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CPUE standardization of blue marlin (*Makaira mazara*) caught by Taiwanese longline fishery in the Indian Ocean for 1980 to 2010

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ABSTRACT

Since blue marlin are bycatch specie of Taiwanese lognline fleet, large amount of zero catches are recorded from Taiwanese longline fleet. Therefore, this study attempts to the standardize CPUE of blue marlin caught by Taiwanese longline fleet in the Indian Ocean using delta-lognormal GLM model. The results indicate that the area-specific standardized CPUE in the northern Indian Ocean (north of 10°S) reveal different trends with those in the southern Indian Ocean (south of 10°S). Standardized CPUEs in the northern Indian Ocean generally reveal decline trends during 1980 to 1990, increased during 1990 to 2000, and slightly decrease in recent years. However, Standardized CPUEs in the southern Indian Ocean increase during 1980 to 1995, fluctuated during 1995 to 2002, obviously decreased during 2003 to 2009, and substantially increased in 2010. The area-aggregated standardized CPUE of blue marlin in the Indian Ocean reveals four phases: sharply decreased during 1984-1990 when the catch began increasing; increased gradually during during1991-1999; decrease gradually during 2000-2007; CPUE obviously increased in recent years.

INTRODUCTION

Based on the report of IOTC WPB (IOTC, 2011), blue marlin are considered to be bycatch of industrial and artisanal fisheries. Blue marlin are caught mainly under drifting longlines (60%) and gillnets (30%) with remaining catches recorded under troll and hand lines, and the fleets of Taiwan (longline), Indonesia (longline), Sri Lanka (gillnet) and India (gillnet) are attributed with the highest catches of blue marlin in recent years. The catches of blue marlin under drifting longlines were more or less stable until the mid-1980's, and steadily increasing since then. The largest catches were recorded in 1997.

To explore the pattern of relative abundance of blue marlin in the Indian Ocean, this paper attempt to the standardize CPUE of blue marlin caught by Taiwanese longline fleet in the Indian Ocean for the period of 1980 to 2010. Since blue marlin are bycatch species of Taiwanese lognline fleet, large amount of zero catches are recorded from Taiwanese longline fleet. Historically, ignoring zero observations or replacing them by a constant was the most common approach. Currently, the most popular way to deal with zeros is through the delta approach (Maunder and Punt, 2004). Therefore, the delta-lognormal GLM (Pennington, 1983; Lo et. al., 1992; Pennington, 1996) is applied to standardize the CPUE in this study.

MATERIAL AND METHODS

Catch and Effort data

In this study, daily set-by-set catch and effort data (logbook) of Taiwanese longline fishery with 5x5 degree grid in the period of 1980-2010 are provided by Oversea Fisheries Development Council of Taiwan (OFDC).

Definition of fishing areas

Based on the patterns of the distributions of CPUE and number of years of catching blue marlin by Taiwanese fleet (Wang et al., 2011), the definition of four areas are adopted as the factor of fishing area for the CPUE standardization (Fig. 1).

Environmental data

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

CPUE Standardization

The delta-lognormal GLM is applied to standardize the CPUE in this study and the main effects considered in this analysis are year, quarter, area and CPUEs of target species (bigeye tuna, yellowfin tuna and albacore).

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 characters of number of hooks between float (NHBF) are known to be informative to describe the operation characters for target species. However, NHBF is only available from Taiwanese longline fleet since 1994. Therefore, CPUEs of main tunas are considered as the effects of fishing operations. The CPUEs of main tunas are characterized by combining the NHBF information.

The effects of year, quarter, area and CPUE of main tunas are treated as category variables. All of environmental effects are treated as continuous variables. Since environmental conditions might be high correlated to each other, the interactions between environmental effects are not considered in the model. The delta and lognormal models are conducted as follows:

lognormal model:

$$\begin{aligned}\log(CPUE) = \mu + Y + Q + A + Y \times A + T\_BET + T\_YFT + T\_ALB \\ + DMI + IOI + MP + SC + AM + TD + TG + \text{interactions} + \varepsilon^{\log}\end{aligned}$$

delta model:

$$\begin{aligned}PA = \mu + Y + Q + A + Y \times A + T\_BET + T\_YFT + T\_ALB \\ + DMI + IOI + MP + SC + AM + TD + TG + \text{interactions} + \varepsilon^{del}\end{aligned}$$

where	*CPUE*	is the nominal CPUE of blue marlin (catch in number/1,000 hooks),
	PA	is the nominal presence of positive catch,
	μ	is the intercept,
	Y	is the effect of year,
	Q	is the effect of quarter,
	A	is the effect of fishing area,
	T_BET	is the effect of the CPUE of bigeye tuna,
	T_YFT	is the effect of the CPUE of yellowfin tuna,
	T_ALB	is the effect of the CPUE of albacore tuna,
	DMI	are the environmental effects of Dipole Mode Index,
	IOI	are the environmental effects of Indian Oscillation Index,
	MP	are the environmental effects of Moon phase,
	SC	are the environmental effects of sheer currents,
	AM	are the environmental effects of amplitude of the shear

	current,
TD	are the environmental effects of thermocline depth,
TG	are the environmental effects of temperature gradient,
ε^{log}	is the error term, $\varepsilon^{log} \sim N(0, \sigma^2)$,
ε^{del}	is the error term, $\varepsilon^{del} \sim Bin(n, p)$.

The model selection is based on the values of Akaike information criterion (AIC) and Bayesian information criterion (BIC). The area-specific standardized CPUE trends are estimated based on the exponentiations of the adjust means of the interaction between year and area effects (Butterworth, 1996; Maunder and Punt, 2004).

The standardized relative abundance index is calculated by the product of the standardized CPUE of positive catches and the standardized probability of positive catches:

$$index = e^{\log(CPUE)} \times \left(\frac{e^P}{1+e^P} \right)$$

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 fishing areas are calculated by GIS software and the relative sizes are listed below.

Area I	Area II	Area III	Area IV
0.215	0.207	0.253	0.326

RESULTS AND DISCUSSION

For the effects of CPUEs of main tunas, this study analyzed the CPUE probability distributions of bigeye tuna, yellowfin tuna and albacore caught by regular operations (NHBF < 10), deep operations (10 ≤ NHBF ≤ 14) and ultra-deep operations (NHBF > 14). Based on the results, the CPUE probability distributions of bigeye tuna and albacore reveal significantly distinct patterns for different operations, while the CPUE probability distributions of yellowfin tuna are quite similar among different operations (Fig. 2). Therefore, the CPUE of yellowfin tuna is not considered as the effect in the CPUE standardization analysis. In this study, the CPUEs of bigeye tuna and albacore are characterized into 3 categories based on the median of CPUEs for regular and ultra-deep operations:

T_BET: (1) CPUE < 1.736; (2) 1.736 ≤ CPUE ≤ 4.644; (3) CPUE > 4.644.

T_ALB: (1) CPUE < 1.270; (2) 1.270 ≤ CPUE ≤ 9.643; (3) CPUE > 9.643.

Based on the model selection, nine lognormal models are conducted for CPUE standardization analysis:

$$\text{Model 1: } \log(CPUE+c)=\mu+Y+Q+A+Y\times A+\varepsilon$$

$$\text{Model 2: } \log(CPUE+c)=\mu+Y+Q+A+Y\times A+T\_BET+\varepsilon$$

$$\text{Model 3: } \log(CPUE+c)=\mu+Y+Q+A+Y\times A+T\_ALB+\varepsilon$$

$$\text{Model 4: } \log(CPUE+c)=\mu+Y+Q+A+Y\times A+T\_BET+T\_ALB+\varepsilon$$

$$\text{Model 5: } \log(CPUE+c)=\mu+Y+Q+A+Y\times A+T\_BET+T\_ALB+DMI+IOI+MP+\varepsilon$$

$$\begin{aligned}\text{Model 6: } \log(CPUE+c)=&\ \mu+Y+Q+A+Y\times A+T\_BET+T\_ALB+DMI+IOI+MP\\&+SC+AM+TD+TG+\varepsilon\end{aligned}$$

$$\begin{aligned}\text{Model 7: } \log(CPUE+c)=&\ \mu+Y+Q+A+Y\times A+T\_BET+T\_ALB+DMI+IOI+MP\\&+TD+TG+\varepsilon\end{aligned}$$

$$\begin{aligned}\text{Model 8: } \log(CPUE+c)=&\ \mu+Y+Q+A+Y\times A+T\_BET+T\_ALB+DMI+IOI+MP\\&+Q\times A+Q\times T\_BET+Q\times T\_ALB+A\times T\_BET+A\times T\_ALB\\&+T\_BET\times T\_ALB+\varepsilon\end{aligned}$$

$$\begin{aligned}\text{Model 9: } \log(CPUE+c)=&\ \mu+Y+Q+A+Y\times A+T\_BET+T\_ALB+DMI+IOI+MP\\&+Q\times A+Q\times T\_ALB+A\times T\_BET+A\times T\_ALB\\&+T\_BET\times T\_ALB+\varepsilon\end{aligned}$$

Table 1 shows the values of MSE, AIC and BIC for nine models. The results indicate that including the effects related to temporal environmental condition (DMI, IOI and MP) obviously improved AIC and BIC (Model 5), while the effects of SC and AM are not statistically significant and including TD and TG have no improvement for the model fit (Model 6 and 7). Therefore, the effects related to spatial-temporal environmental condition (SC, AM, TD and TG) are not used in the final model. The final model selected in this study is Model 9 and this model excludes the interactions which are not statistically significant. The ANOVA table of the final lognormal model is shown in the Table 2.

Based on the model selection, eight delta models are conducted for CPUE standardization analysis:

$$\text{Model 1}: PA = \mu + Y + Q + A + Y \times A + \varepsilon$$
$$\text{Model 2}: PA = \mu + Y + Q + A + Y \times A + T\_BET + \varepsilon$$
$$\text{Model 3}: PA = \mu + Y + Q + A + Y \times A + T\_ALB + \varepsilon$$
$$\text{Model 4}: PA = \mu + Y + Q + A + Y \times A + T\_BET + T\_ALB + \varepsilon$$
$$\text{Model 5}: PA = \mu + Y + Q + A + Y \times A + T\_BET + T\_ALB + DMI + IOI + MP + \varepsilon$$
$$\begin{aligned}\text{Model 6}: PA = {} & \mu + Y + Q + A + Y \times A + T\_BET + T\_ALB + DMI + IOI + MP \\ & + SC + AM + TD + TG + \varepsilon\end{aligned}$$
$$\begin{aligned}\text{Model 7}: PA = {} & \mu + Y + Q + A + Y \times A + T\_BET + T\_ALB + DMI + IOI + MP \\ & + SC + AM + TD + TG + Q \times A + Q \times T\_BET + Q \times T\_ALB + A \times T\_BET \\ & + A \times T\_ALB + T\_BET \times T\_ALB + \varepsilon\end{aligned}$$
$$\begin{aligned}\text{Model 8}: PA = {} & \mu + Y + Q + A + Y \times A + T\_BET + T\_ALB + IOI + MP \\ & + SC + AM + TD + TG + Q \times A + Q \times T\_BET + Q \times T\_ALB + A \times T\_BET \\ & + A \times T\_ALB + T\_BET \times T\_ALB + \varepsilon\end{aligned}$$

Incorporating all effects can improve the values of AIC and BIC (Table 3). However, the effect of DMI becomes to be statistically insignificant when incorporating the interactions between effects and thus the effect of DMI is not considered in the model. The final model selected in this study is Model 8 and this model excludes the effect of DMI. The ANOVA table of the final delta model is shown in the Table 4.

The area-specific nominal and standardized CPUE are shown in Fig. 3. Standardized CPUEs in the areas NW and NE reveal different trends with those in Area SW and SE. Standardized CPUEs in the areas NW and NE generally reveal decline trends during 1980 to 1990, increased during 1990 to 2000, and slightly decrease in recent years. However, Standardized CPUEs in the areas SW and SE increase during 1980 to 1995, fluctuated during 1995 to 2002, obviously decreased during 2003 to 2009, and substantially increased in 2010.

Fig. 4 shows the area-aggregated standardized CPUE of blue marlin in the Indian Ocean. Standardized CPUE generally reveals four phases: sharply decreased during 1984-1990 when the catch began increasing; increased gradually during during1991-1999; decrease gradually during 2000-2007; CPUE obviously increased in recent years.

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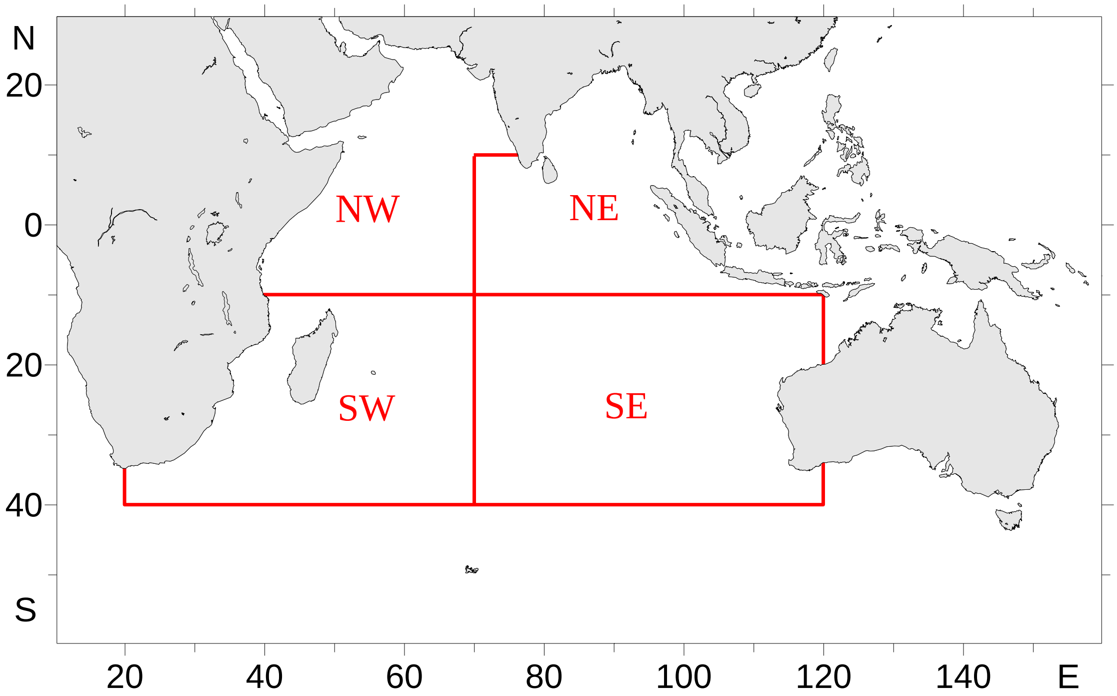


Fig. 1. The definition of four fishing areas for blue marlin in the Indian Ocean.

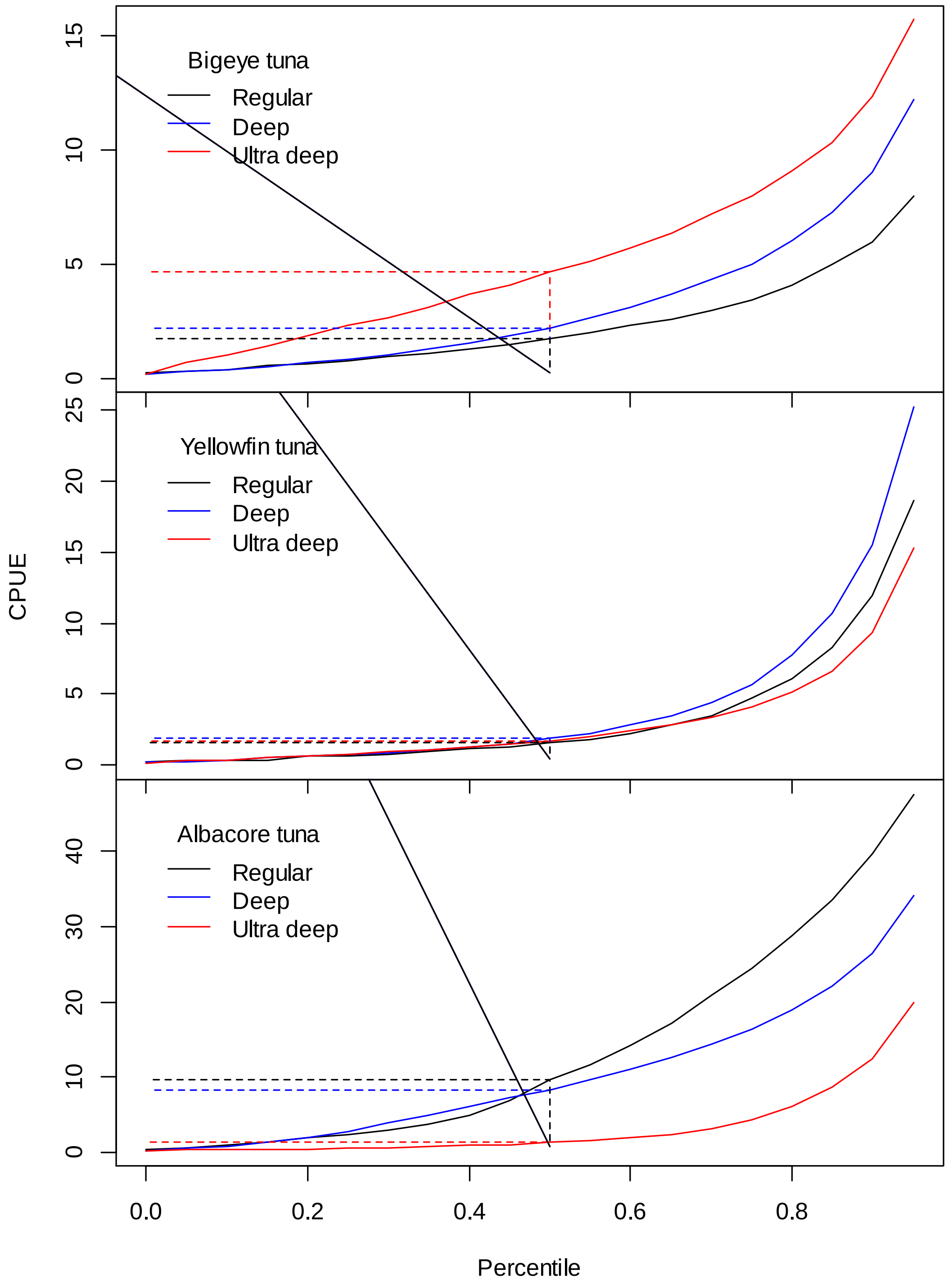
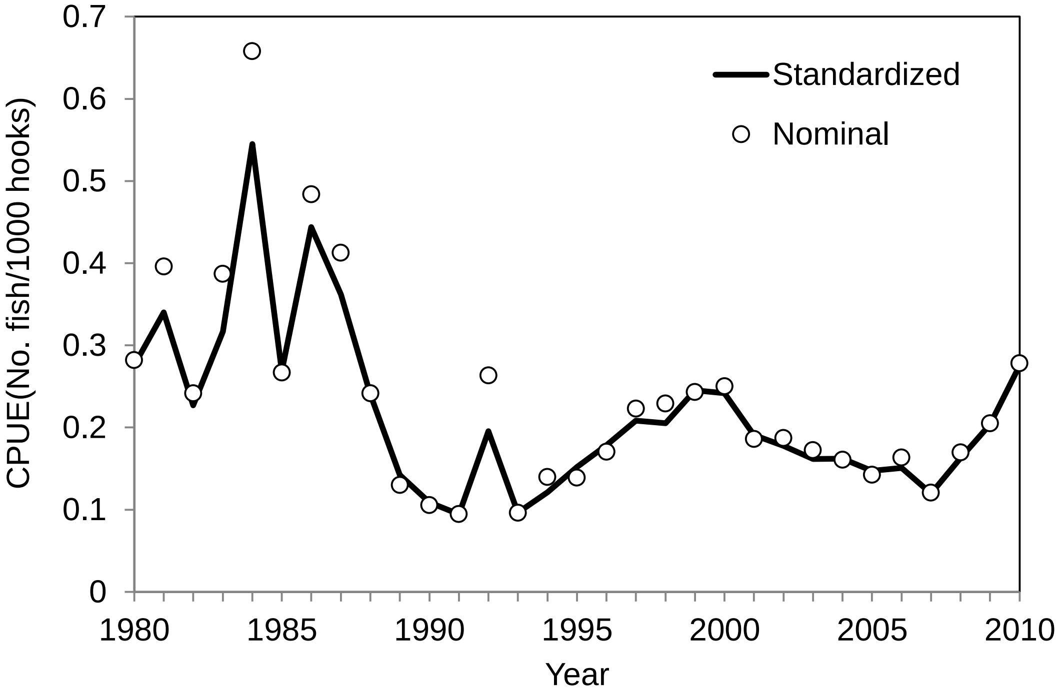


Fig. 2. The probability distributions of CPUE of bigeye tuan, yellowfin tuna and albacore caught Taiwanese lognline fleet in the Indian Ocean with regular, deep and ultra-deep operation tyeps.

Area NW



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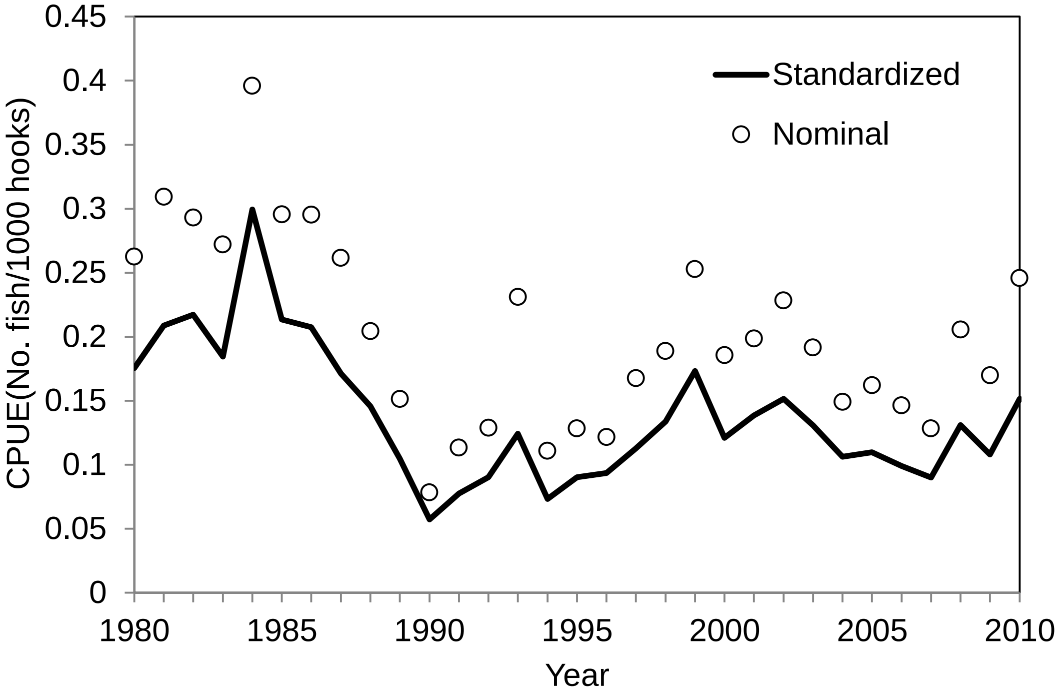
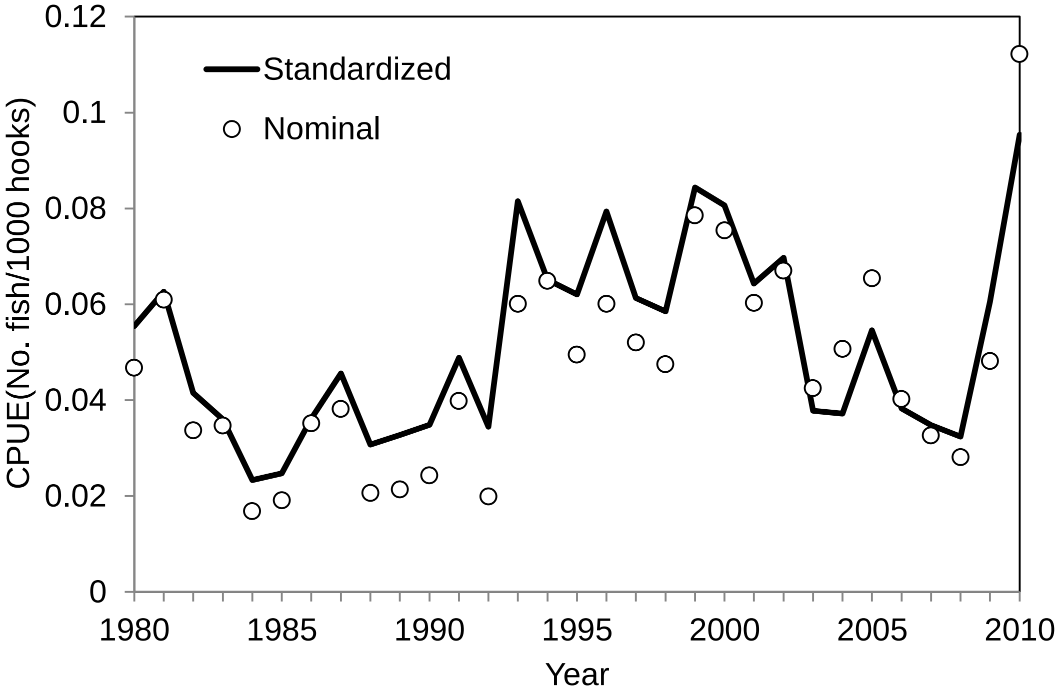


Fig. 3. Area-specific nominal and Standardized CPUE of blue marlin caught by Taiwanese longline fleet.

Area SW



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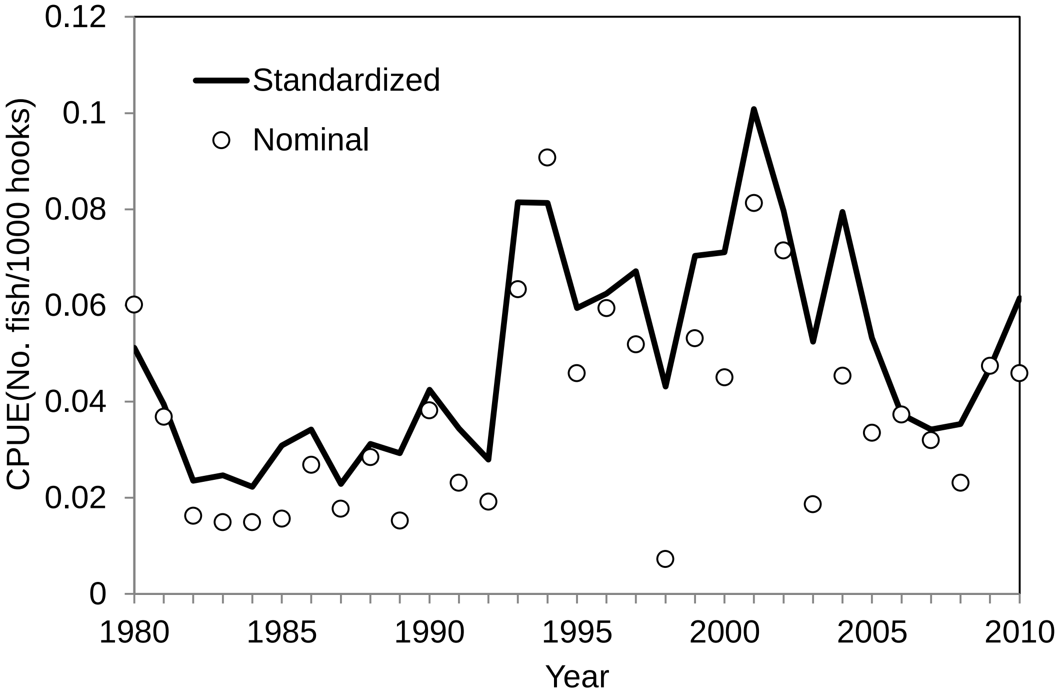

Fig. 3. (Continued).

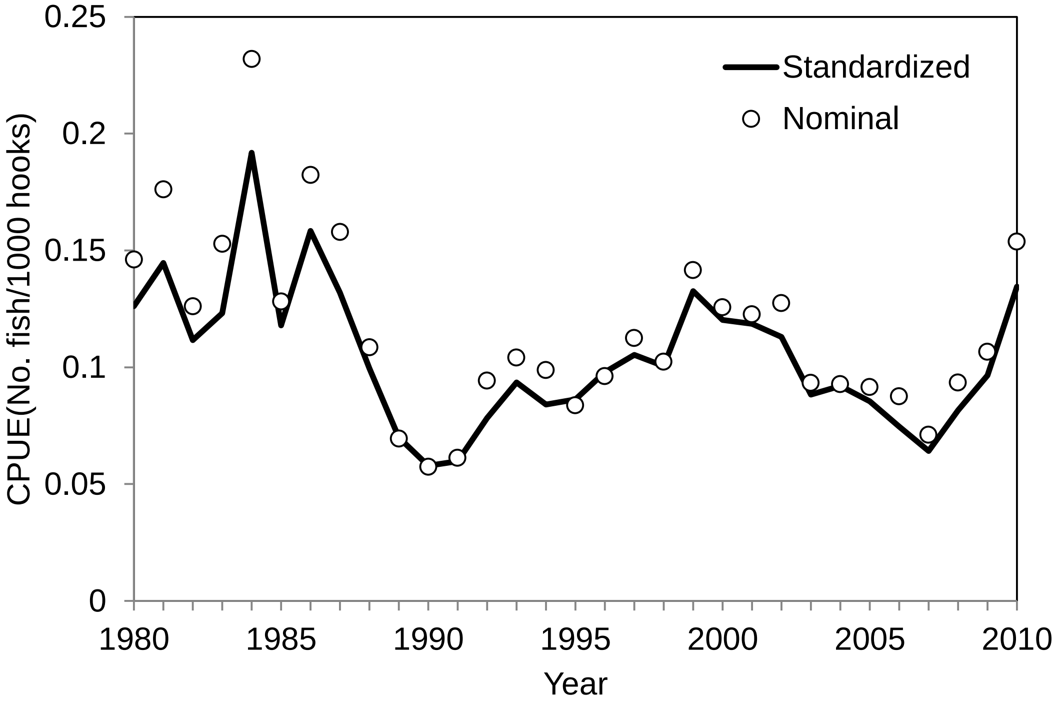

Fig. 4. Area-aggregated nominal and Standardized CPUE of blue marlin caught by Taiwanese longline fleet.

Table 1. The values of MSE, AIC and BIC for lognormal model.

Model	MSE	AIC	BIC	ΔAIC	ΔBIC
1	14.60875	501696.2929	502973.785		
2	14.4478	499628.689	500926.4588	-2068	-2047
3	14.50896	500418.5915	501716.3613	-1278	-1257
4	14.34211	498259.7511	499577.7985	-3437	-3396
5	14.10321	495124.7298	496473.1937	-6572	-6501
6	14.44802	499649.5363	501038.5556	-2047	-1935
7	14.65856	502350.7798	503719.5214	654	746
8	12.06624	466029.5121	467753.1126	-35667	-35221
9	12.50402	472681.7037	474344.4712	-29015	-28629

Table 2. The ANOVA table of Model 9 for lognormal model.

Source	DF	Sum of Squares	Mean Square	F Value	Pr > F
Model	164	2050.65859	12.50402	49.28	<.0001
Error	186828	47403.8651	0.25373		
Corrected Total	186992	49454.52369			

Source	DF	Type III SS	Mean Square	F Value	Pr > F
Y	30	395.920573	13.1973524	52.01	<.0001
Q	3	29.3578339	9.7859446	38.57	<.0001
A	3	97.9795405	32.6598468	128.72	<.0001
Y*A	90	453.0466778	5.033852	19.84	<.0001
T_BET	2	25.122613	12.5613065	49.51	<.0001
T_ALB	2	20.7943374	10.3971687	40.98	<.0001
DMI	1	2.2101052	2.2101052	8.71	0.0032
IOI	1	7.4425988	7.4425988	29.33	<.0001
MP	1	5.331771	5.331771	21.01	<.0001
Q*A	9	50.5455812	5.6161757	22.13	<.0001
Q*T_ALB	6	16.9636885	2.8272814	11.14	<.0001
A*T_BET	6	24.6813517	4.1135586	16.21	<.0001
A*T_ALB	6	14.8196576	2.4699429	9.73	<.0001
T_BET*T_ALB	4	42.6243469	10.6560867	42	<.0001

Table 3. The values of MSE, AIC and BIC for delta model.

Model	lnL	AIC	BIC	ΔAIC	ΔBIC
1	-398933.7448	798195.4896	800102.854		
2	-397466.5299	795267.0598	797209.315	-2928	-2894
3	-398704.3167	797742.6334	799684.8886	-453	-418
4	-397349.6126	795039.2252	797016.3712	-3156	-3086
5	-397273.1561	794892.3122	796904.349	-3303	-3199
6	-392770.9678	785895.9356	787954.4935	-12300	-12148
7	-388760.0344	778020.0688	780927.6365	-20175	-19175
8	-388772.5620	778043.1240	780939.0614	-20152	-19164

Table 4. The ANOVA table of Model 8 for delat model.

	Df	Deviance	Resid. Df	Resid. Dev	Pr(>Chi)
NULL			830904	886114	
Y	30	10413	830874	875702	< 2.2e-16
Q	3	8996	830871	866706	< 2.2e-16
A	3	58150	830868	808556	< 2.2e-16
T_BET	2	3794	830866	804762	< 2.2e-16
T_ALB	2	1785	830864	802977	< 2.2e-16
IOI	1	133	830863	802844	< 2.2e-16
MP	1	7	830862	802837	0.009772
SC	1	1924	830861	800913	< 2.2e-16
AM	1	1611	830860	799302	< 2.2e-16
TG	1	514	830859	798788	< 2.2e-16
TD	1	4716	830858	794072	< 2.2e-16
Y*A	90	8527	830768	785545	< 2.2e-16
Q*A	9	3280	830759	782265	< 2.2e-16
Q*T_BET	6	769	830753	781496	< 2.2e-16
Q*T_ALB	6	89	830747	781407	< 2.2e-16
A*T_BET	6	3152	830741	778255	< 2.2e-16
A*T_ALB	6	363	830735	777892	< 2.2e-16
T_BET*T_ALB	4	347	830731	777545	< 2.2e-16