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CPUE standardization of striped marlin (*Tetrapterus audax*) caught by Taiwanese longline fishery in the Indian Ocean for 1980 to 2010

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ABSTRACT

Since striped 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 striped 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 1980s. The standardized CPUEs in the southern Indian Ocean generally reveal increasing trends during 1980 to 1995 and gradually decreased thereafter. In both of northern and southern Indian Oceans, the standardized CPUEs slightly increased in 2010. Although two CPUE peaks are observed in around 1985 and 1995, the area-aggregated standardized CPUE generally reveals a decline trend since 1980.

INTRODUCTION

Based on the report of IOTC WPB (IOTC, 2011), striped marlin are considered to be bycatch of industrial fisheries. Striped marlin are caught almost exclusively under drifting longlines (98%) with remaining catches recorded under gillnets and troll lines. The catches under drifting longlines have been recorded under Taiwan, Japan, Republic of Korea fleets and, recently, Indonesia and several NEI fleets. In recent years, the fleets of Taiwan (longline) and to a lesser extent Indonesia (longline) are attributed with the highest catches of striped marlin. The minimum average annual catch estimated for the period 2005 to 2009 is around 2,779 t.

To explore the pattern of relative abundance of striped marlin in the Indian Ocean, this paper attempt to the standardize CPUE of striped marlin caught by Taiwanese longline fleet in the Indian Ocean for the period of 1980 to 2010. Since striped 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

Fig. 1 shows the distributions of CPUE and number of years of catching striped marlin by Taiwanese longline fleet for 1995-2010 using the data with 1x1 degree grid. Although high CPUE concentrates in the waters north of 10°S, the catch frequency is relatively low in the waters north of 10°N before the early 1990s. Therefore, we roughly make a definition of four fishing areas for examining the influence of area factor on the CPUE standardization (Fig. 2).

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 striped 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

Based on the results of Wang et al. (2012), 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, six lognormal models are conducted for CPUE standardization analysis:

$$
\begin{aligned}
&\text{Model 1: } \log(CPUE+c) = \mu + Y + Q + A + Y\times A + \varepsilon \\
&\text{Model 2: } \log(CPUE+c) = \mu + Y + Q + A + Y\times A + T\_BET + \varepsilon \\
&\text{Model 3: } \log(CPUE+c) = \mu + Y + Q + A + Y\times A + T\_ALB + \varepsilon \\
&\text{Model 4: } \log(CPUE+c) = \mu + Y + Q + A + Y\times A + T\_ALB + DMI + IOI + MP + \varepsilon \\
&\text{Model 5: } \log(CPUE+c) = \mu + Y + Q + A + Y\times A + T\_ALB + DMI + IOI \\
&\qquad\qquad\qquad\qquad\qquad + SC + AM + TD + TG + \varepsilon \\
&\text{Model 6: } \log(CPUE+c) = \mu + Y + Q + A + Y\times A + T\_ALB + DMI + IOI \\
&\qquad\qquad\qquad\qquad\qquad + Q\times A + Q\times T\_BET + Q\times T\_ALB + A\times T\_BET \\
&\qquad\qquad\qquad\qquad\qquad + A\times T\_ALB + T\_BET\times T\_ALB + \varepsilon
\end{aligned}
$$

Table 1 shows the values of MSE, AIC and BIC for nine models. The results indicate that including the CPUE of bigeye tuna as the fishing operation effect (Model 2) and including the effects related to spatial -temporal environmental conditions (SC, AM, TD and TG) (Model 5) cannot improve AIC and BIC. AIC and BIC are obviously improved when including the effects related to temporal environmental conditions of DMI and IOI but the effect of MP are not statistically significant (Model 4). The final model selected in this study is Model 6 and this model includes the statistically significant effects and the interactions between these effects. 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:

$$\text{Model 1}: PA = \mu + Y + Q + A + Y \times A + \varepsilon$$

$$\text{Model 2}: PA = \mu + Y + Q + A + Y \times A + T\_BET + \varepsilon$$

$$\text{Model 3}: PA = \mu + Y + Q + A + Y \times A + T\_ALB + \varepsilon$$

$$\text{Model 4}: PA = \mu + Y + Q + A + Y \times A + T\_BET + T\_ALB + \varepsilon$$

$$\text{Model 5}: PA = \mu + Y + Q + A + Y \times A + T\_BET + T\_ALB + DMI + IOI + MP + \varepsilon$$

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

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

$$\begin{aligned}\text{Model 8}: PA = {} & \mu + Y + Q + A + Y \times A + T\_BET + T\_ALB + DMI + IOI \\ & + SC + AM + TD + TG + Q \times A + Q \times T\_BET + Q \times T\_ALB + A \times T\_BET \\ & + A \times T\_ALB + T\_BET \times T\_ALB + \varepsilon\end{aligned}$$

Incorporating all effects can improve the values of AIC and BIC (Table 3). However, the effect of moon phase (MP) becomes to be statistically insignificant when incorporating the interactions between effects and thus the effect of MP 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 since 1980s. Although the trends of standardized CPUEs in the areas SW and SE changes with fluctuations, they generally reveal increasing trends during 1980 to 1995, gradually decreased thereafter, and slightly increased in 2010.

Fig. 4 shows the area-aggregated standardized CPUE of striped marlin in the Indian Ocean. Although two CPUE peaks are observed in around 1985 and 1995, the standardized CPUE generally reveals a decline trend since 1980.

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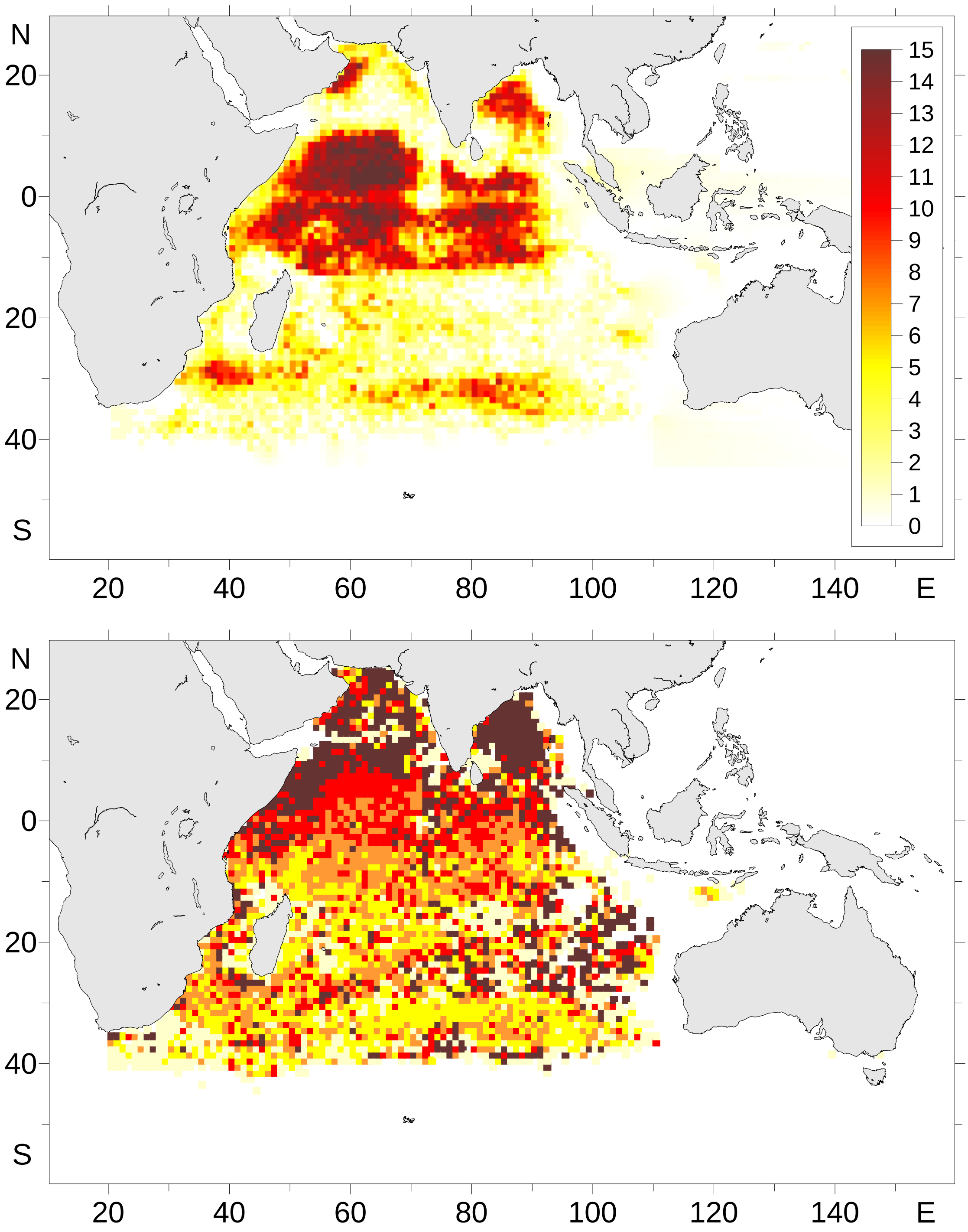


Fig. 1. The distributions of number of years of catching striped marlin (upper) and CPUE of striped marlin (lower) caught by Taiwanese longline fleet for 1995-2010.

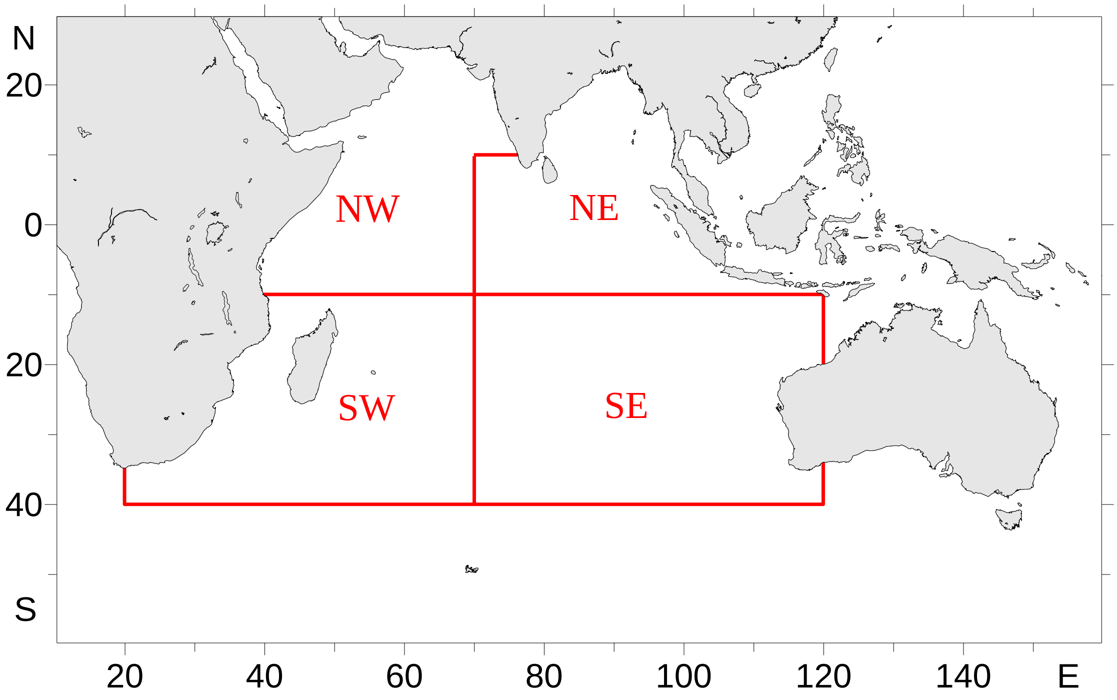
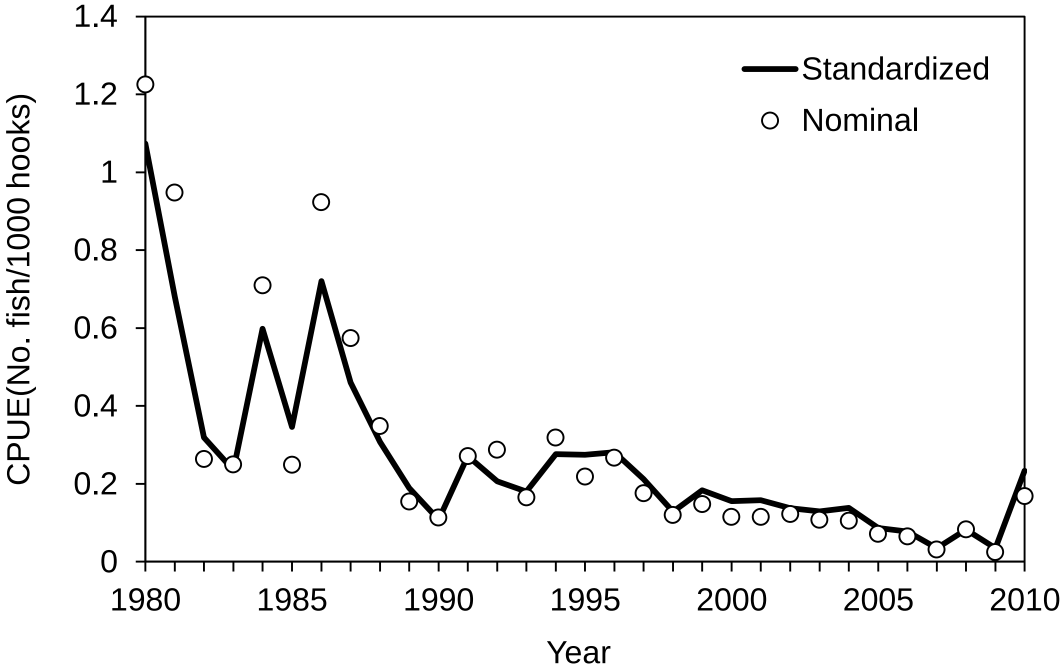


Fig. 2. The definition of four fishing areas for striped marlin in the Indian Ocean.

Area NW



Area NE

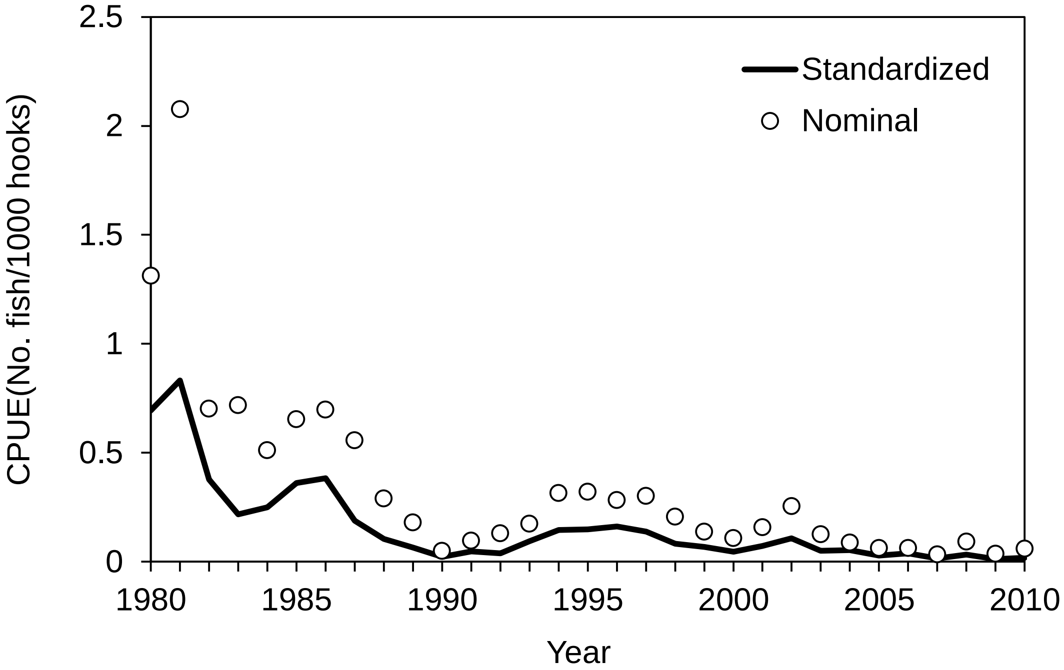
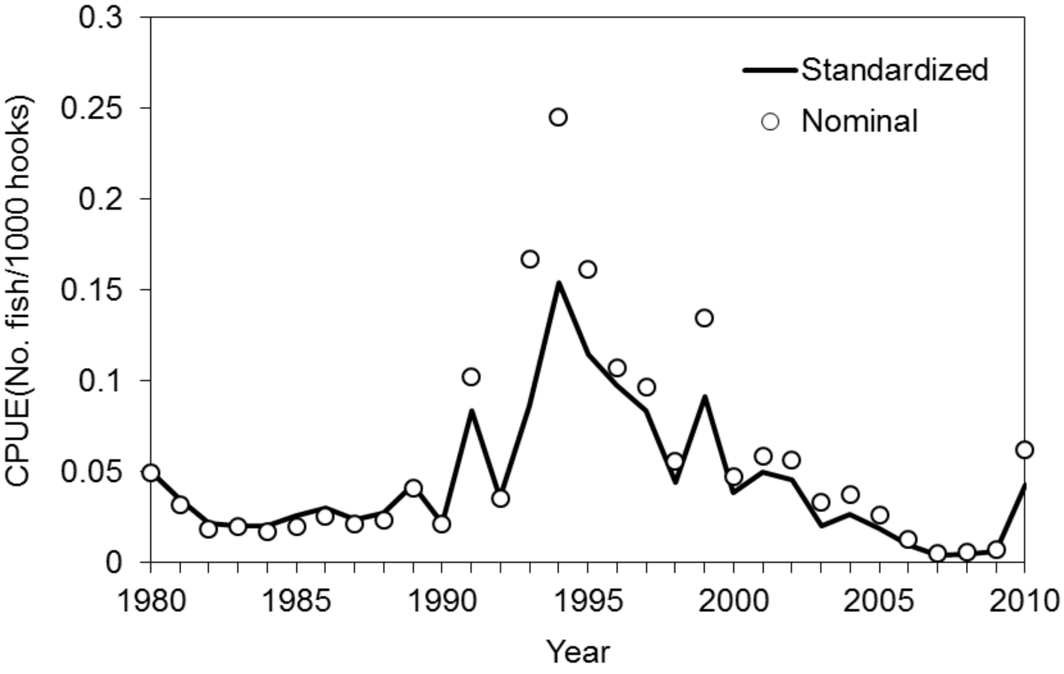


Fig. 3. Area-specific nominal and Standardized CPUE of striped marlin caught by Taiwanese longline fleet.

Area SW



Area SE

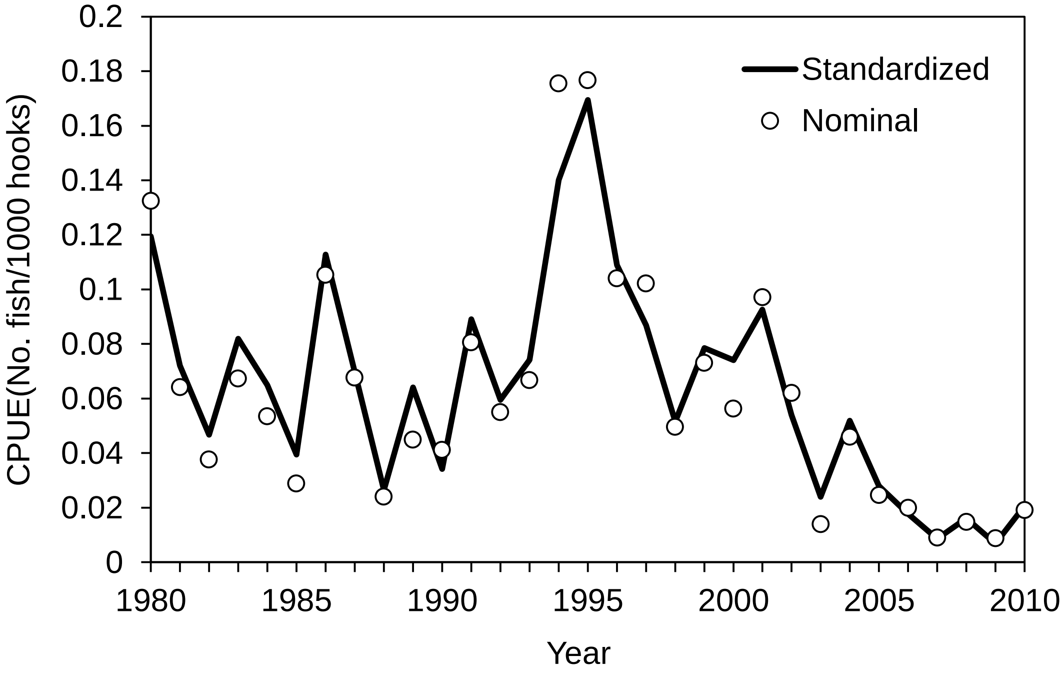


Fig. 3. (Continued).

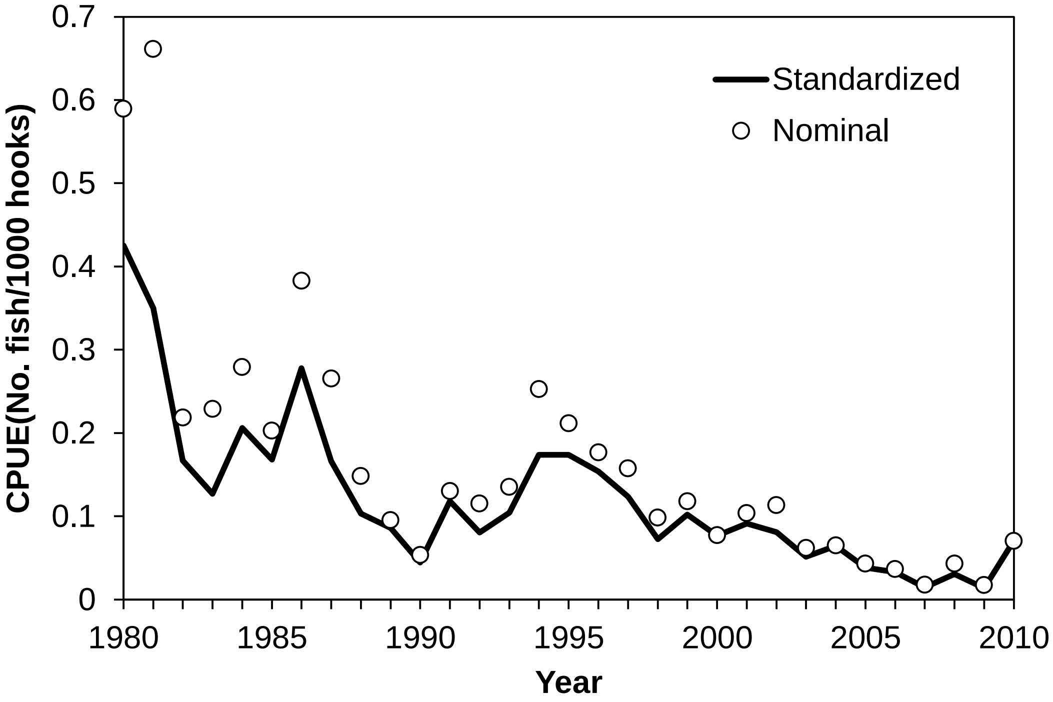


Fig. 4. Area-aggregated nominal and Standardized CPUE of striped marlin caught by Taiwanese longline fleet.

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

Model	MSE	AIC	BIC	ΔAIC	ΔBIC
1	128.5574	732311.7	733562.1		
2	138.7665	743835.1	745105.3	11523	11543
3	126.9334	730399.4	731669.6	-1912	-1893
4	124.6374	727653.8	728953.7	-4658	-4608
5	136.5428	741411.8	742741.6	9100	9180
6	123.5693	726432.4	728109.5	-5879	-5453

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

Source	DF	Sum of Squares	Mean Square	F Value	Pr > F
Model	169	20883.21475	123.56932	382.93	<.0001
Error	150572	48589.03338	0.3227		
Corrected Total	150741	69472.24813			

Source	DF	Type III SS	Mean Square	F Value	Pr > F
Y	30	1689.246103	56.308203	174.49	<.0001
Q	3	105.894265	35.298088	109.38	<.0001
A	3	146.39202	48.79734	151.22	<.0001
Y*A	90	1444.283124	16.04759	49.73	<.0001
T_ALB	2	17.706838	8.853419	27.44	<.0001
DMI	1	13.262458	13.262458	41.1	<.0001
IOI	1	23.13117	23.13117	71.68	<.0001
Q*A	9	718.86137	79.873486	247.52	<.0001
Q*T_BET	6	395.57247	65.928745	204.31	<.0001
Q*T_ALB	6	63.730753	10.621792	32.92	<.0001
A*T_BET	6	770.820803	128.470134	398.11	<.0001
A*T_ALB	6	110.137633	18.356272	56.88	<.0001
T_BET*T_ALB	4	35.624536	8.906134	27.6	<.0001

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

Model	lnL	AIC	BIC	ΔAIC	ΔBIC
1	-332913.4297	666154.8594	668062.2238		
2	-332859.6338	666053.2676	667995.5228	-102	-67
3	-332541.4708	665416.9416	667359.1968	-738	-703
4	-332445.5812	665231.1624	667208.3084	-924	-854
5	-332190.6441	664727.2882	666739.325	-1428	-1323
6	-329451.1849	659256.3698	661314.9277	-6898	-6747
7	-326385.5636	653271.1272	656178.6949	-12884	-11884
8	-326385.5977	653269.1954	656165.1328	-12886	-11897

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

	Df	Deviance	Resid. Df	Resid. Dev	Pr(>Chi)
NULL			830904	786931	
Y	30	48024	830874	738907	< 2.2e-16
Q	3	13384	830871	725523	< 2.2e-16
A	3	40174	830868	685349	< 2.2e-16
T_BET	2	37	830866	685312	8.34E-09
T_ALB	2	4662	830864	680650	< 2.2e-16
DMI	1	184	830863	680466	< 2.2e-16
IOI	1	469	830862	679998	< 2.2e-16
SC	1	508	830861	679490	< 2.2e-16
AM	1	1297	830860	678192	< 2.2e-16
TG	1	39	830859	678153	4.79E-10
TD	1	2905	830858	675249	< 2.2e-16
Y*A	90	16346	830768	658902	< 2.2e-16
Q*A	9	1784	830759	657119	< 2.2e-16
Q*T_BET	6	762	830753	656356	< 2.2e-16
Q*T_ALB	6	77	830747	656280	1.81E-14
A*T_BET	6	2676	830741	653604	< 2.2e-16
A*T_ALB	6	660	830735	652944	< 2.2e-16
T_BET*T_ALB	4	173	830731	652771	< 2.2e-16