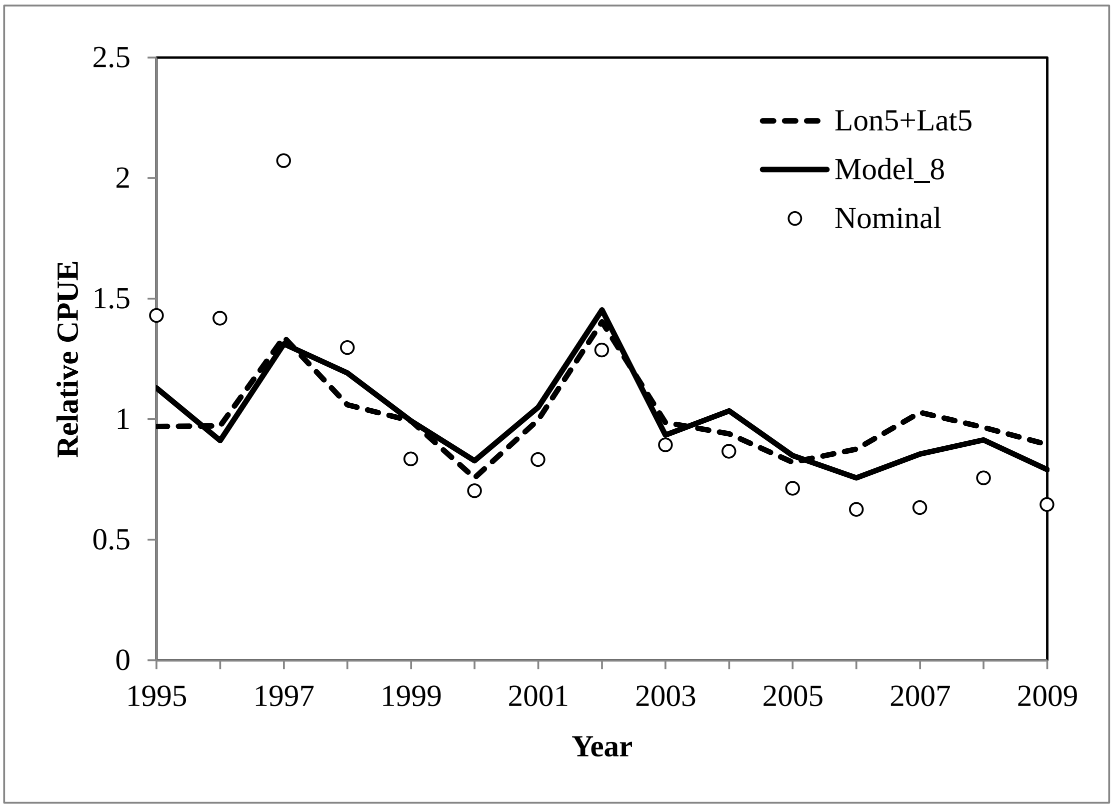


Fig. 6. Area-aggregated standardized CPUE of swordfish caught by Taiwanese longline fishery in the Indian Ocean based on the model incorporated the effect of longitude and latitude.

Table 1. The values of R2, AIC and BIC for nine models.

Model	Model DF	AIC	BIC	R2(%)	ΔR2(%)	ΔAIC	ΔBIC
1	62	265244	265925	7.3			
2	457	222304	227323	16.3	9	-42940	-38602
3	63	263877	264569	7.6	0	-1367	-1356
4	64	262173	262876	8.0	1	-3071	-3049
5	462	219909	224983	16.8	9	-45335	-40942
6	466	217894	223012	17.1	10	-47350	-42913
7	466	219681	224799	16.8	9	-45563	-41126
8	487	211115	216463	18.4	11	-54129	-49462
9	4744	161064	213158	29.4	22	-104180	-52767

Table 2. ANOVA table of Model 8.

Source	DF	Sum of Squares	Mean	Square	F Value	Pr > F
Model	487	159037.33	3	26.57	201.24	<0.0001
Error	433607	703632.62		1.62		
Corrected Total	434094	862669.94				

Source	DF	Type III SS	Mean Square	F Value	Pr > F
Y	14	4670.46	333.60	205.58	<.0001
Q	3	3167.61	1055.87	650.67	<.0001
A	3	2274.26	758.09	467.16	<.0001
Y*A	42	4799.40	114.27	70.42	<.0001
NHBF2	2	1882.31	941.15	579.98	<.0001
V	395	68392.42	173.15	106.70	<.0001
DMI	1	22.00	22.00	13.56	0.0002
IOI	1	184.40	184.40	113.63	<.0001
MP	1	242.62	242.62	149.52	<.0001
SC	1	2821.43	2821.43	1738.68	<.0001
AM	1	122.38	122.38	75.42	<.0001
TD	1	109.25	109.25	67.32	<.0001
TG	1	42.63	42.63	26.27	<.0001
Q*A	9	2921.54	324.62	200.04	<.0001
Q*NHBF2	6	2872.27	478.71	295.00	<.0001
A*NHBF2	6	3473.58	578.93	356.76	<.0001

Table 3. The nonparametric test for the effects of the GAM analysis.

Area NW

	Df	Npar Df	Npar F	Pr(F)
(Intercept)	1			
s(Y)	1	3	133.47	< 2.2e-16 ***
s(Q)	1	2	2309	< 2.2e-16 ***
s(NHBF)	1	3	134.1	< 2.2e-16 ***
s(DMI)	1	3	78.52	< 2.2e-16 ***
s(IOI)	1	3	75.23	< 2.2e-16 ***
s(MP)	1	3	118.17	< 2.2e-16 ***
s(SC)	1	3	643.38	< 2.2e-16 ***
s(AM)	1	3	124.88	< 2.2e-16 ***
s(TD)	1	3	222.75	< 2.2e-16 ***
s(TG)	1	3	122.75	< 2.2e-16 ***

Area NE

	Df	Npar Df	Npar F	Pr(F)
(Intercept)	1			
s(Y)	1	3	79.17	< 2.2e-16 ***
s(Q)	1	2	173.14	< 2.2e-16 ***
s(NHBF)	1	3	364.96	< 2.2e-16 ***
s(DMI)	1	3	13.17	1.36E-08 ***
s(IOI)	1	3	11.12	2.71E-07 ***
s(MP)	1	3	26.72	< 2.2e-16 ***
s(SC)	1	3	285.19	< 2.2e-16 ***
s(AM)	1	3	89.1	< 2.2e-16 ***
s(TD)	1	3	77.26	< 2.2e-16 ***
s(TG)	1	3	8.81	7.77E-06 ***