CPUE standardization of black marlin (*Makaira indica*) caught by Taiwanese large scale longline fishery in the Indian Ocean

Sheng-Ping Wang

Department of Environmental Biology and Fisheries Science, National Taiwan Ocean University, Keelung, Taiwan.

ABSTRACT

In this study, the delta-gamma general linear models with the targeting effect derived from cluster analysis were used to conduct the CPUE standardization of black marlin caught by the Taiwanese large scale longline fishery in the Indian Ocean for 1979-2017. CPUE trends were obviously different for northern and southern Indian Ocean, while the area-aggregated CPUE fluctuated before early 1990s, gradually declined until late 2000s, and reveals an increasing trend in recent years.

1. INTRODUCTION

Black marlin is considered to be a non-target species of industrial and artisanal fisheries. Gillnets account for around 54% of total catches in the Indian Ocean, followed by longlines (17%), with remaining catches recorded under troll and handlines. The catches were mainly made by Iran (gillnet, 29%), India (gillnet and troll, 20%), Sri Lanka (gillnet and fresh longline, 19%) and Indonesia (fresh longline and hand lines, 15%). In recent years, Taiwan has made only about 2% of total catches of black marlin in the Indian Ocean. Catches have increased steadily since the 1990s, from 2,800 t in 1991 to over 10,000 t since 2008. The highest catches were recorded in 2014, at nearly 18,000 t due to increases reported by the offshore gillnet fisheries of Iran. (IOTC, 2017).

Annual catches of black marlin caught by Taiwanese longline fishery were generally less than 1,000t and catch proportions were less 1-2% of total catches, except for the years before the early 1960s (Wang, 2016). Based on the areas defined by Wang and Nishida (2011) (Fig. 1), the catches of black marlin are mainly made by Taiwanese large scale longline operated in the northern areas (Fig. 2). The nominal CPUE distribution of black marlin of Taiwanese fleet indicated that high CPUE generally occurred in the northern waters of 15S in the 1980s and 1990s, while high

CPUEs were only observed in the waters around the Bay of Bengal in 2000s and 2010s (Wang, 2016).

Because black marlin was bycatch species of Taiwanese lognline fishery, large amount of zero-catches was recorded in the operational catch and effort data sets of Taiwanese longline fishery. The annual proportions of zero-catch were about 95% of total data sets. In previous study (Wang, 2015), the delta-lognormal GLM (Pennington, 1983; Lo et. al., 1992; Pennington, 1996) was applied to conduct CPUE standardization of black marlin in the Indian Ocean but the model with lognormal assumption for the residuals might not appropriate for fitting to the data. Therefore, a delta-gamma GLM was adopted in this study. In addition, the targeting of fishing operation was identified from the cluster analyses as recommended by the Fifth IOTC CPUE Workshop.

2. MATERIALS AND METHODS

2.1. Catch and Effort data

In this study, daily operational catch and effort data (logbook) with 5x5 degree longitude and latitude grid for Taiwanese longline fishery during 1980-2017 were provided by Oversea Fisheries Development Council of Taiwan (OFDC). It should be noted that the data in 2017 is preliminary.

The data of number of hooks between float (NHBF) were available since 1994 and the collection of NHBF data were more complete since 1995. Therefore, the data of NHBF may not be applicable to conduct the long-term CPUE standardization for fishes caught by Taiwanese longline fishery in the Indian Ocean.

2.2. CPUE Standardization

A delta-gamma GLM was applied to standardize the CPUE. As the approach of Wang (2017), the models were simply conducted with the main effects considered in this analysis were year, month, 5x5 longitude-latitude grid, and the effects related to the fishing configurations (clusters), while interactions between main effects were not incorporated into the models. In addition, CPUE standardizations were also performed by four fishing areas separately. The gamma and delta models were conducted as follows:

Gamma model for CPUE of positive catch:

$$\log(CPUE) = \mu + Y + M + G + T + \varepsilon^{\text{gamma}}$$

Delta model for presence and absence of catch:

$$PA = \mu + Y + M + CT + G + T + \varepsilon^{del}$$

where	*CPUE*	is the nominal CPUE of positive catch of black marlin (catch in number/1,000 hooks),
	PA	is the nominal presence and absence of catch,
	μ	is the intercept,
	Y	is the effect of year,
	M	is the effect of month,
	CT	is the effect of vessel scale,
	G	is the effect of 5x5 longitude-latitude grid,
	T	is the effect of targeting (principal component scores (PC_i) derived from the ith principle component),
	ε^{gamma}	is the error term, ε^{gamma} ~ Gamma distribution with log link function,
	ε^{del}	is the error term, ε^{del} ~ Binomial distribution.

The models performed by stepwise search ("both" direction, i.e. "backward" and "forward") and selected based on the values of the coefficient of determination (R^2), Akaike information criterion (AIC) and Bayesian information criterion (BIC). The standardized CPUE were calculated based on the estimates of least square means of the interaction between the effects of year and area.

The area-specific standardized CPUE trends were estimated based on the exponentiations of the adjust means (least square means) of the year effects (Butterworth, 1996; Maunder and Punt, 2004). The standardized relative abundance index was calculated by the product of the standardized CPUE of positive catches and the standardized probability of positive catches:

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

where	*CPUE*	is the adjust means (least square means) of the year effect of the lognormal model,
	$\tilde{P}$	is the adjust means (least square means) of the year effect of the delta model.

2.3. Area-aggregated CPUE series

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

$$U_y = \sum_a S_a^1 U_{y,a}$$

Where U_y is CPUE for year y,
$U_{y,a}$ is CPUE for year y and area a,
S_a^1 is the relative size of the area a.

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.

Area	NW	NE	SW	SE
Relative area size	0.2478	0.2577	0.1638	0.3307

In addition, area-specific standardized CPUE was also aggregated by the proportions of annual area-specific catch and effort data:

$$U_y = \sum_a S_{y,a}^2 U_{y,a}$$

Where $S_{y,a}^2$ is the proportion of the catch or hooks in year y and area a.

3. RESULTS AND DISCUSSION

3.1. Catches and distributions by clusters

Please see Wang (2018) for the details of the results of cluster analysis. Generally, the BLM catches were very low in all of four areas, except for relative higher catches occurred in the coastal waters between Indonesia and Malaysia (Fig. 3). BLM catches were contained in all of four clusters but the catch proportions by clusters changed over time (Fig. 4).

3.2. CPUE standardization

Based on the model selections for the gamma models incorporated clusters as the effects related to targeting of operations, all of main effects were statistically significant and remained in the models for areas NW and NE, while the effects of month were not significant for areas SW and SE and the effect of vessel scale was also not significant for area SW. The ANOVA tables for selected gamma models are shown in the Table 1. The results indicate that the effects of *T* (clusters) generally provided significant contributions to explanation of variance for the models for all of four areas. Thus, the targeting of fishing operation might influence the CPUE derived from the positive catch of black marlin.

For the delta models, all of the effects were statistically significant and remained in the models. The ANOVA tables for selected delta models are shown in the Table 2. Comparing to the gamma models for positive catches, the effect of *T* (clusters) were less influential for the catch probability although this effect still significant in the models for all of four areas. The results indicated that the catch probability of black marlin in the Indian Ocean might be mainly influenced by spatial effect.

The area-specific standardized CPUE are shown in Fig. 5. The trends of CPUE series in the northern areas (NW and NE) reveal relatively similar patterns and they fluctuated before early 1990s, reveal decreasing trends until late 2000s, increased with fluctuations thereafter, and declined again in recent years. Also, the CPUE series in the southern areas (SW and SE) are similar and they fluctuated before early 2000s, decreased thereafter, and increased in recent years.

Since very few BLM catches were made in southern areas and no catches occurred in some years, the area-aggregated CPUE series were calculated based on the results from northern areas. Although the CPUE series aggregated by various weightings were slightly different, the area-aggregated CPUE series fluctuated before early 1990s, gradually declined until late 2000s, and reveals an increasing trend in recent years (Fig. 6).

3.3. Retrospect analysis

The retrospect analysis was conducted to test the influence of including the updated data on the CPUE standardization. The analysis was performed by removing the data from 2017 to 2012. The results indicated that the influence of including the updated data on the CPUE standardization was negligible for all of four areas (Fig. 7).

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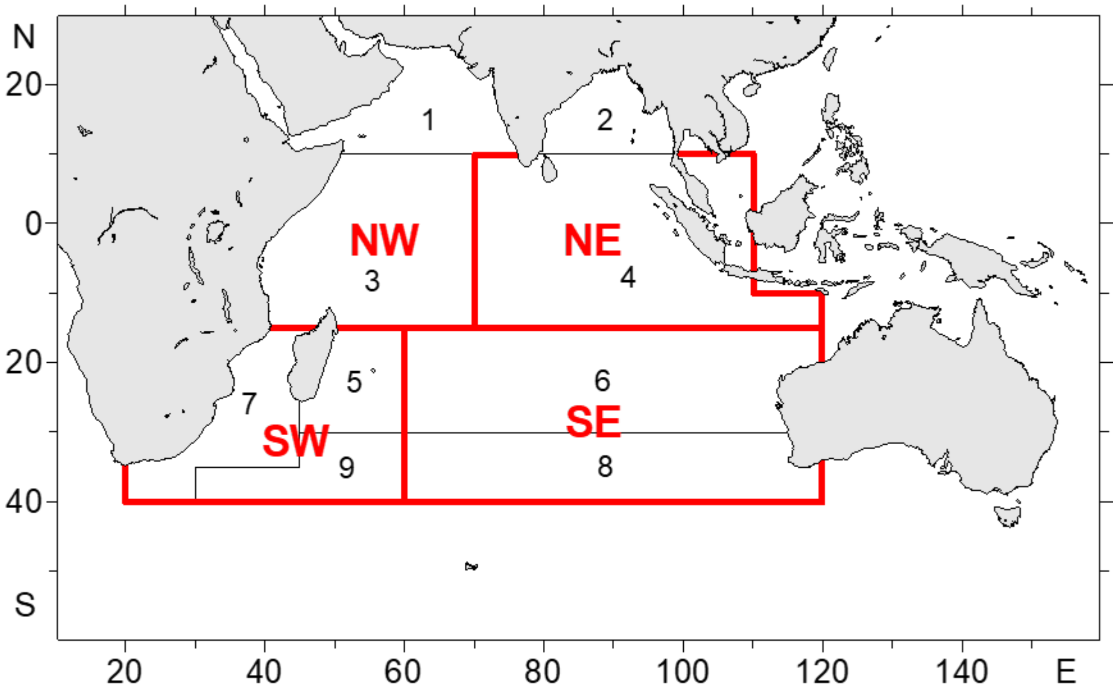


Fig. 1. Area stratification used for black marlin in the Indian Ocean.

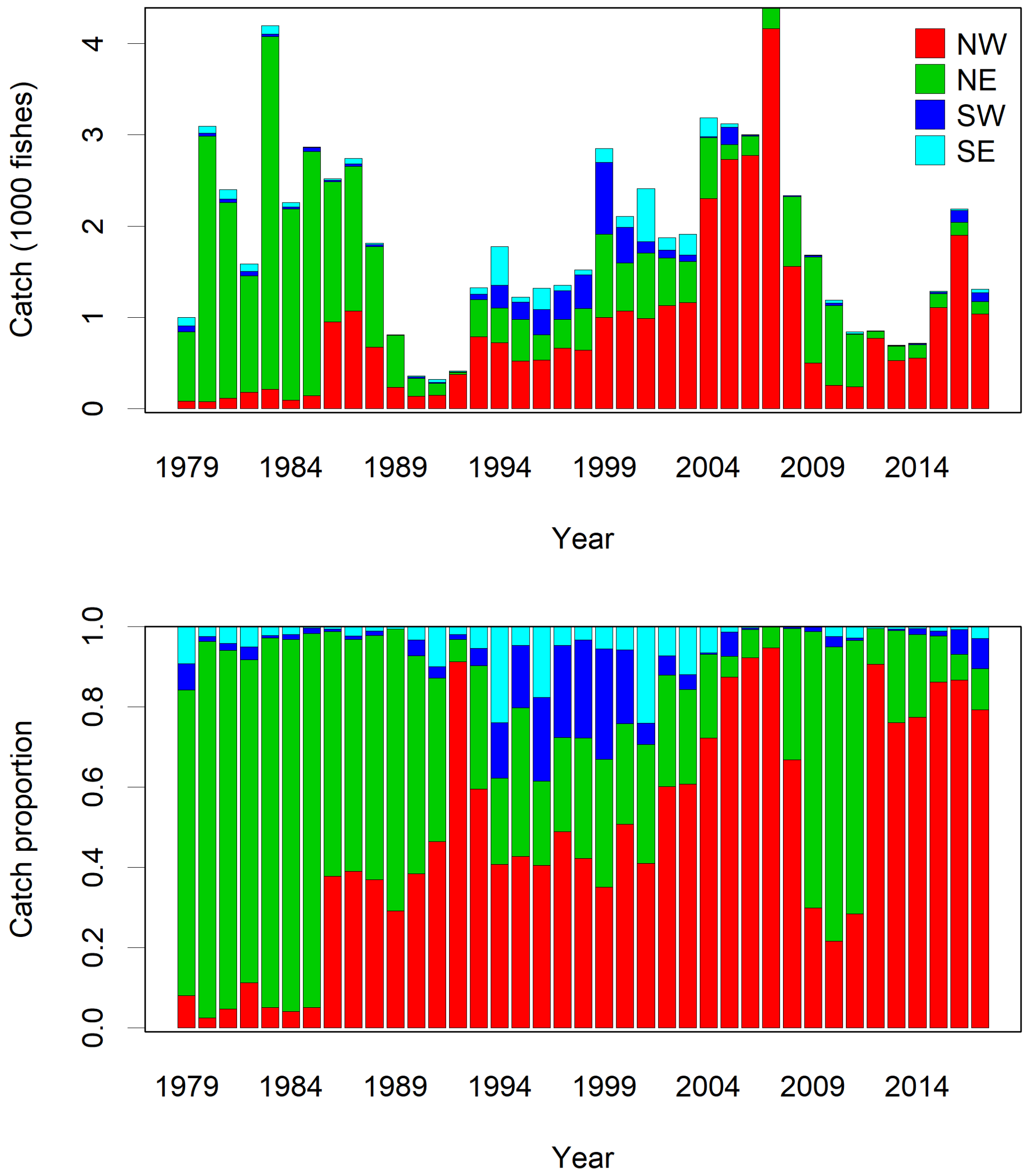
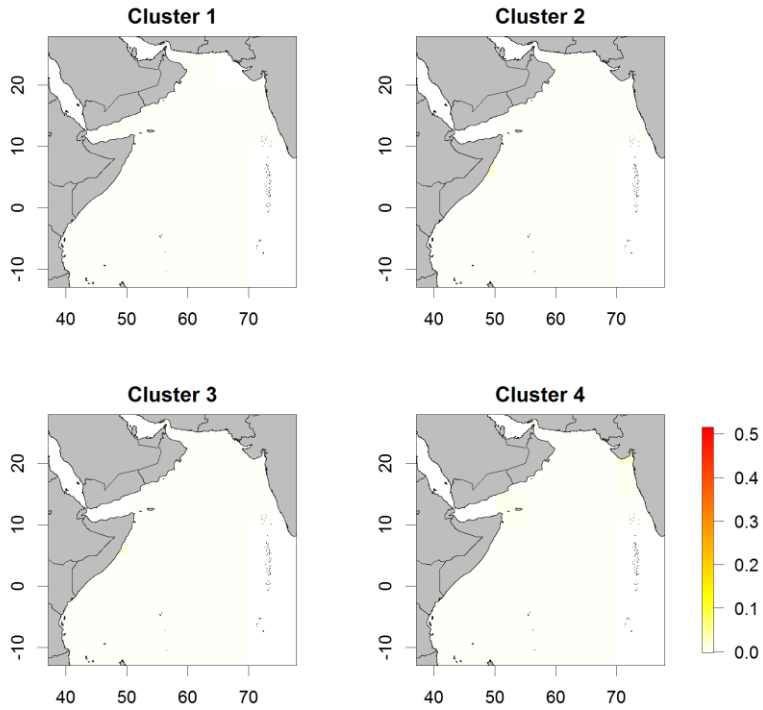


Fig. 2. The catches and catch proportions by areas of black marlin caught by Taiwanese large scale longline operated in the Indian Ocean.

Area NW



Area NE

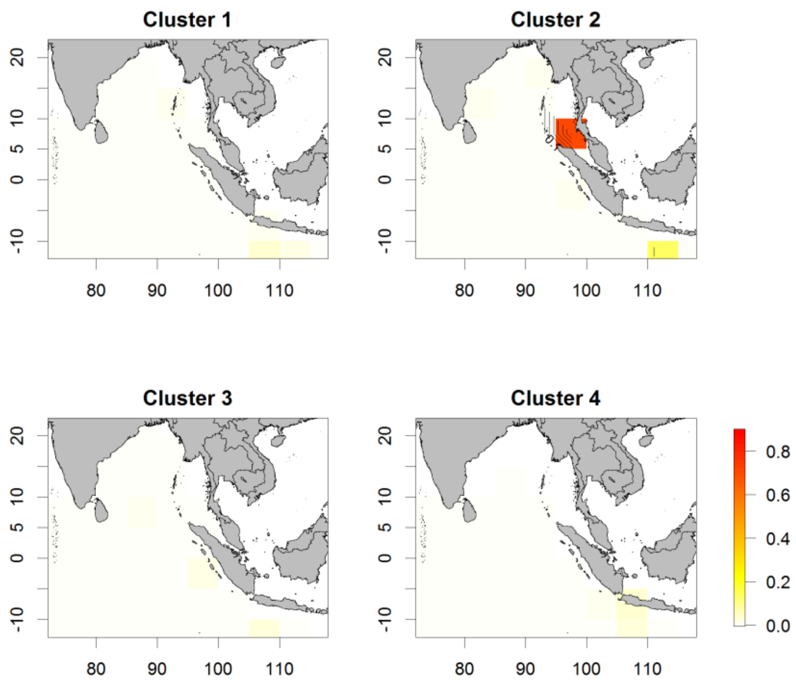
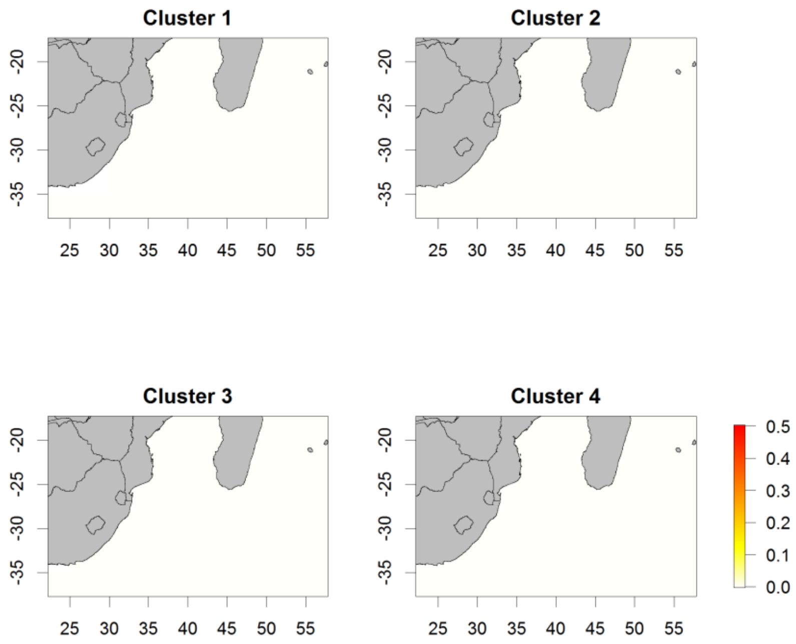


Fig. 3. Black marlin catch distribution for each cluster of Taiwanese large scale longline fishery in the Indian Ocean. Yellow is high catch and red is low catch.

Area SW



Area SE

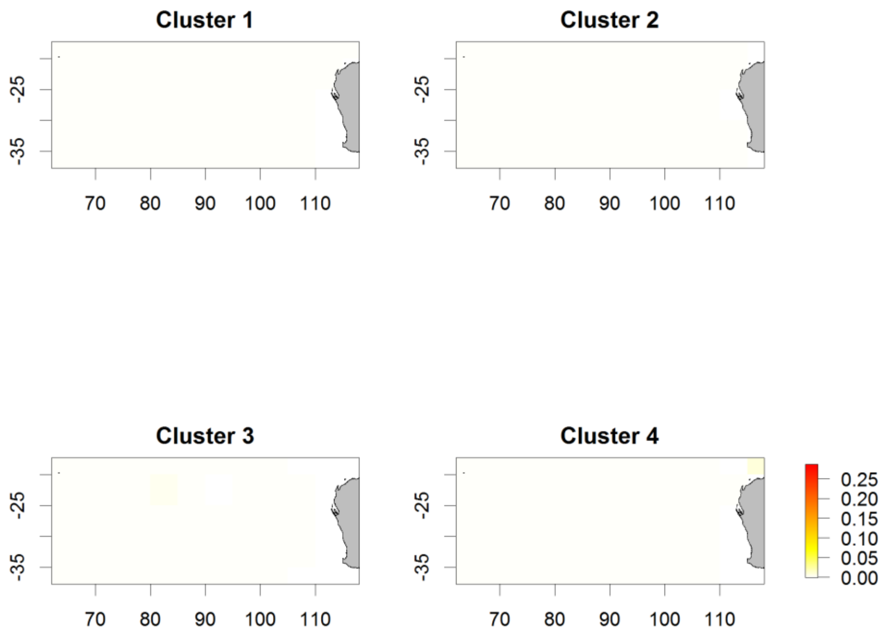
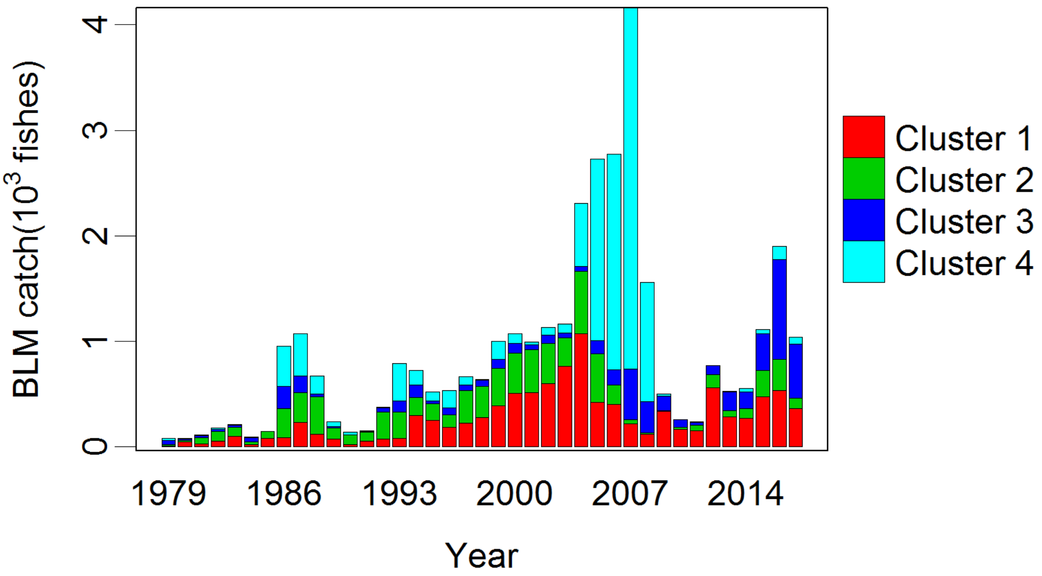


Fig. 3. (Continued).

Area NW



Area NE

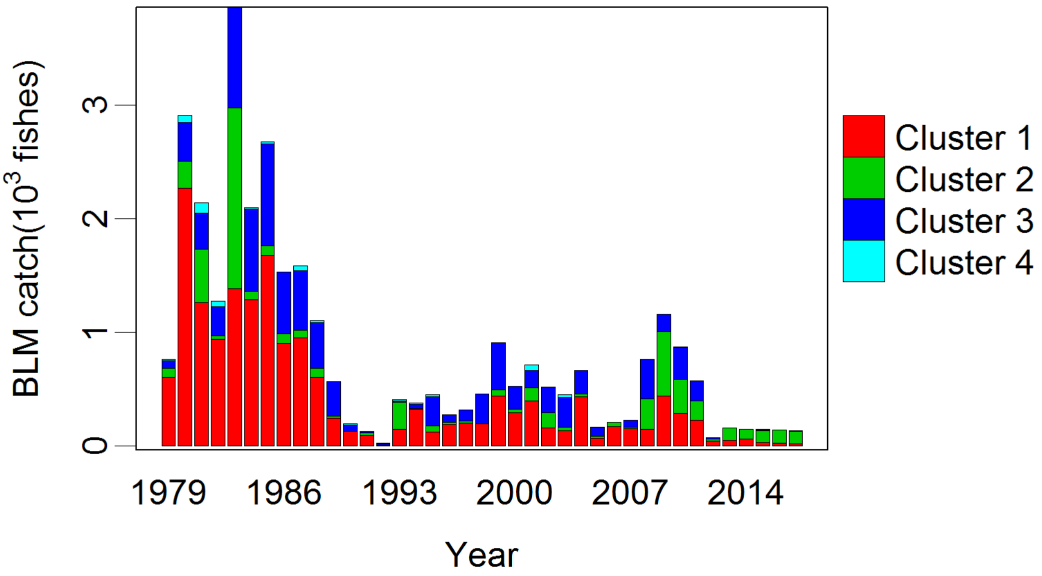
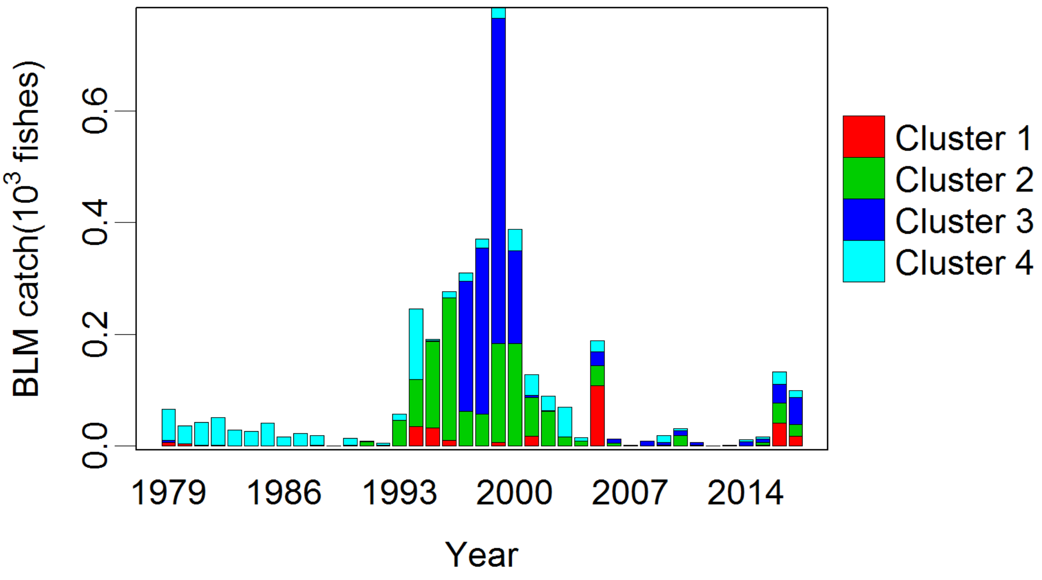


Fig. 4. Annual black marlin catches for each cluster of Taiwanese large scale longline fishery in the Indian Ocean.

Area SW



Area SE

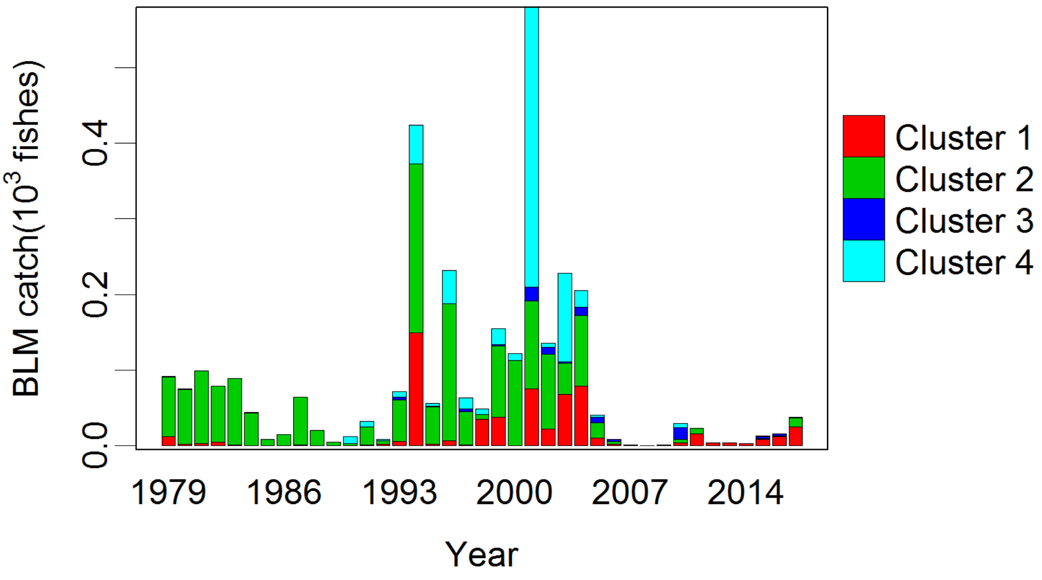
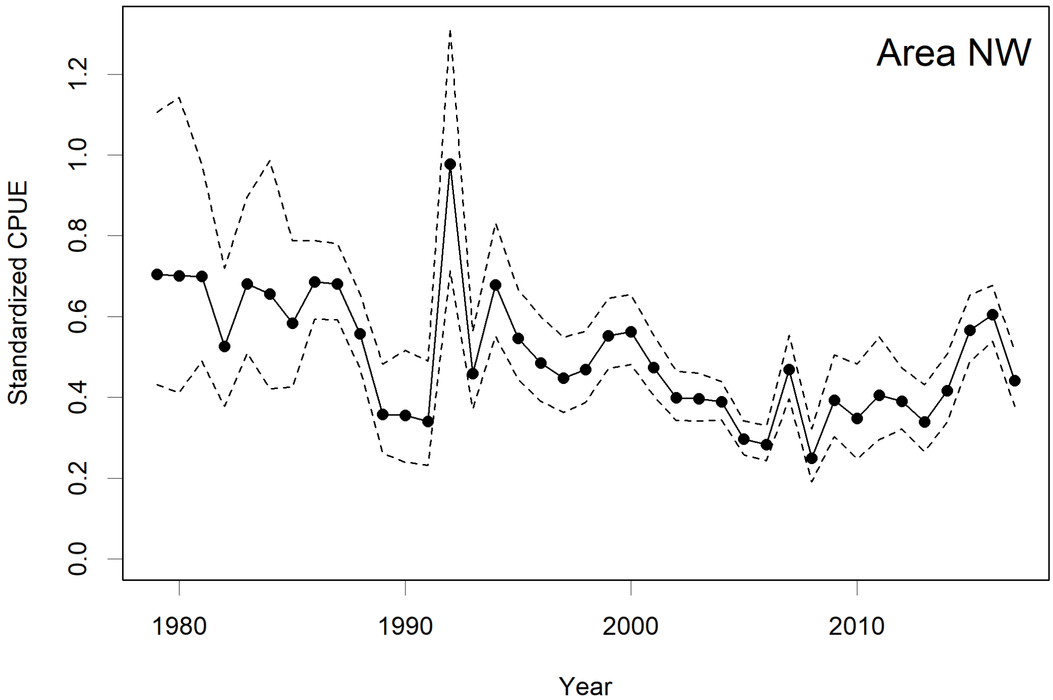


Fig. 4. (Continued).



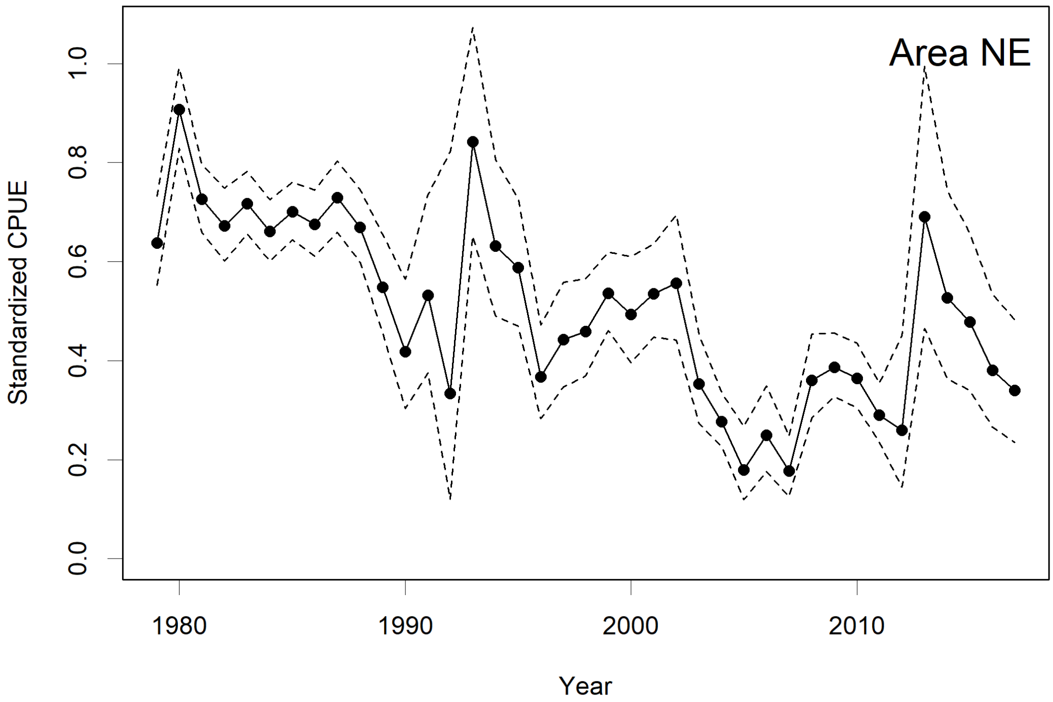


Fig. 5. The trajectory of area-specific standardized CPUE with 95% confidence interval for black marlin caught by Taiwanese large scale longline fishery in the Indian Ocean.

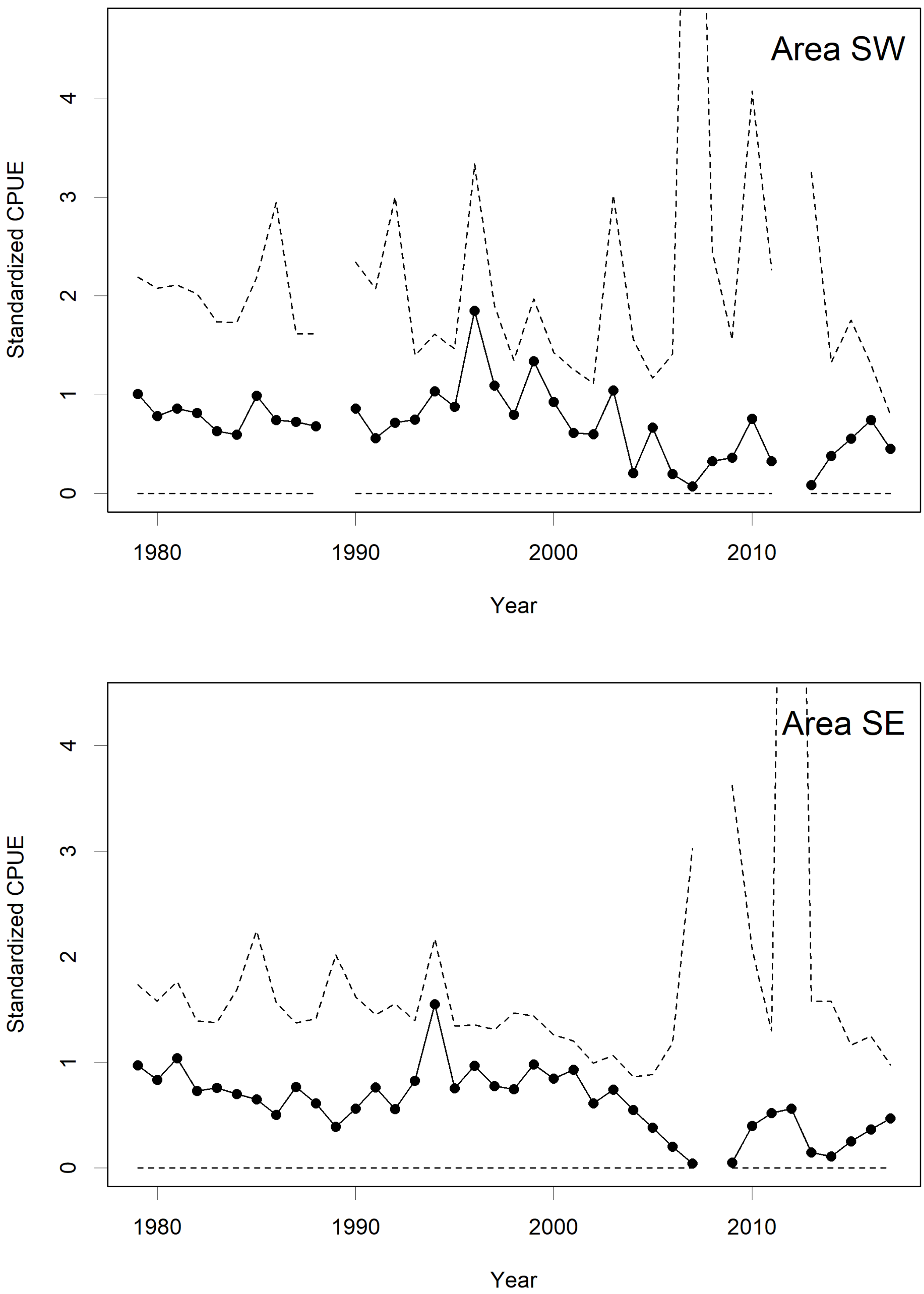


Fig. 5. (Continued).

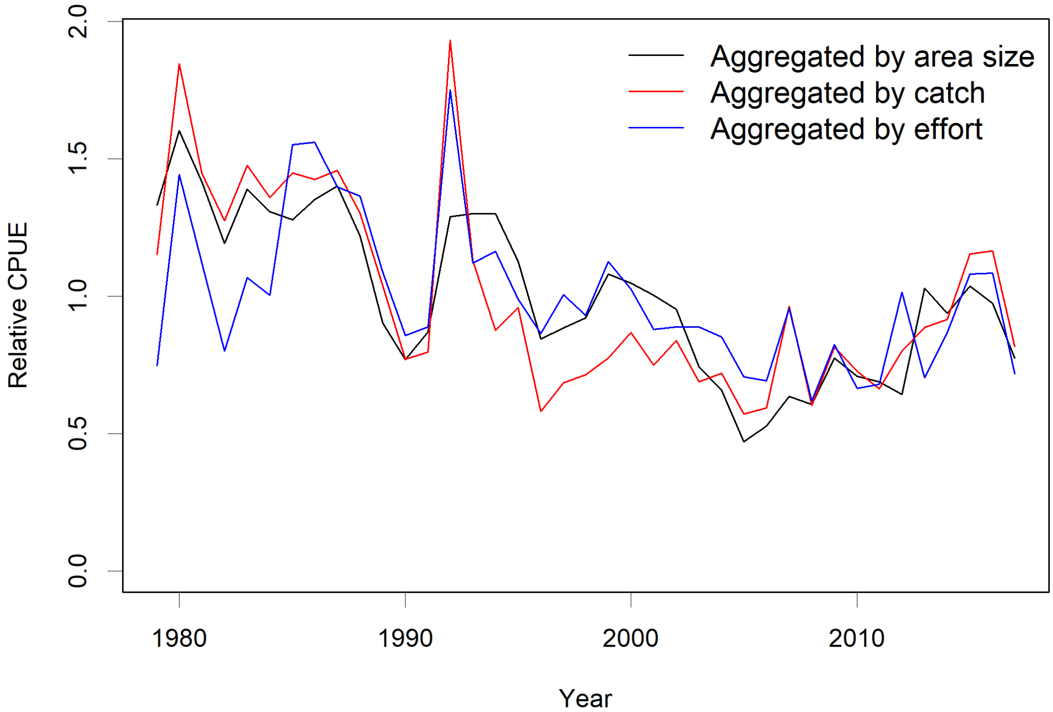
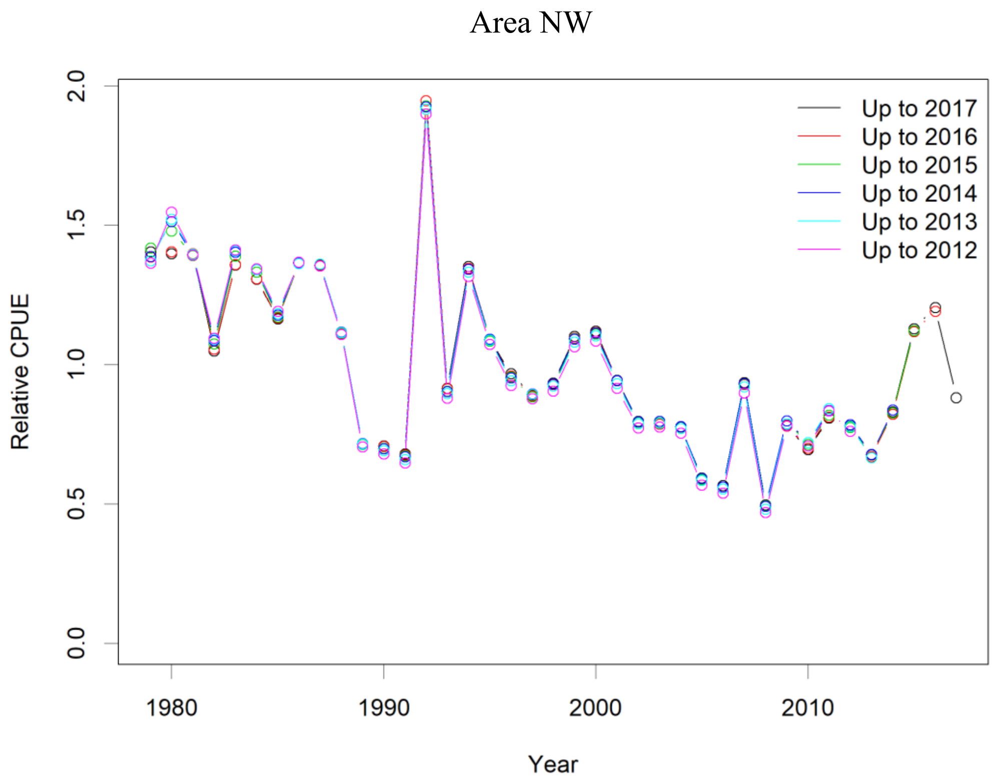


Fig. 6. The trajectory of area-aggregated standardized CPUE with 95% confidence interval for black marlin caught by Taiwanese large scale longline fishery in the Indian Ocean.



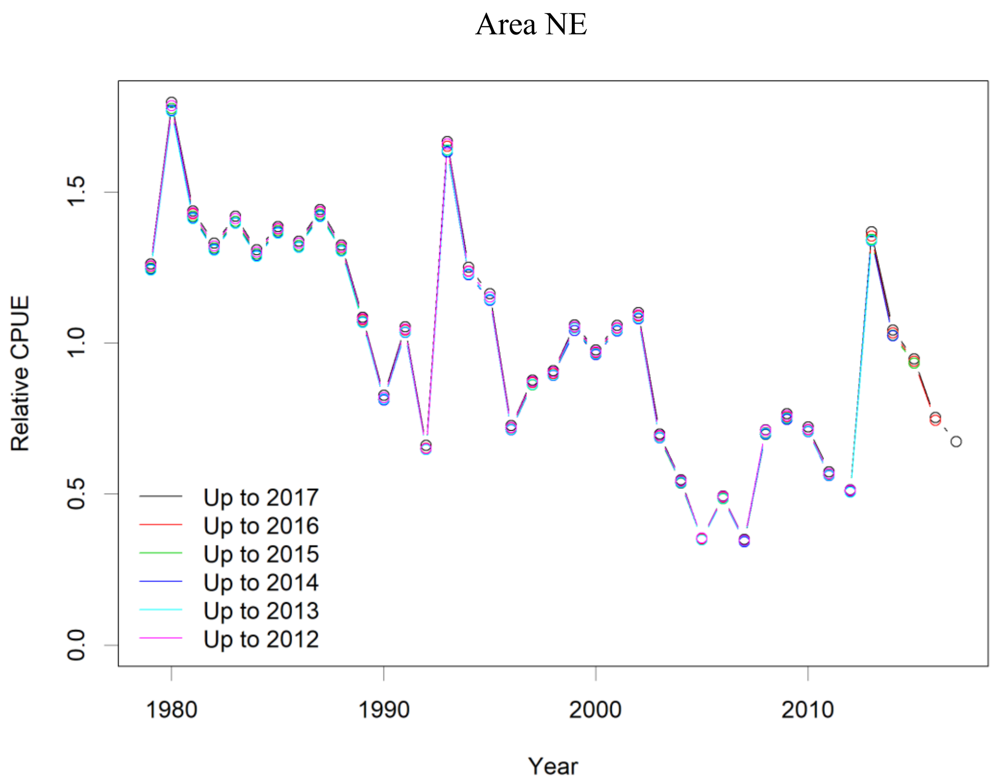
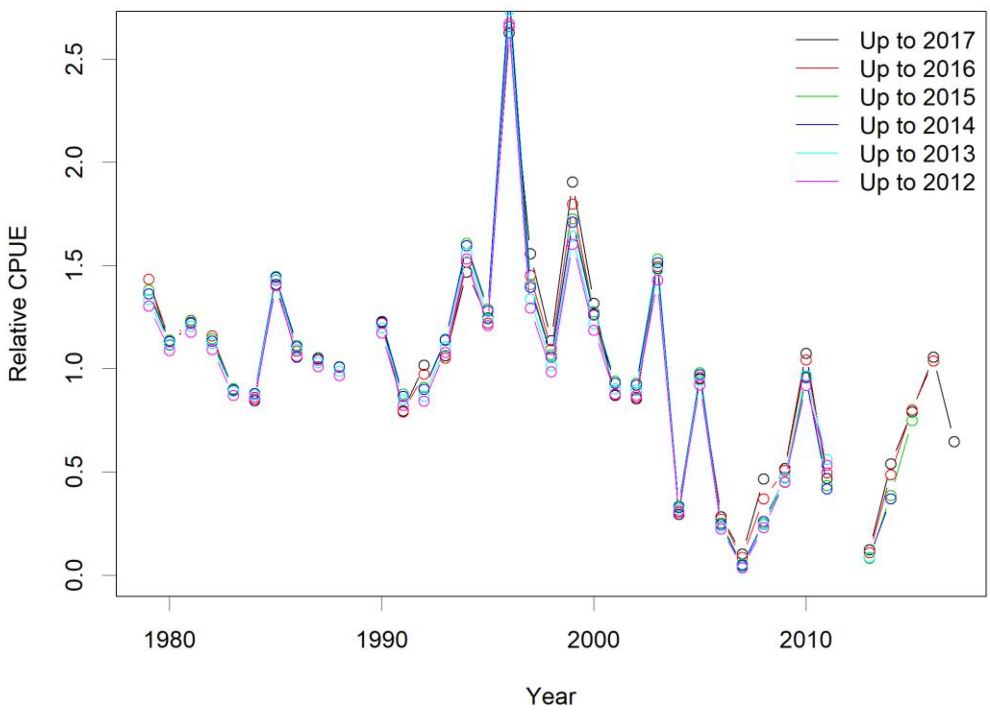


Fig. 7. CPUE standardization with retrospective analysis for black marlin of Taiwan large scale longline fishery in the Indian Ocean.

Area SW



Area SE

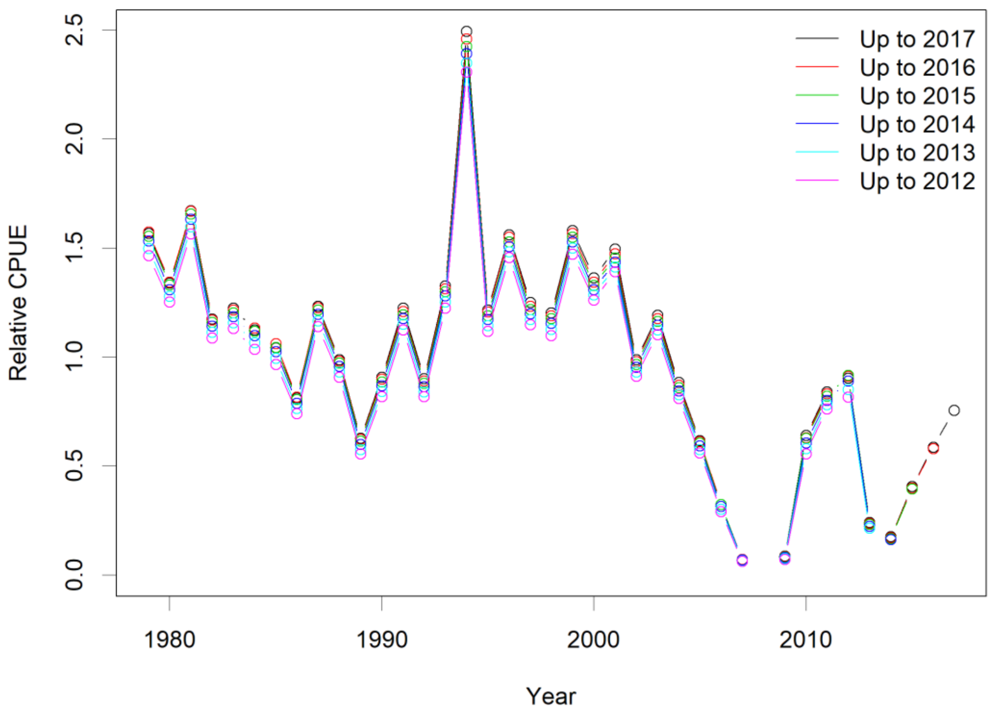


Fig. 7. (Continued).

Table 1. The ANOVA tables for selected gamma models.

Area NW

Variable	SS	Df	F	Pr(>F)
Y	270.7	38	11.1392	< 2.2e-16 ***
M	50.2	11	7.1349	3.06E-12 ***
CT	9.2	2	7.1788	7.64E-04 ***
G	360.1	45	12.5122	< 2.2e-16 ***
T	65.4	3	34.1038	< 2.2e-16 ***
Residuals	14242.2	22269		

Area NE

Variable	SS	Df	F	Pr(>F)
Y	318.8	38	20.572	< 2.2e-16 ***
M	92.4	11	20.607	< 2.2e-16 ***
CT	15.7	3	12.824	2.28E-08 ***
G	790.6	42	46.165	< 2.2e-16 ***
T	35.7	3	29.16	< 2.2e-16 ***
Residuals	8907.7	21845		

Area SW

Variable	SS	Df	F	Pr(>F)
Y	145.45	36	6.051	<2e-16 ***
M	10.76	11	1.4651	1.38E-01
CT	0.54	2	0.4074	6.65E-01
G	121.46	29	6.2727	<2e-16 ***
T	110.96	3	55.3927	<2e-16 ***
Residuals	1310.69	1963		

Area SE

Variable	SS	Df	F	Pr(>F)
Y	98.03	37	10.6927	< 2.2e-16 ***
M	2.91	11	1.067	0.3843
CT	4.74	2	9.5668	7.29E-05 ***
G	25.29	51	2.0013	3.95E-05 ***
T	7.91	3	10.6432	6.03E-07 ***
Residuals	550.8	2223		

Signif. codes: 0 ‘***’ 0.001 ‘**’ 0.01 ‘*’ 0.05 ‘.’ 0.1 ‘ ’ 1

Table 2. The ANOVA tables for selected delta models.

Area NW

Variable	LR Chisq	Df	Pr(>Chisq)
Y	4527.6	38	< 2.2e-16 ***
M	400.1	11	< 2.2e-16 ***
CT	133.7	4	< 2.2e-16 ***
G	5486.1	49	< 2.2e-16 ***
T	146.4	3	< 2.2e-16 ***

Area NE

Variable	LR Chisq	Df	Pr(>Chisq)
Y	5590.9	38	< 2.2e-16 ***
M	1021.8	11	< 2.2e-16 ***
CT	220.1	4	< 2.2e-16 ***
G	3114.4	42	< 2.2e-16 ***
T	192.8	3	< 2.2e-16 ***

Area SW

Variable	LR Chisq	Df	Pr(>Chisq)
Y	613.28	38	< 2.2e-16 ***
M	133.79	11	< 2.2e-16 ***
CT	11.89	3	0.007775 **
G	1081.67	32	< 2.2e-16 ***
T	70.26	3	3.75E-15 ***

Area SE

Variable	LR Chisq	Df	Pr(>Chisq)
Y	1023.55	38	< 2.2e-16 ***
M	144.62	11	< 2.2e-16 ***
CT	17.3	4	1.69E-03 **
G	312.46	54	< 2.2e-16 ***
T	75.11	3	3.43E-16 ***

Signif. codes: 0 ‘***’ 0.001 ‘**’ 0.01 ‘*’ 0.05 ‘.’ 0.1 ‘ ’ 1