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

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ABSTRACT

This study attempts to the standardize CPUE of blue marlin caught by Taiwanese longline fleet in the Indian Ocean using generalized linear model (GLM). Based on the distributions of catch made by Japanese and Taiwanese longline fleets, CPUE of Taiwanese fleet and number of years of catching blue marlin by Taiwanese fleet, six fishing areas are defined for blue marlin in the Indian Ocean. However, there are large amount missing data occur in the northern Indian Ocean before early 1990s and thus four aggregated fishing areas also used to exam the influence of fishing area definition on CPUE standardization. The results reveal similar trends of CPUE standardized based on three combinations of fishing areas definitions and data period. There are no obvious trends for CPUEs in the northwestern and southeastern Indian Ocean, while standardized CPUEs reveal decreasing patterns for other areas. The area-aggregated standardized CPUE reveals three phases: sharply decreased during 1984-1990; increased gradually during during1991-2002; decrease gradually during 2002-2007. In recent two years, CPUEs obviously increased in most areas, especially for recent two years.

INTRODUCTION

Based on the report of IOTC WPB (IOTC, 2010), blue marlin is considered as bycatch for industrial and artisanal fisheries, but they are targeted by sport fisheries. Before the early 1980s, blue marlin was mainly exploited by longline fishery and the catch fluctuated around 3,000-4,000 tons. Since the mid 1980s, the catch of blue marlin substantially increased and it was mainly caught by longlines (70%) and gillnets (20%) and some troll and hand lines. The catch of blue marlin reached a maximum of about 14,000 tons in the mid 1997 while current catch is around 8,000 tons. In recent years, the longline fleets of Taiwan, Japan and several NEI fleets and the gillnet fleet of Sri Lanka are attributed with the highest catches of blue marlin. The distribution of blue marlin catches has changed since the 1980‘s, with catches in the western Indian Ocean increasing and an increase in the catch by the Taiwanese longline fleets.

In this paper, we attempt to the standardize CPUE of blue marlin caught by Taiwanese longline fleet in the Indian Ocean for the period of 1980 to 2009. The characters of fishing operation, such as number of hooks between float (NHBF), are known to be informative to describe the change in target species. However, NHBF is only available since 1995. Therefore, we also standardize CPUE of blue marlin for the period of 1995 to 2009 by including the NHBF information.

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 1980-2009 and 1x1 degree grid in the period of 1995-2009 are provided by Oversea Fisheries Development Council of Taiwan (OFDC).

Definition of fishing areas

Figs. 1-3 show the distributions of catch made by Japanese and Taiwanese longline fleets, CPUE of Taiwanese fleet and number of years of catching blue marlin by Taiwanese fleet. Based on the patterns of these distributions, this study attempts to define six fishing areas for blue marlin (Fig. 4). However, large amount of missing data occurs in Area 1 and Area2 before the early 1990s. Therefore, we make an alternative definition of fishing areas by combining Area 1 and 3 as one area and combing Area 2 and 4 as one area. A definition of four fishing areas is shown in Fig. 5. Both definitions of fishing areas are used in this study for examining the influence of this factor on the CPUE standardization.

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. The effect of NHBF is 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.

For the definition of six fishing areas, only the data with 1x1 degree grid in the period of 1995-2009 are used in this study because large amount of missing data before the early 1990s. Six models with different combination of effect are considered:

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

where

where	$CPUE$	is the nominal CPUE of blue marlin (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 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),
ε is the error term, $\varepsilon \sim N(0, \sigma^2)$.

For the definition of four fishing areas, the data with 5x5 degree grid in the period of 1980-2009 and the data with 1x1 degree grid in the period of 1995-2009 both are used in this study. However, NHBF is not available before 1995 and thus we include the CPUE of three main species (albacore (ALB), bigeye tuna (BET) and yellowfin tuna (YFT)) for considering the effect of target operation for the data series of 1980-2009. Six models with different combination of effect are considered:

$$\text{Model 1}: \log(CPUE+c) = \mu + Y + Q + A + Y \times A + \varepsilon$$
$$\text{Model 2}: \log(CPUE+c) = \mu + Y + Q + A + Y \times A + V + \varepsilon$$
$$\text{Model 3}: \log(CPUE+c) = \mu + Y + Q + A + Y \times A + ALB + BET + YFT + \varepsilon$$
$$\text{Model 4}: \log(CPUE+c) = \mu + Y + Q + A + Y \times A + ENV1 + \varepsilon$$
$$\text{Model 5}: \log(CPUE+c) = \mu + Y + Q + A + Y \times A + ENV2 + \varepsilon$$
$$\begin{aligned}\text{Model 6}: \log(CPUE+c) = {} & \mu + Y + Q + A + Y \times A + V + ALB + BET + YFT + ENV1 + ENV2 \\ & + Q \times A + Q \times ALB + Q \times BET + Q \times YFT + A \times ALB \\ & + A \times BET + A \times YFT + ALB \times BET + ALB \times YFT + \varepsilon\end{aligned}$$

The same models designed for six fishing areas are used for the analysis based on the data with 1x1 degree grid in the period of 1995-2009 and four fishing areas.

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.

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.

Six fishing areas:

Area 1	Area 2	Area 3	Area 4	Area 5	Area 6
0.083	0.040	0.132	0.167	0.253	0.326

Four fishing areas:

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

RESULTS AND DISCUSSION

Table 1 shows the values of R^2, AIC and BIC for six models based on the data with 1x1 degree grid in the period of 1995-2009 and six fishing areas. The results indicate that including the effect of vessel obviously improved the proportion of explained variances (R^2), AIC and BIC. Including the effects of IOI, DMI and MP have no improvement for the model fit and thus these effects are not used in the final model. The final model selected in this study is Model 6 (excluding the effects of Q×NHBF) and the ANOVA table is shown in the Table 2. The analyses based on four fishing areas show similar results. Including the effects of IOI, DMI and MP have limited improvement for the model and thus these effects are also not used in the final model (Table 3 and 5). The final models selected in this study are Model 6 (excluding the effects of ALB, interactions related to ALB and BET×YFT for the data of 1980-2009) and the ANOVA tables are shown in the Table 4 and 6.

The area-specific nominal and standardized CPUE based on six fishing areas are shown in Fig. 6. Standardized CPUE in Area 1 fluctuated with no obvious trend. The trends of standardized CPUE in Area 2-5 show decreasing patterns in 1999-2001, especially for CPUE in Area 3 which continuously decreased since 1995. Standardized CPUEs in 2008 obviously increase for most areas. For Area 6, standardized CPUE has no significant trend but there are high values during 2001-2004.

The area-specific nominal and standardized CPUE based on the data with 1x1 degree grid in the period of 1995-2009 and four fishing areas are shown in Fig. 7. Standardized CPUEs in Area I (combined Area 1 and 3), II (combined Area 2 and 4) and III show similar patterns, which increased before 1998, gradually decreased during 1999-2007 and increased in recent two years. The result of Area IV is close to that of Area 6.

Fig. 8 shows the area-specific nominal and standardized CPUE based on the data with 1x1 degree grid in the period of 1980-2009 and four fishing areas. For Area I and II, standardized CPUEs substantially decreased since the mid 1980s, slightly increased during 1990-2000, and decreased gradually thereafter. For Area III and IV, standardized CPUEs show no obvious trends before the early 2000s but they also decreased in recent years. In recent two years, CPUEs obviously increased in most areas.

Figs. 9 and 10 show the area-aggregated CPUE. Standardized CPUE of blue marlin in the Indian Ocean reveals three phases: sharply decreased during 1984-1990 when the catch began increasing; increased gradually during during1991-2002; decrease gradually during 2002-2007. In recent two years, CPUEs obviously increased in most areas, especially for recent two years.

The trends of standardized CPUEs based on using CPUEs of main species and NHBF are very similar. High CPUE and high catch frequency mainly distribute in the tropical waters where more deep operations occur (Figs. 2 and 3). However, NHBF effect has less improvement for the model fit (Tables 1 and 5) and similar results are found for CPUE standardization of swordfish in the Indian Ocean caught by Taiwanese longline fleet (Wang and Nishida, 2011). The relationship between CPUE and NHBF needs further analysis. In addition, the results based on six fishing areas are similar to those based on four fishing areas (Fig. 10). However, using four fishing areas can avoid the problem related to the missing data in the Area 1 and 2.

Because blue marlin is bycatch of Taiwan longline fleet, the proportion of 0 catch of blue marlin is very high and this might lead to the estimation problem when using GLM. Therefore, alternative analysis approach could be used for further CPUE standardization, such as two-step delta-lognormal approach (Lo et. al., 1992; Pennington, 1996).

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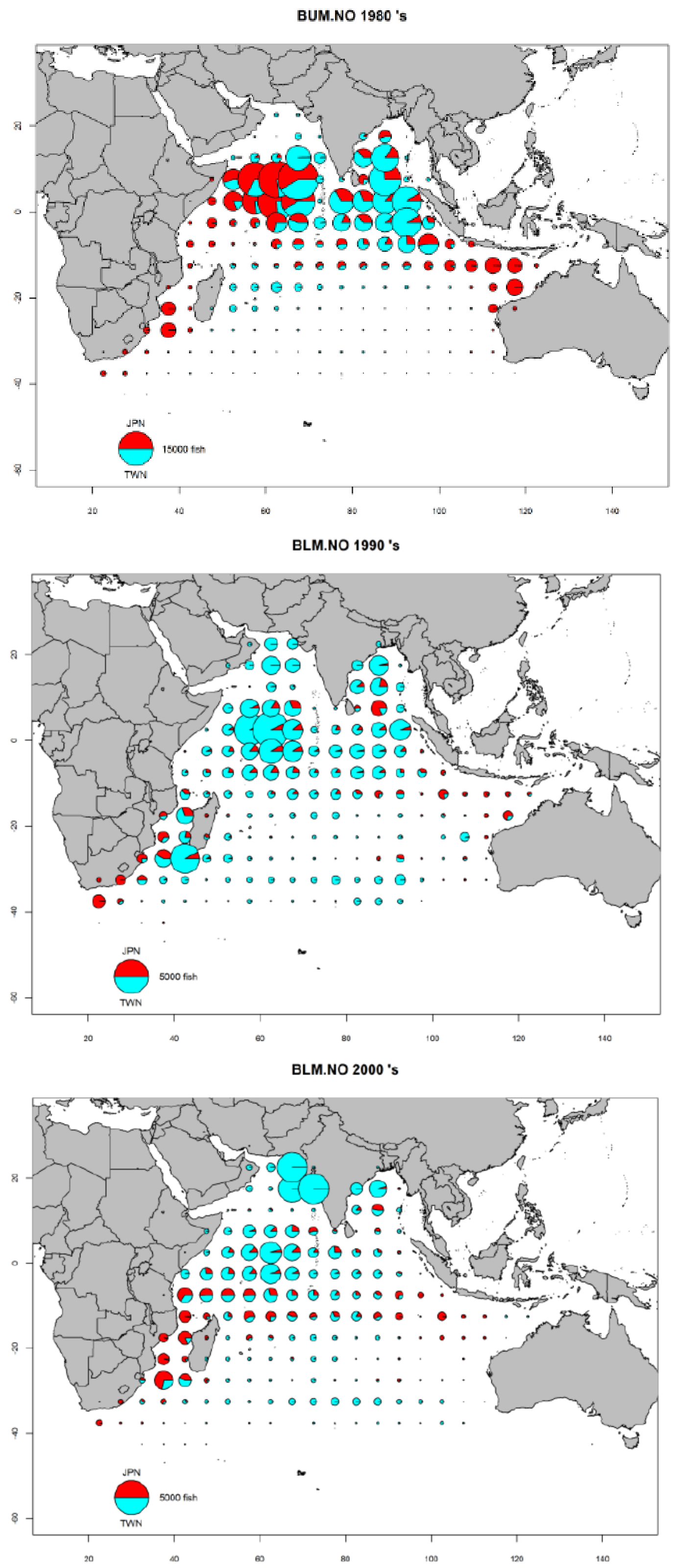


Fig. 1. Total catches of blue marlin (number) by longline vessels operating in the Indian Ocean per decade over the period 1952 to 2008 (IOTC, 2010).

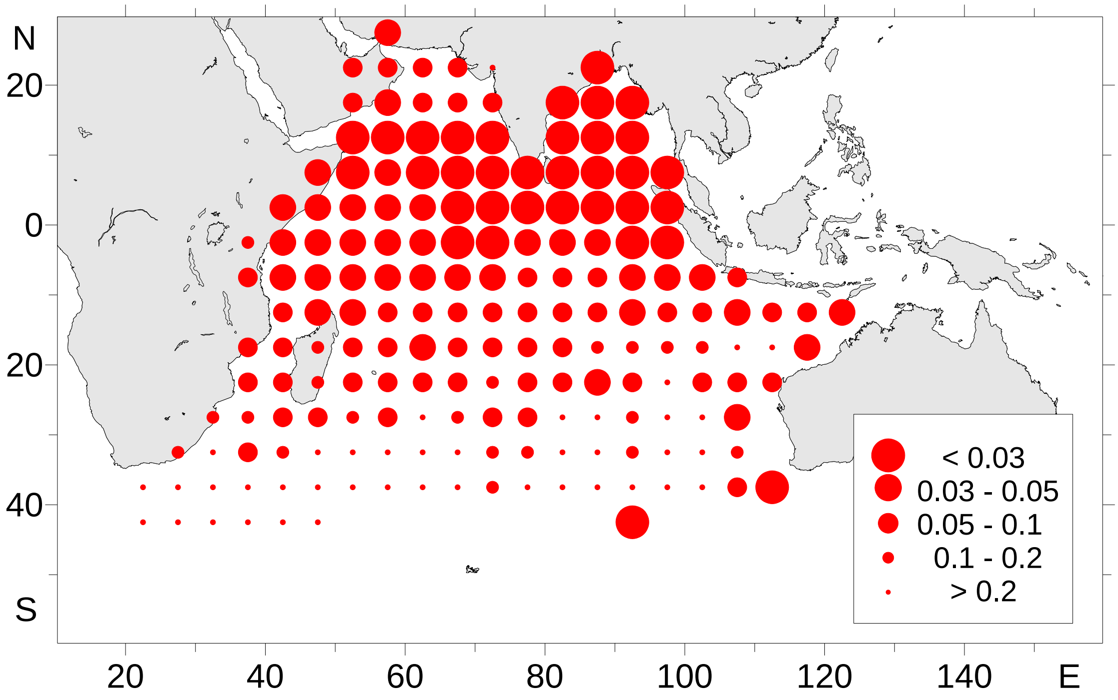


Fig. 2. CPUE distribution of blue marlin caught by Taiwanese longline fleet over the period of 1980-2009.

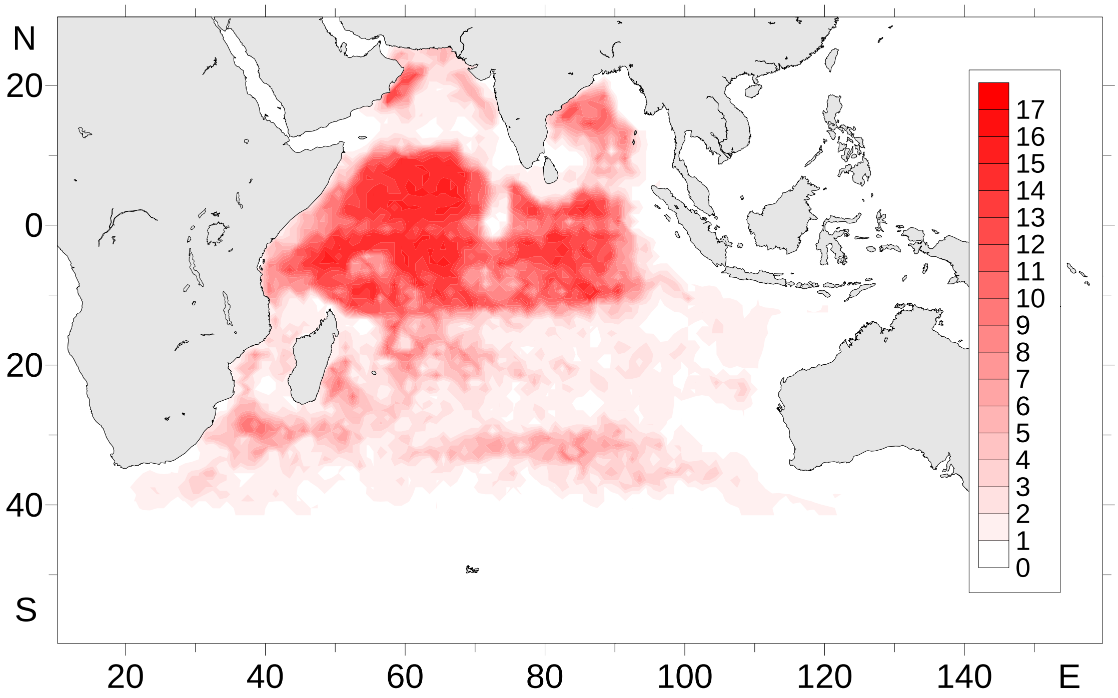


Fig. 3. Number of years of catching blue marlin by Taiwanese lognline fleet over the period of 1980-2009.

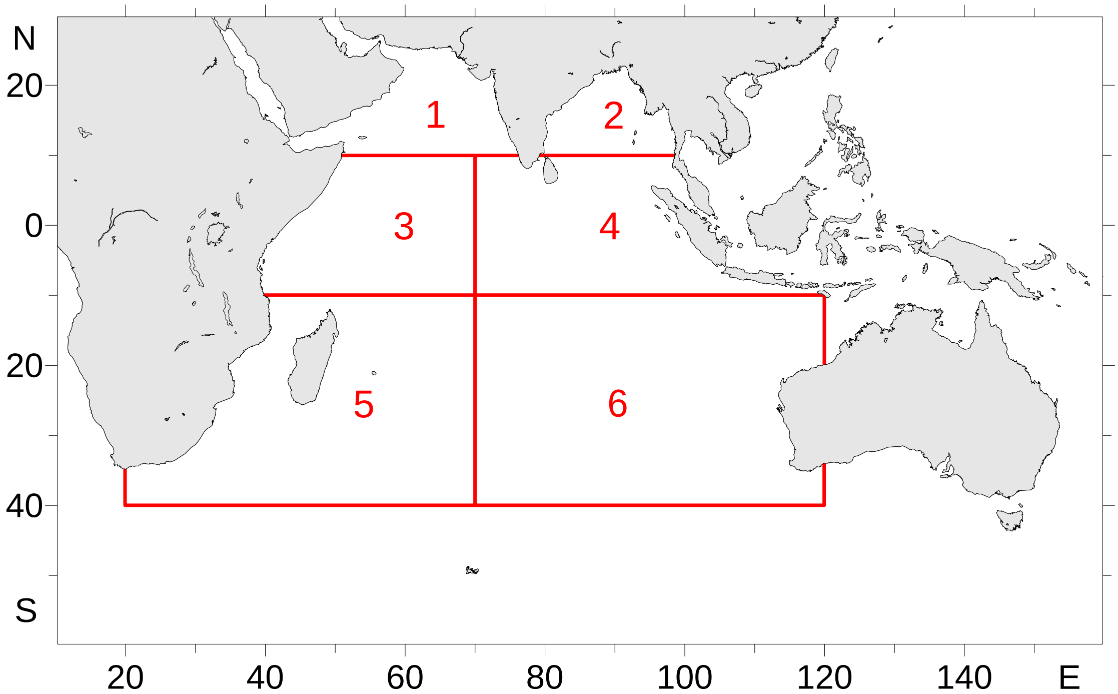


Fig. 4. The definition of six fishing areas for blue marlin in the Indian Ocean.

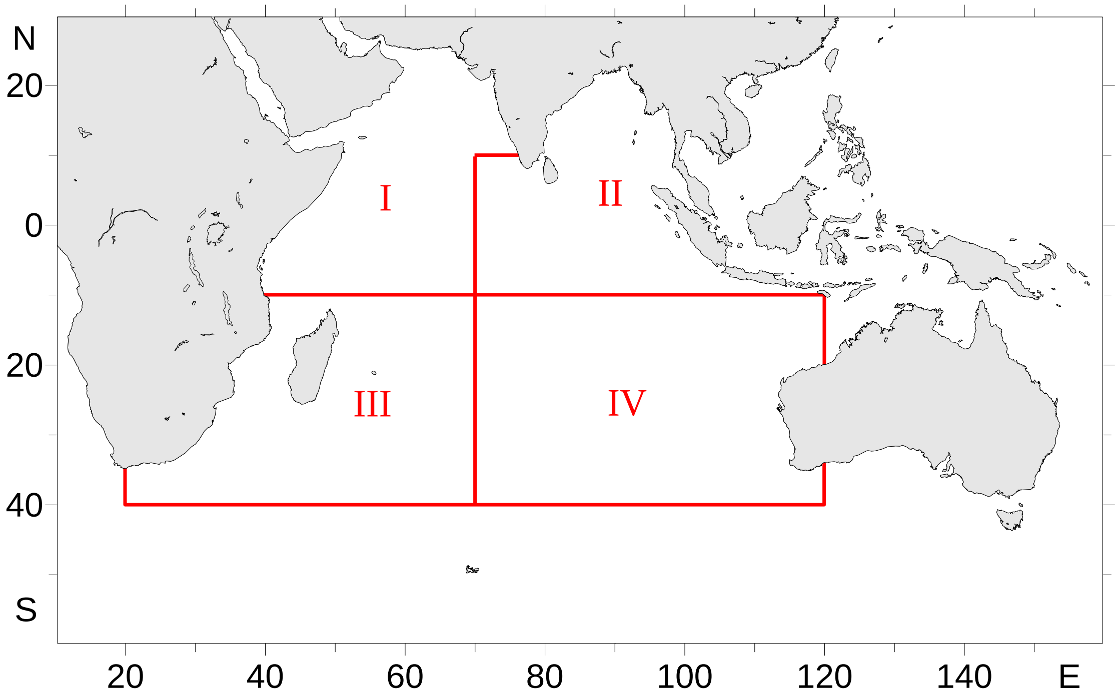
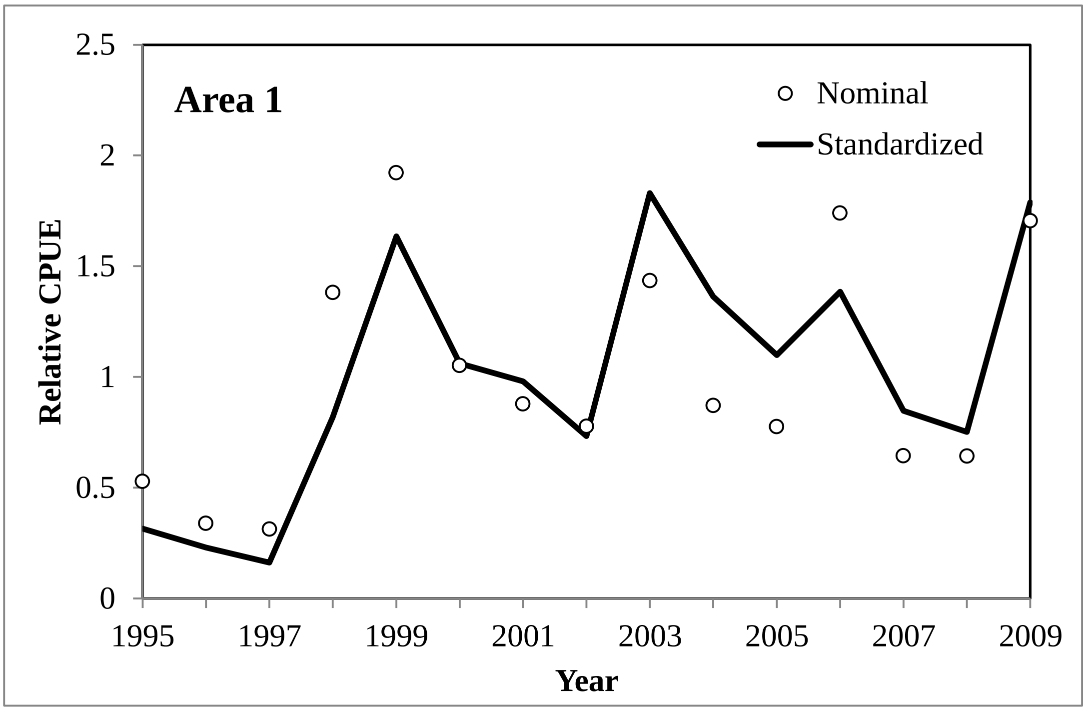


Fig. 5. The definition of four fishing areas for blue marlin in the Indian Ocean.



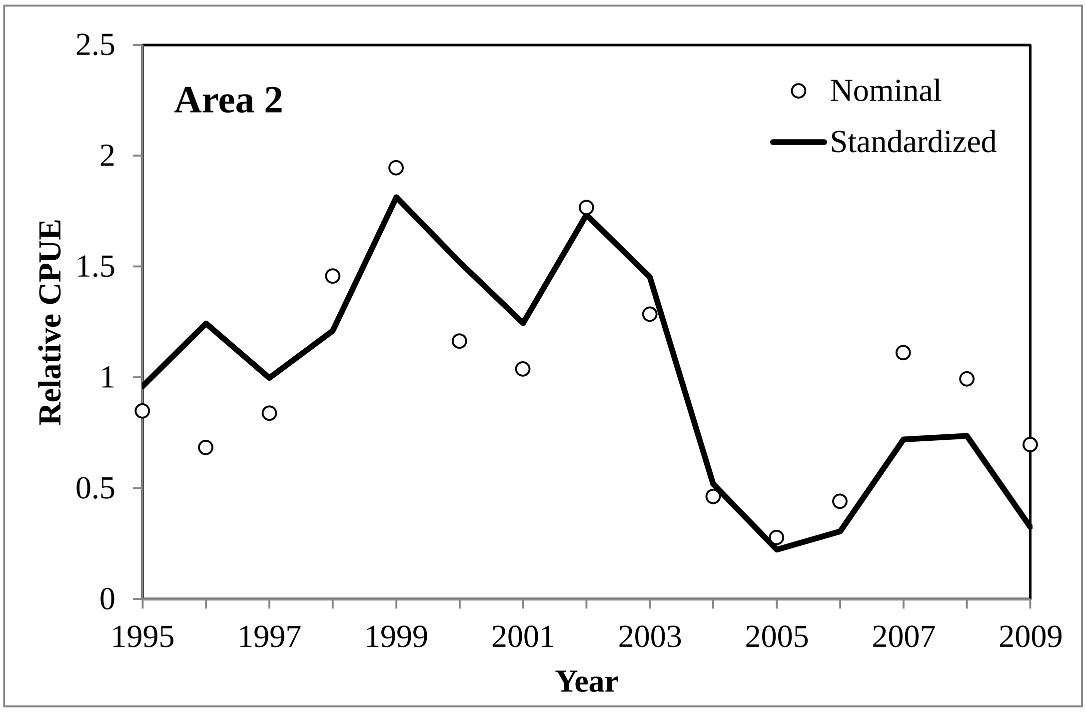
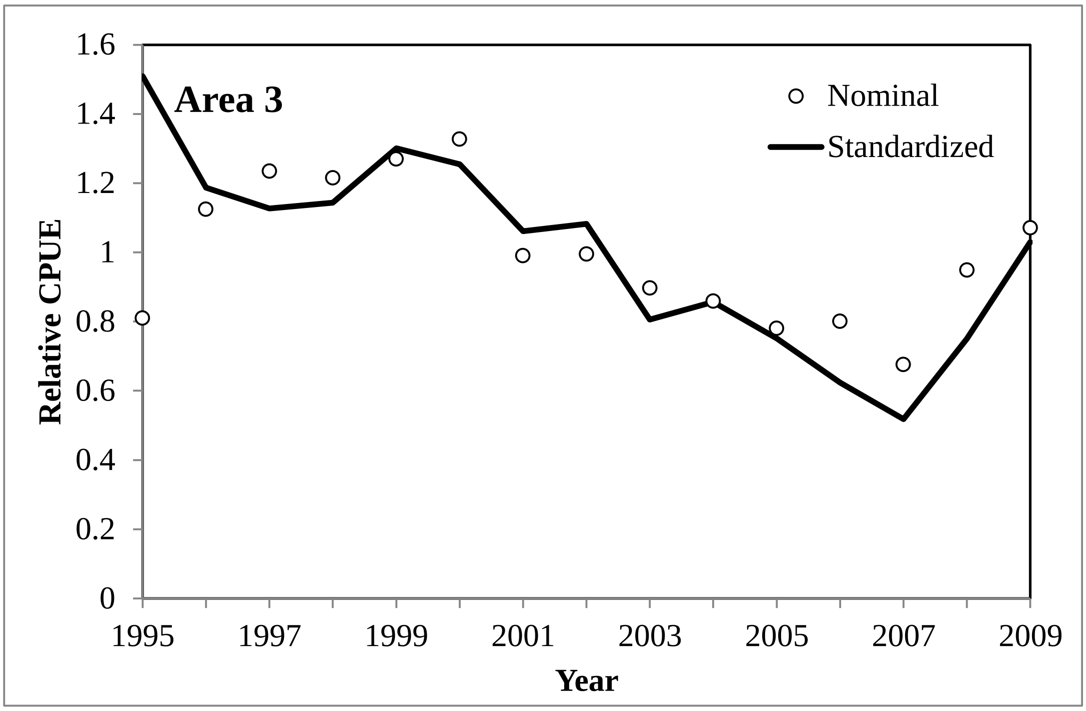


Fig. 6. Nominal and Standardized CPUE of blue marlin caught by Taiwanese longline fleet based the data with 1x1 degree grid and the definition of six fishing areas.



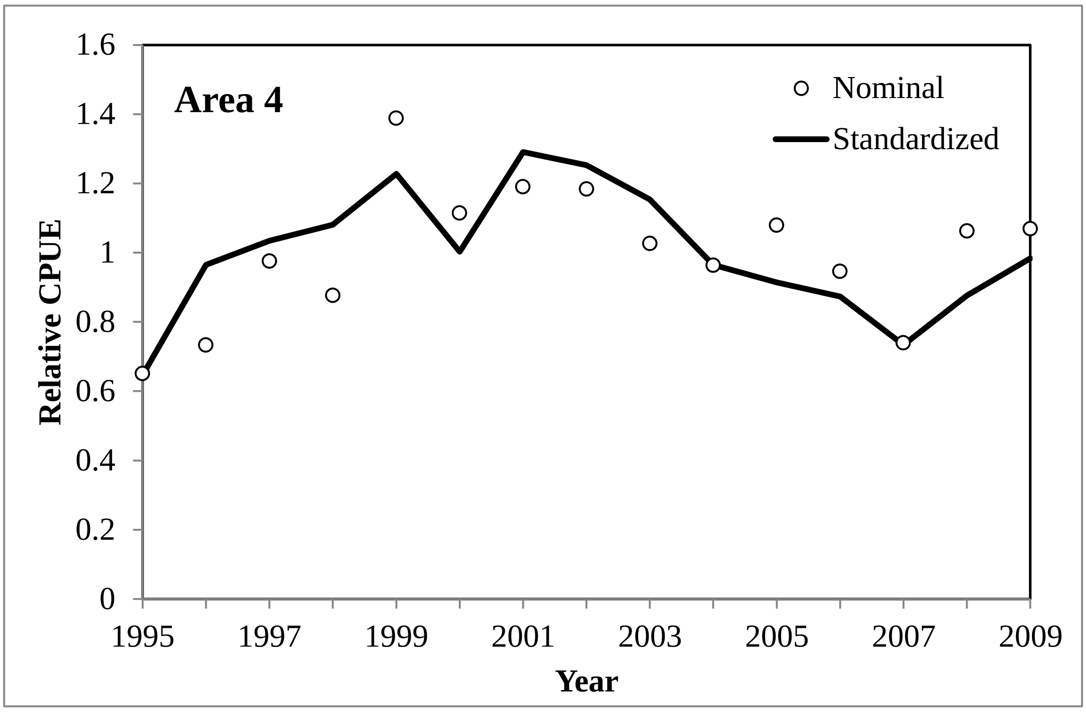
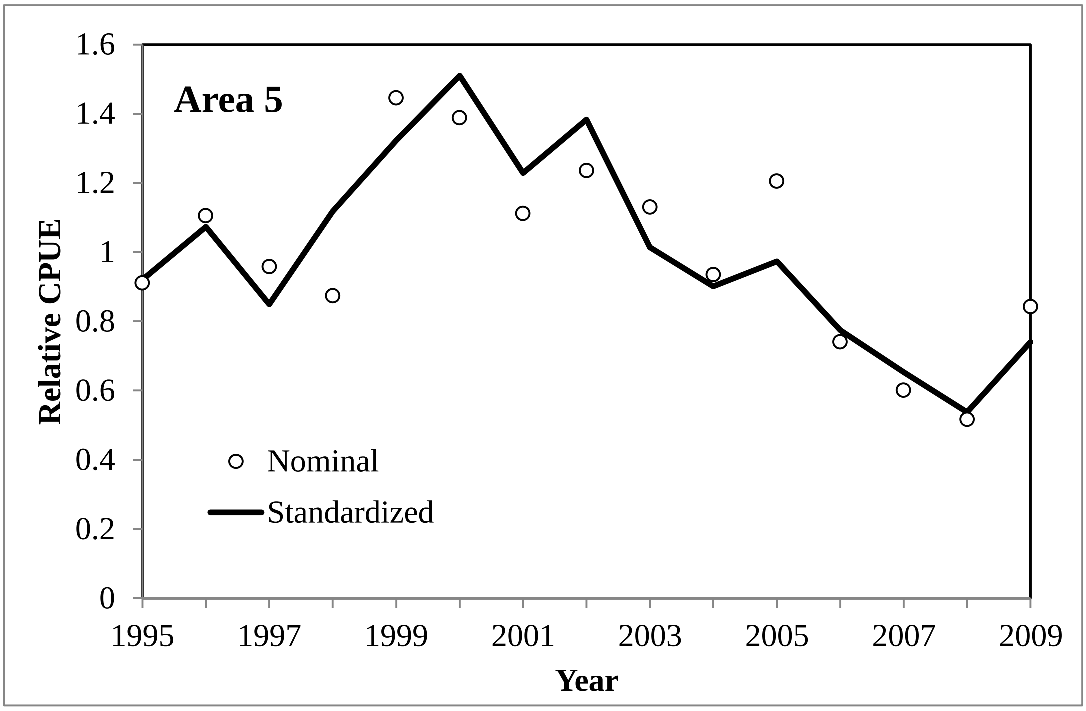
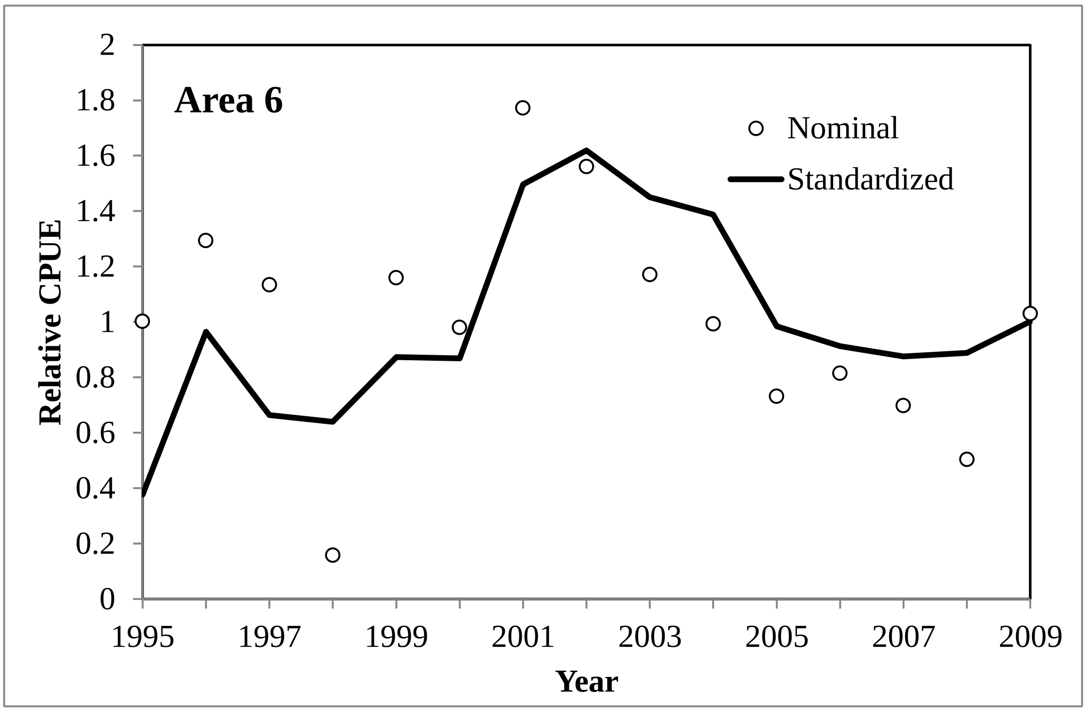


Fig. 6. (Continued).





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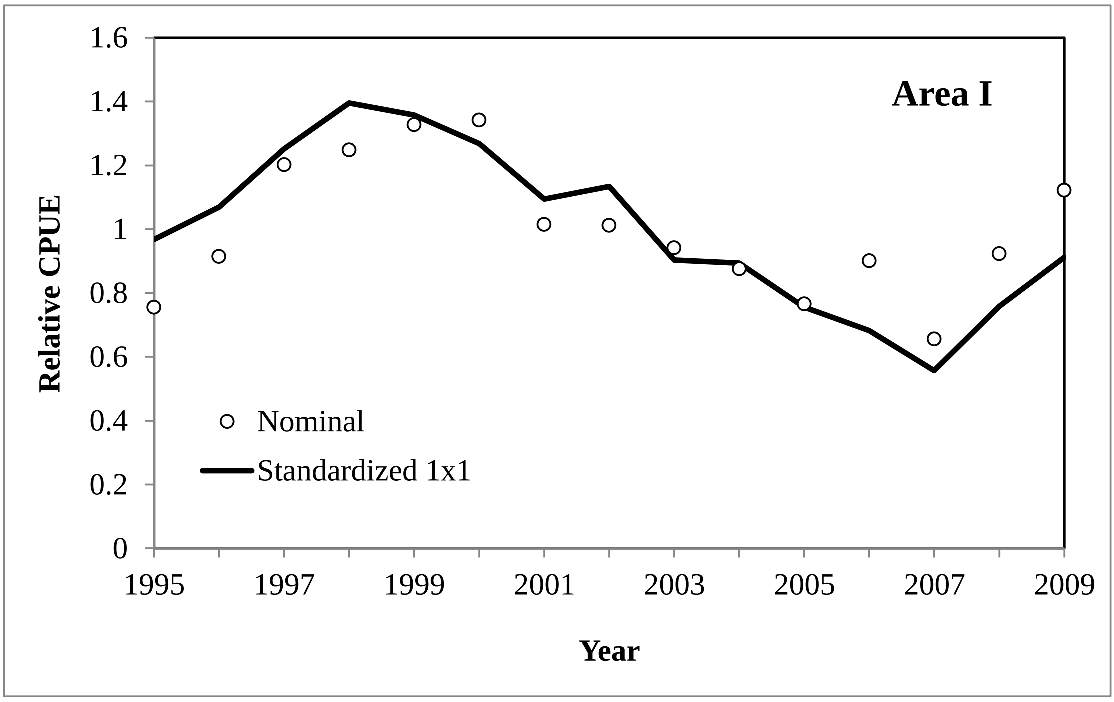


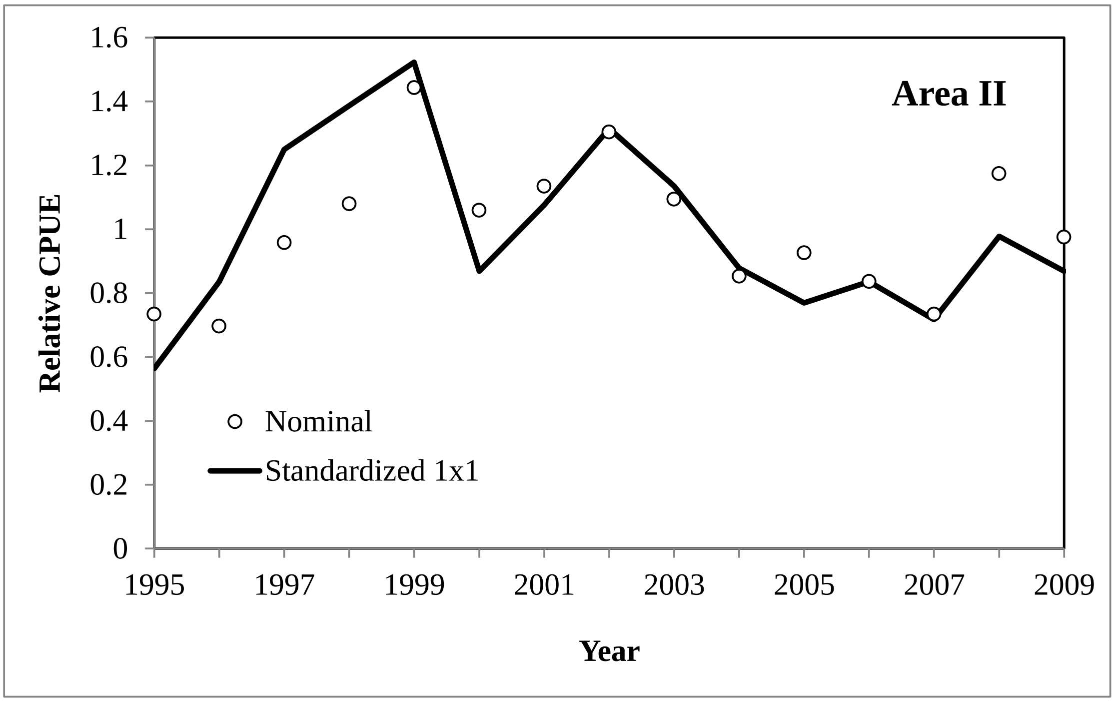
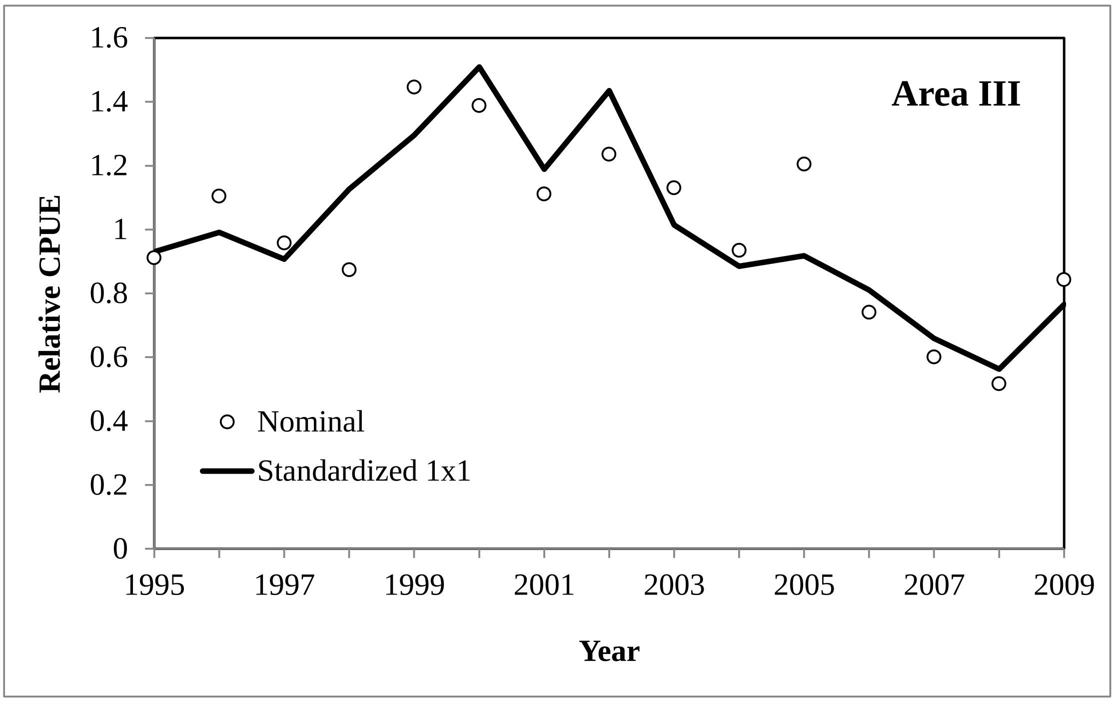
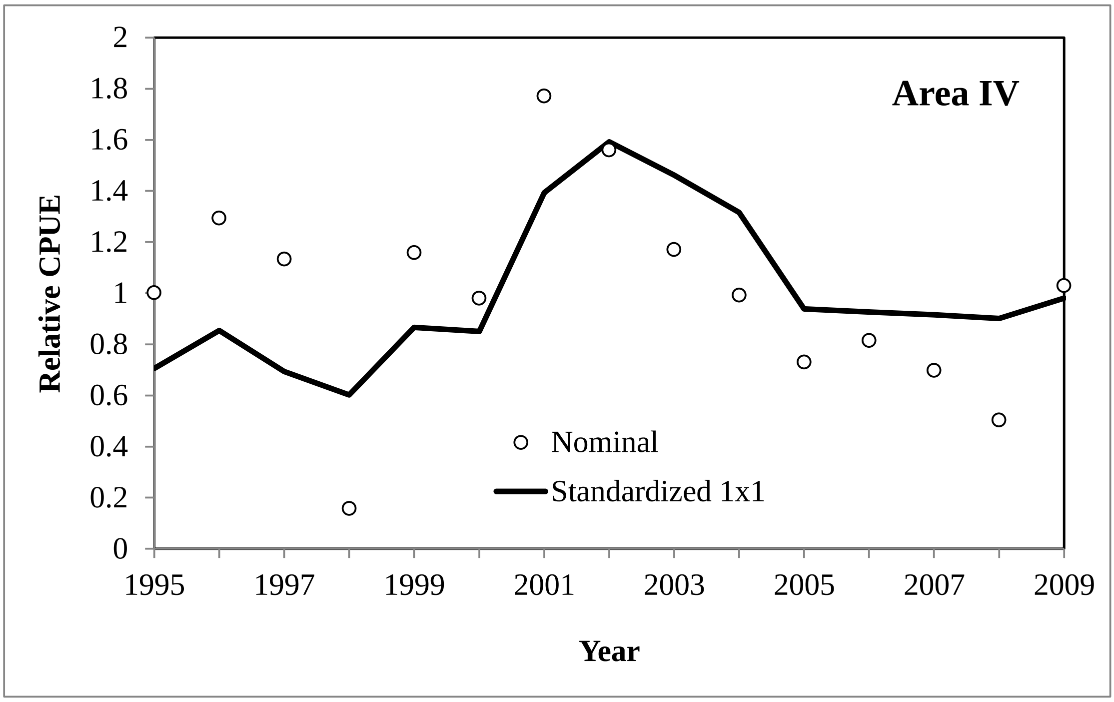


Fig. 7. Nominal and Standardized CPUE of blue marlin caught by Taiwanese longline fleet based the data with 1x1 degree grid and the definition of four fishing areas.





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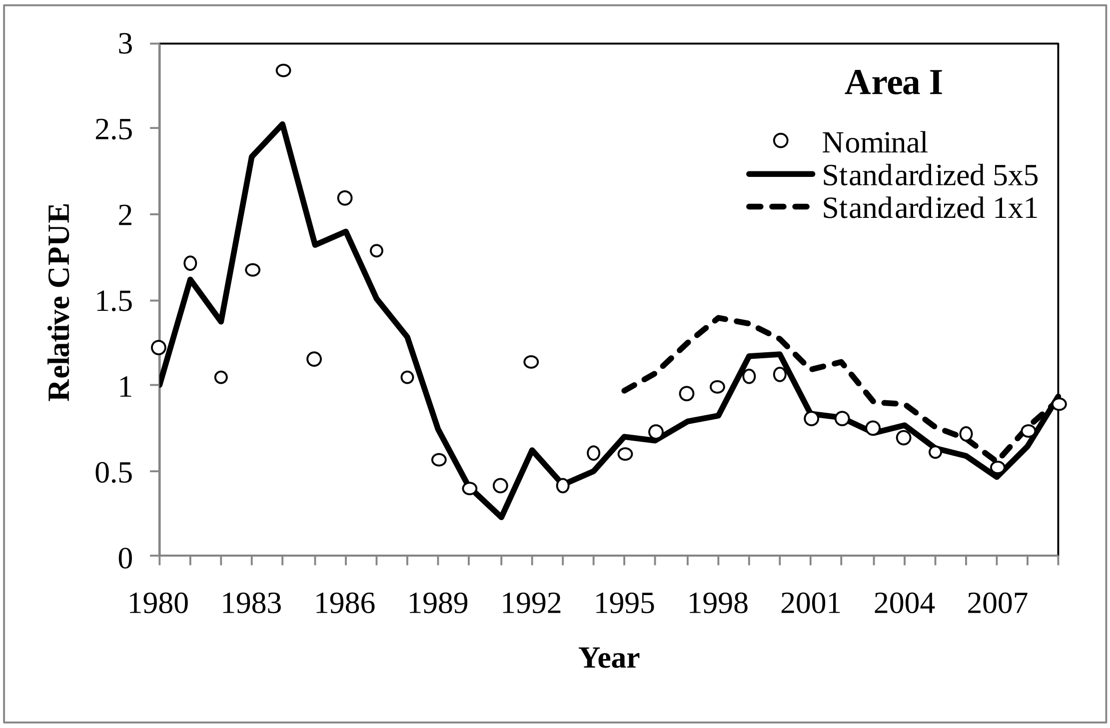


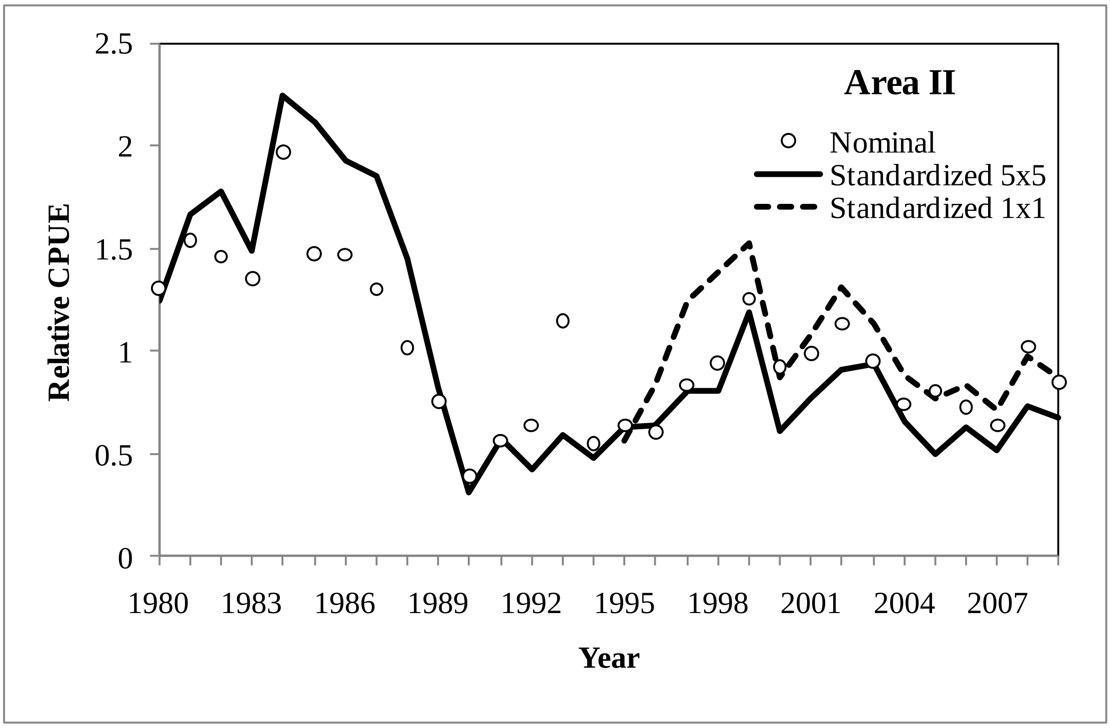
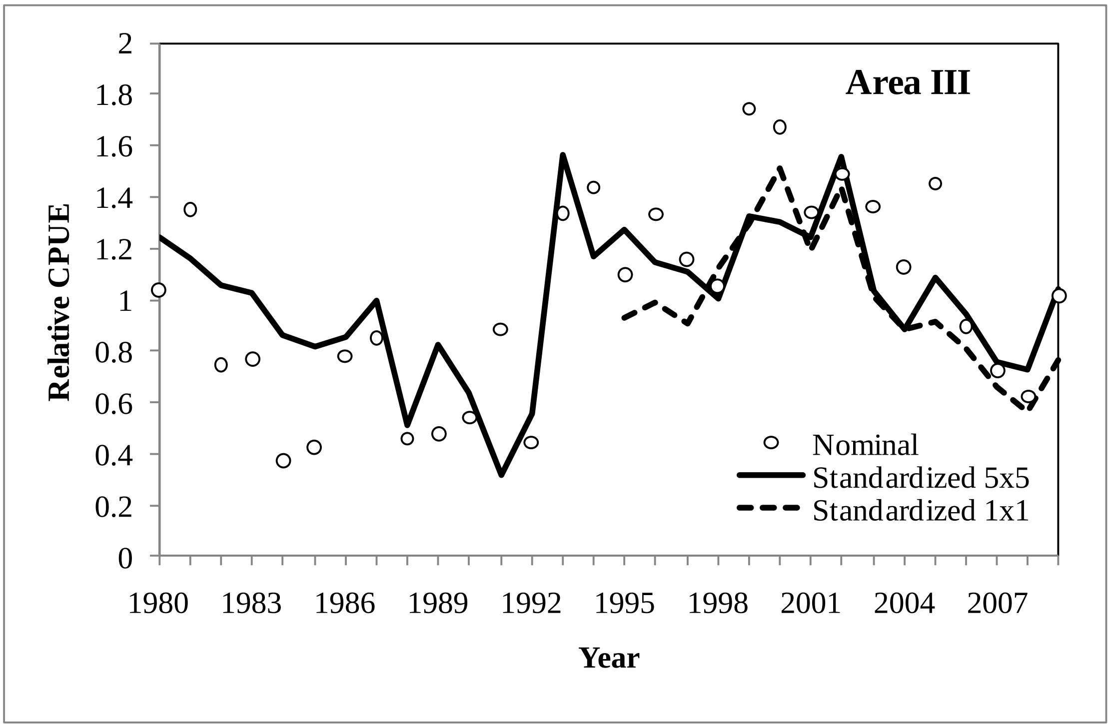
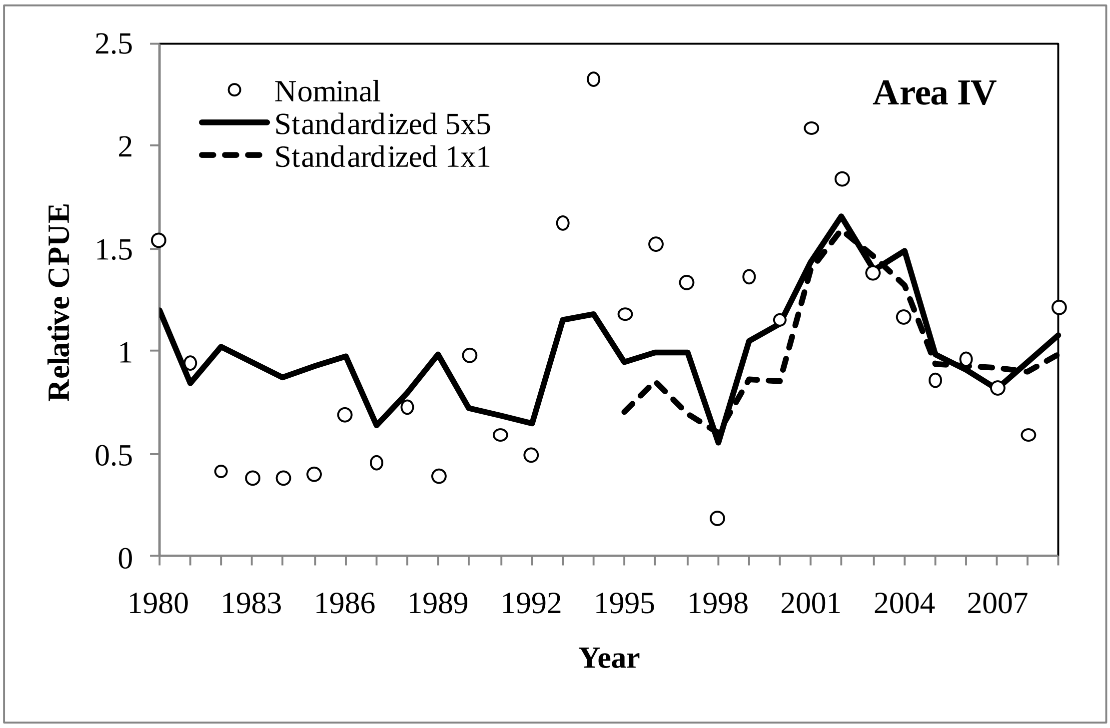


Fig. 8. Nominal and Standardized CPUE of blue marlin caught by Taiwanese longline fleet based the data with 5x5 degree grid and the definition of four fishing areas.





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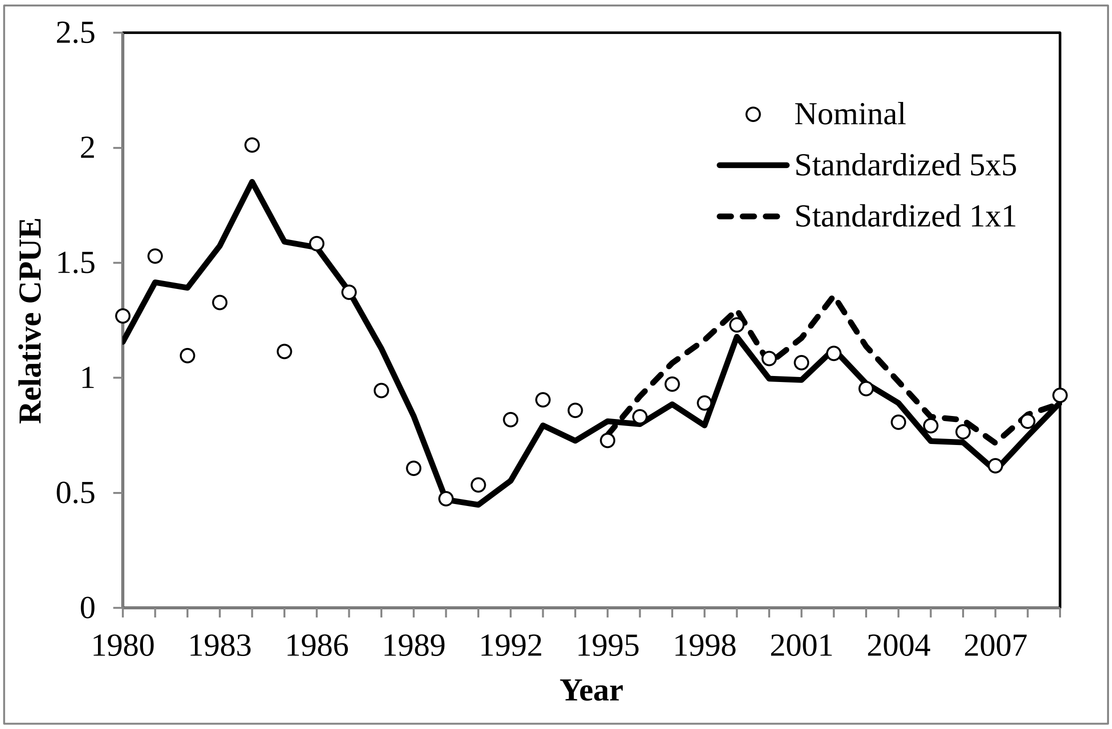

Fig. 9. Area-aggregated nominal and Standardized CPUE of blue marlin caught by Taiwanese longline fleet based the definition of four fishing areas.

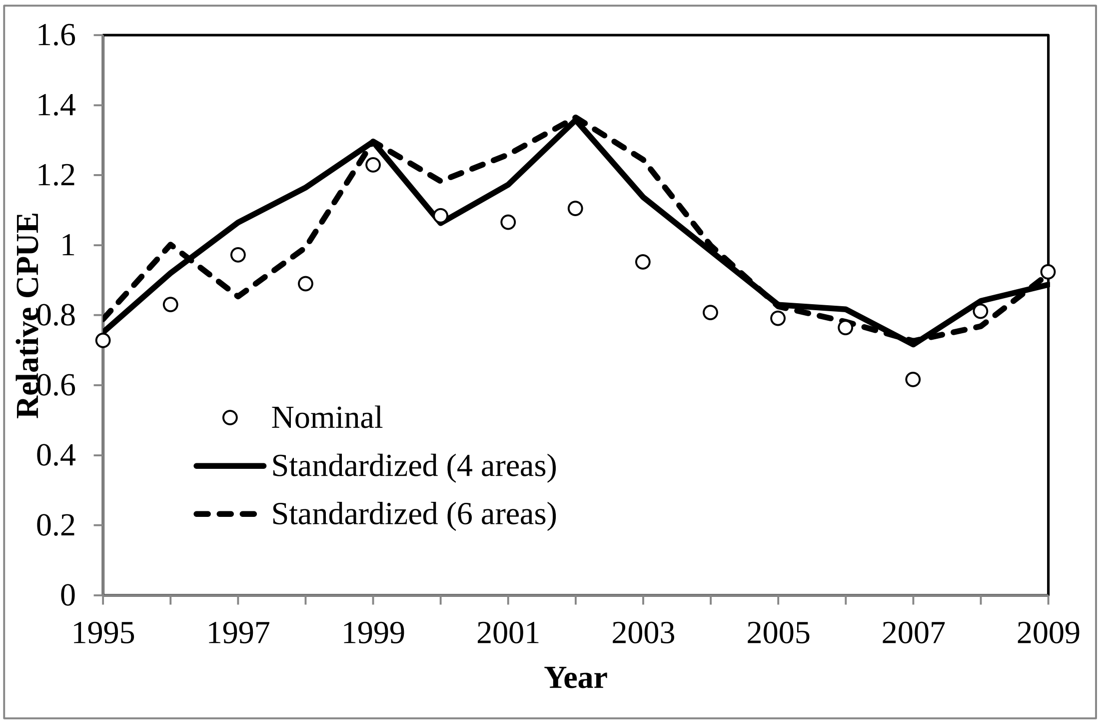

Fig. 9. Area-aggregated nominal and Standardized CPUE of blue marlin caught by Taiwanese longline fleet based the data with 1x1 degree grid.

Table 1. The values of R2, AIC and BIC for six models based the data with 1x1 degree grid and the definition of six fishing areas.

Model	Model DF	AIC	BIC	R2(%)	ΔR2(%)	ΔAIC	ΔBIC
1	92	352590	353600	6.1			
2	487	323458	328806	12.5	6.3	-29132	-24794
3	94	351629	352661	6.3	0.2	-961	-939
4	95	352596	353639	6.2	0.0	6	39
5	98	350088	351165	6.7	0.5	-2501	-2435
6	503	320381	325904	13.1	7.0	-32209	-27695

Table 2. The ANOVA table for Model 6 based the data with 1x1 degree grid and the definition of six fishing areas.

Source	DF	Sum of Squares	Mean Square	F Value	Pr > F
Model	503	136429.90	271.23	129.96	<.0001
Error	433590	904949.64	2.09		
Corrected Total	434093	1041379.539			

Source	DF	Type III SS	Mean Square	F Value	Pr > F
Y	14	2281.48	162.96	78.08	<.0001
Q	3	918.14	306.05	146.64	<.0001
A	5	4481.32	896.26	429.43	<.0001
Y*A	70	5221.95	74.60	35.74	<.0001
V	395	64608.39	163.57	78.37	<.0001
NHBF	2	131.89	65.94	31.60	<.0001
SC	1	1164.98	1164.98	558.18	<.0001
AM	1	4.56	4.56	2.18	0.1395
TD	1	2293.44	2293.44	1098.86	<.0001
TG	1	13.62	13.62	6.52	0.0106
A*NHBF	10	992.04	99.20	47.53	<.0001

Table 3. The values of R2, AIC and BIC for six models based the data with 5x5 degree grid and the definition of four fishing areas.

Model	Model DF	AIC	BIC	R2(%)	ΔR2(%)	ΔAIC	ΔBIC
1	122	598598	600010	9.5			
2	869	547012	557067	15.5	6.0	-51586	-42943
3	125	595687	597134	9.8	0.3	-2911	-2876
4	124	598602	600037	9.5	0.0	4	27
5	126	592761	594219	10.2	0.7	-5837	-5791
6	896	536873	547239	16.6	7.1	-61726	-52771

Table 4. The ANOVA table for Model 6 based the data with 5x5 degree grid and the definition of four fishing areas.

Source	DF	Sum of Squares	Mean Square	F Value	Pr > F
Model	896	308364.02	344.16	173.62	<.0001
Error	781263	1548649.49	1.98		
Corrected Total	782159	1857013.51			

Source	DF	Type III SS	Mean Square	F Value	Pr > F
Y	29	6571.36	226.60	114.31	<.0001
Q	3	3185.52	1061.84	535.68	<.0001
A2	3	6956.33	2318.78	1169.78	<.0001
Y*A2	87	12304.73	141.43	71.35	<.0001
V	747	101358.75	135.69	68.45	<.0001
BET	1	714.98	714.98	360.69	<.0001
YFT	1	1174.77	1174.77	592.65	<.0001
SC	1	2323.84	2323.84	1172.33	<.0001
AM	1	298.17	298.17	150.42	<.0001
TD	1	2931.07	2931.07	1478.66	<.0001
TG	1	72.72	72.72	36.69	<.0001
Q*A2	9	1962.29	218.03	109.99	<.0001
BET*Q	3	316.28	105.43	53.19	<.0001
YFT*Q	3	199.89	66.63	33.61	<.0001
BET*A2	3	1010.66	336.89	169.95	<.0001
YFT*A2	3	3096.21	1032.07	520.66	<.0001

Table 5. The values of R2, AIC and BIC for six models based the data with 1x1 degree grid and the definition of four fishing areas.

Model	Model DF	AIC	BIC	R2(%)	ΔR2(%)	ΔAIC	ΔBIC
1	62	355986	356666	5.4			
2	457	325458	330476	12.0	6.6	-30527	-26190
3	64	355224	355927	5.6	0.2	-762	-740
4	65	355800	356514	5.4	0.0	-185	-152
5	66	353885	354610	5.9	0.5	-2101	-2057
6	484	321797	327111	12.8	7.4	-34189	-29555

Table 6. The ANOVA table for Model 6 based the data with 1x1 degree grid and the definition of four fishing areas.

Source	DF	Sum of Squares	Mean Square	F Value	Pr > F
Model	484	133268.44	275.35	131.47	<.0001
Error	433609	908111.10	2.09		
Corrected Total	434093	1041379.54			

Source	DF	Type III SS	Mean Square	F Value	Pr > F
Y	14	2679.32	191.38	91.38	<.0001
Q	3	649.08	216.36	103.31	<.0001
A2	3	2960.56	986.85	471.21	<.0001
Y*A2	42	2988.37	71.15	33.97	<.0001
V	395	66656.67	168.75	80.58	<.0001
NHBF	2	414.22	207.11	98.89	<.0001
SC	1	1139.73	1139.73	544.21	<.0001
AM	1	45.41	45.41	21.68	<.0001
TD	1	1674.03	1674.03	799.32	<.0001
TG	1	20.24	20.24	9.67	0.0019
Q*A2	9	583.98	64.89	30.98	<.0001
Q*NHBF	6	65.53	10.92	5.21	<.0001
A2*NHBF	6	1637.93	272.99	130.35	<.0001