CPUE standardization of striped marlin (*Tetrapturus audax*) caught by Taiwanese large scale longline fishery in the Indian Ocean

Wen-Qi Xu, Sheng-Ping Wang*, Chih-Yu Lin

Department of Environmental Biology and Fisheries Science, National Taiwan Ocean University, Keelung, Taiwan.
* Corresponding author: wsp@mail.ntou.edu.tw

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ABSTRACT

This study aggregated and analyzed catch, effort and length data of striped marlin caught by Taiwanese large longline fisheries in the Indian Ocean and conducted CPUE standardization for striped marlin for 1979-2020 and 2005-2020. This paper briefly describes historical patterns of fishing operations and striped marlin catches caught by Taiwanese large scale longline in the Indian Ocean. The groups of data sets derived from cluster analysis based on species compositions were incorporated in the CPUE standardization models as a covariate for explaining the target to obtain the relative abundance indices for further stock assessments. Except for the delta-lognormal models, the standardized CPUE series obtained from different model assumptions revealed similar trends.

INTRODUCTION

Striped marlin is largely considered to be the bycatch species of industrial fisheries. Most of the striped marlin were caught by the longline fishery before the mid-1990s. Thereafter, gillnet catches have gradually increased while longline catches have gradually decreased. In recent years, the proportion of gillnet catches has surpassed that of the longline fishery. Gillnets account for around 50% of total catches in the Indian Ocean between 2014 and 2018, followed by longlines (40%). The remaining catches are mostly recorded under troll and handlines. The catch trends of striped marlin in the Indian Ocean varied, ranging from 2,000 t to 8,000 t per year. In particular, catches reported under longlines highly varied, with lower catch levels between 2009 and 2011 largely due to declining catches reported by Taiwan. Since 2012, catches of striped marlin have fluctuated between 3,000 t to 5,000 t (IOTC, 2020).

The striped marlin were mainly caught by Taiwan and Japan. Before the 1970s, Japan was the main country for the striped marlin. Thereafter, Taiwan catches increased significantly and became the most important country for striped marlin in the Indian Ocean. In recent years, catches of striped marlin have increased by Indonesian fisheries and small-scale longlines fisheries, which occupied a very important proportion. The distribution of striped marlin catches has changed since the 1980s with most of the catches now taken in the north-west Indian Ocean. In recent years, the catches of striped marlin caught by Taiwan and Japan revealed a decreasing trend, and the reason is still unclear. However, changes in fishing grounds and catches are thought to be related to changes in access agreements to the EEZs of coastal countries in the Indian Ocean instead of changing in the distribution of the species over time. In recent years, striped marlin catches were mainly made by Iran (gillnet, 25%), Taiwan (longline, 20%), Indonesia (longline, 18%), and Pakistan (gillnet, 12%) (IOTC, 2020).

Since the current stock status of striped marlin was pessimistic and may still be uncertain (IOTC, 2018), this study conducted CPUE standardization for striped marlin in the Indian Ocean for providing the relative abundance indices for further stock assessments.

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 1979-2020 were provided by Oversea Fisheries Development Council of Taiwan (OFDC). For the area stratification, this study adopted the four areas stratification for swordfish by Wang and Nishida (2011) (Fig. 1). For conducting the cluster analysis prior to the CPUE standardizations, the data were aggregated by 10-days duration (1st-10th, 11th-20th, and 21st~ for each month) (Kitakado et al., 2021).

2.2. CPUE Standardization

A large amount of zero-catches was recorded in the operational catch and effort data sets because striped marlin was caught as the bycatch species of Taiwanese longline fishery in the Indian Ocean. Historically, ignoring zero observations or replacing them by a constant was the most common approach. An alternative and popular way to deal with zeros was through the delta approach (Hinton and Maunder, 2004; Maunder and Punt, 2004). IOTC (2016) also noted the use of the delta approach to accommodate the high proportion of zero catches. Therefore, the delta-general linear models with different assumptions of error distribution were applied to conduct the CPUE standardization of striped marlin in the Indian Ocean (Pennington, 1983; Lo et. al., 1992; Pennington, 1996; Andrade, 2008; Lauretta et al., 2016; Langley, 2019).

As the approach of Wang (2018), the models were simply conducted with the main effects of year, quarter, longitude, latitude and fishing targeting (clusters), while interactions between main effects were not incorporated into the models. The models for positive catches and delta model were conducted as follows:

For CPUE of positive catches:

$$Catch = \mu + Y + Q + CT + Lon + Lat + T + offset(\log(Hooks)) + \varepsilon^{pos}$$

For delta model:

$$PA = \mu + Y + Q + CT + Lon + Lat + T + \varepsilon^{del}$$

where	*Catch*	is the catch in number/1,000 hooks
	PA	is the presence/absence of catch,
	Hooks	is the effort of 1,000 hooks,
	μ	is the intercept,
	Y	is the effect of year,
	Q	is the effect of quarter,
	CT	is the effect of vessel scale,
	Lon	is the effect of longitude,
	Lat	is the effect of latitude,
	T	is the effect of targeting (cluster),
	ε^{pos}	is the error term assumed based on various distribution,
	ε^{del}	is the error term, ε^{del} ~ Binomial distribution.

To examine the appropriateness of the assumption of error distribution, this study applied normal, poisson, gamma, negative-binomial and tweedie distributions to the error distribution of the model for the positive catches and specified “log” for the model link function. For the model with tweedie distribution, the index of power variance function was tested using values of 1.1-1.9.

The stepwise searches (“both” direction, i.e. “backward” and “forward”) based on the values of Akaike information criterion (AIC) were performed for selecting the explanatory variables for each model. Then, the coefficient of determination (R^2), and Bayesian information criterion (BIC) were calculated for the models with selected explanatory variables. The AIC and BIC, which were calculated based on the likelihoods with full constants obtained glm() and glm.nb(), were used to compare the models with different error distributions (e.g. Setyadji et al., 2019). In addition, the dispersion statistics for Pearson residuals were calculated to check whether under- or overdispersions resulted from the models with an assumed error distribution.

The standardized CPUE were calculated based on the estimates of least square means of the interaction between the effects of year and area, and calculated by the product of the standardized CPUE of positive catches and the delta model:

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

where DL^{index} is the standardized CPUE

2.3 Time series of data for analysis

As the suggestion of WPTT (IOTC, 2021), Taiwanese data before 2005 were recommended not using to analyze the targeting of fishing operations and conduct the CPUE standardization for tropical tunas due to the problem of data quality. However, the influence of the data problem might not only occur for the catches of major tuna species but also for the catch and effort data for other species. Therefore, CPUE standardizations were conducted using the data from 1979 to 2020 and from 2005 to 2020 for the use of further stock assessments.

RESULTS AND DISCUSSION

3.1 Historical fishing trends

Fig. 2 and Fig. 3 show the striped marlin catch in numbers and nominal CPUE distribution based on the logbook data of Taiwanese large scale longline fishery in the Indian Ocean aggregated by 5 years. Striped marlin were mainly caught in tropical and coastal waters of the northern Indian Ocean. Although the amount of fish caught in the southern Indian Ocean increased significantly during the 1990s and 2000s due to the increase of effort, the distribution of high CPUE over the years was still limited to the coastal waters of the northern Indian Ocean.

Striped marlin catches were mainly made with high effort in northern waters, especially for the northwestern fishing area (NW). Although the catches in the northwestern Indian Ocean increased significantly around 2005, the catches substantially decreased in the following years (Fig. 4 and Fig. 5).

According to the analysis of the length-frequency data by year, month, longitude and latitude (Fig. 6), the central tendency has no obvious change, but the degree of dispersion increases significantly between 40°E and 90°E, that is more large and small fish were caught.

3.2. CPUE standardization

CPUE standardizations were separately performed for only northern areas (Fig. 1) since the catches and CPUE of striped marlin in the southern areas were substantially lower than those in the northern areas, especially for recent decades (Figs. 2 and 3).

3.2.1 Time series from 1979 to 2020

In this study, the positive catch and delta models were selected based on AIC. All factors were remained in the models for all fishing areas and were statistically significant. In terms of the positive catch model, AIC, BIC and dispersion statistics for Pearson residuals show that the models with Gamma distributed error were the optimal models for all fishing areas although the values of R^2 were not higher than other models (Table 1). In addition, the residual diagnostic plots also show that the models with Gamma distributed error should be more suitable than other models because the residual error did not obviously increase or decrease with the predicted values within the range of the predicted values (Fig. 7). Since there were too many diagnostic plots for each model in all fishing areas, only the plots for the models with Gamma distributed error were presented in Fig. 7 but diagnostic plots for other models in all fishing areas show that the residuals have clear patterns with the predicted value. Therefore, the results of the delta-gamma model were selected to provide the standardized CPUE series for the use of further stock assessments.

Table 2 shows the ANOVA table for the selected model for each fishing area. The targeting effects were the most explanatory for the CPUE variation of the positive catch models. For the delta models, the most important explanatory effects were latitude effects except for the year effects. Therefore, the catch rate of the positive catch of the striped marlin may be affected by the strategy of the targeting species, and the latitude of the fishing operation may affect the probability of catching the striped marlin.

Fig. 8 shows the standardized CPUE trends obtained from various models. Except for the delta-lognormal models, the trends obtained from the other models were quite similar. Fig. 9 shows trends of the standardized CPUE of the selected model. The CPUE in the northern Indian Ocean (NW and NE) revealed similar trends, which fluctuated in the early 1980s but showed obviously decreasing trends thereafter. After an increase in 2013, the CPUE decreased again in recent years.

3.2.2 Time series from 2005 to 2020

According to the model selection of AIC for positive catch and delta models by fishing areas, some effects were excluded since they cannot provide a significant improvement to AIC. In terms of the positive catch models, AIC, BIC and dispersion statistics for Pearson residuals show that the models with Gamma distributed error is the optimal models in all fishing areas, although the values of R^2 were not higher than other models (Table 3). In addition, the residual diagnosis plots also show that the models with Gamma distributed error should be more appropriate than other models (Fig. 10, only the plots for the models with Gamma distributed error were presented). Therefore, the delta-gamma models were selected to provide the standardized CPUE series for the use of further stock assessments.

Table 4 shows the ANOVA table for the selected models of each fishing area. Similarly, the targeting effects were still the most explanatory variables for the positive catch models and the latitude effects were the most important explanatory variables for delta models.

Also, the standardized CPUE series obtained from various models revealed similar trends except for the delta-lognormal models (Fig. 11). The standardized CPUE of the selected models showed similar trends in the northern Indian Ocean (NW and NE). CPUE trends were relatively stable before 2010 and decreased sharply after a peak occurred in 2013.

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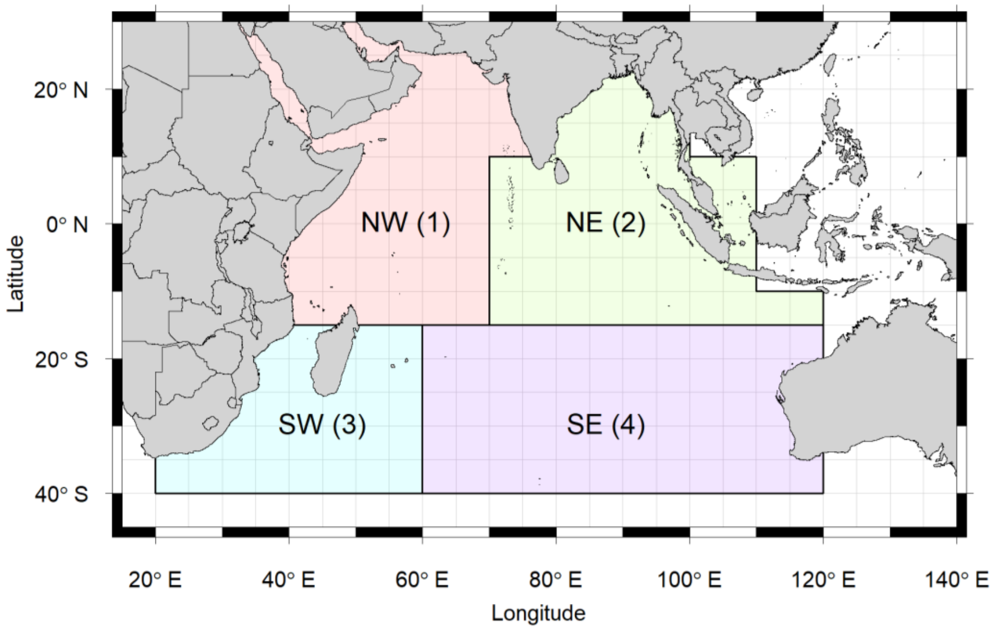


Fig. 1. Area stratification for swordfish in the Indian Ocean.

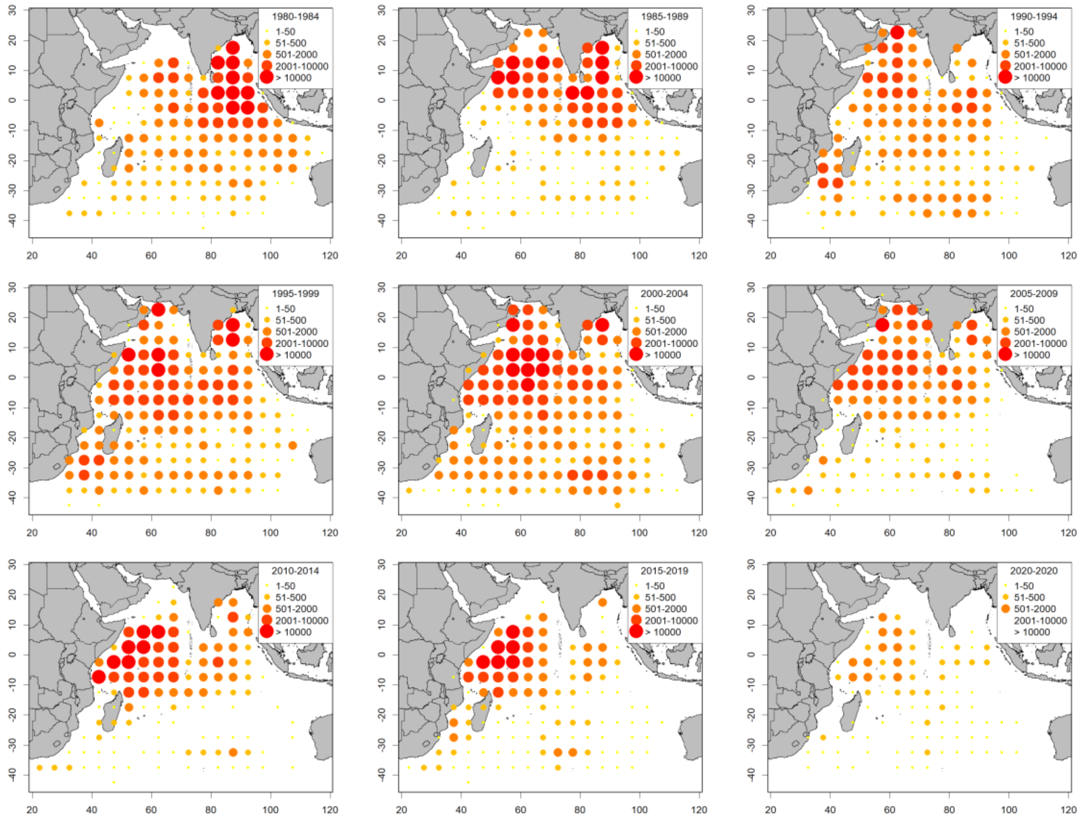


Fig. 2. Striped marlin catch distribution of Taiwanese large scale longline fishery in the Indian Ocean.

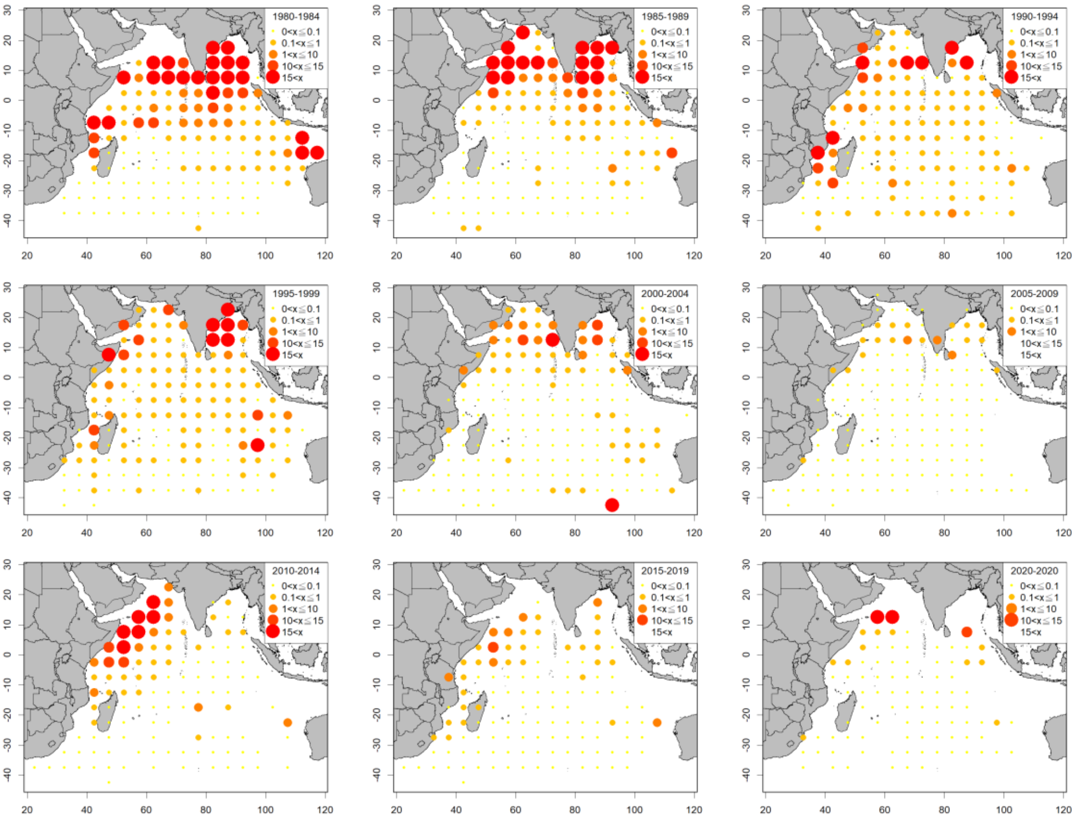


Fig. 3. Striped marlin CPUE distribution of Taiwanese large scale longline fishery in the Indian Ocean.

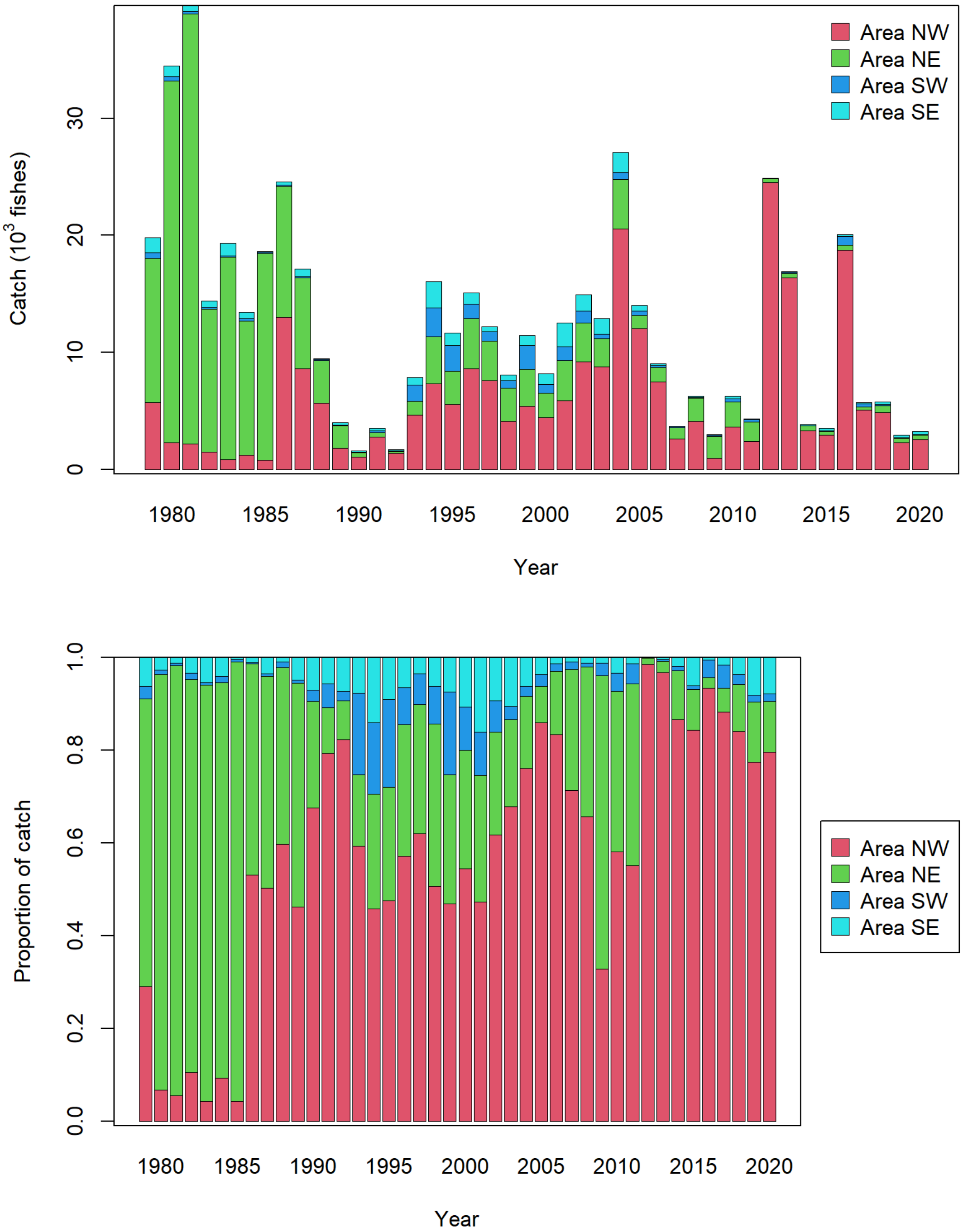
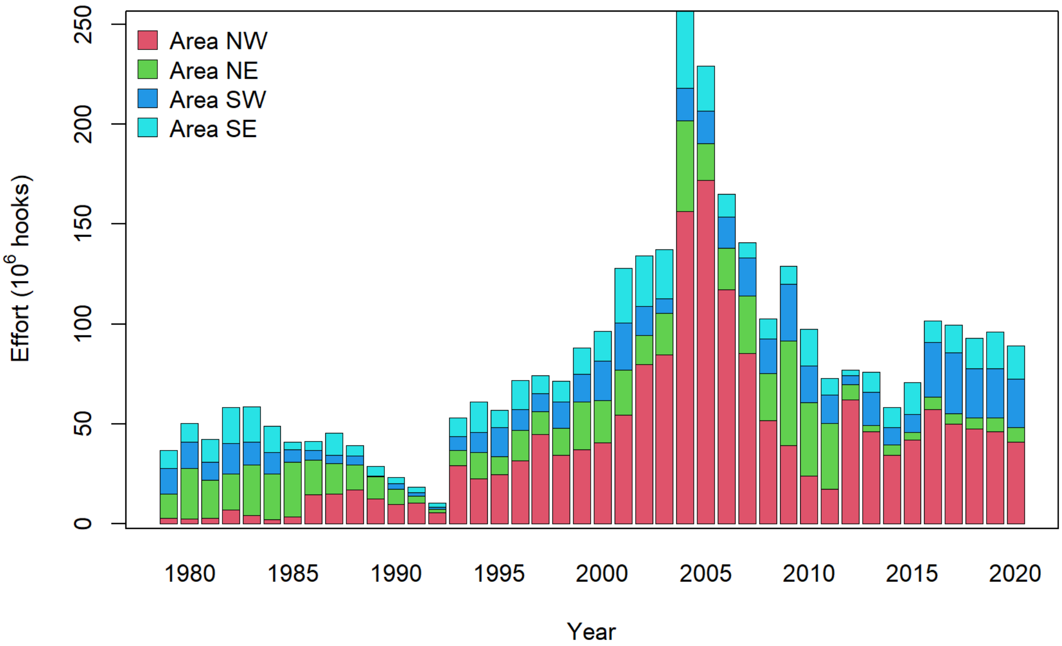


Fig. 4. Annual striped marlin catches of Taiwanese large scale longline fishery in the defined billfish area the Indian Ocean.



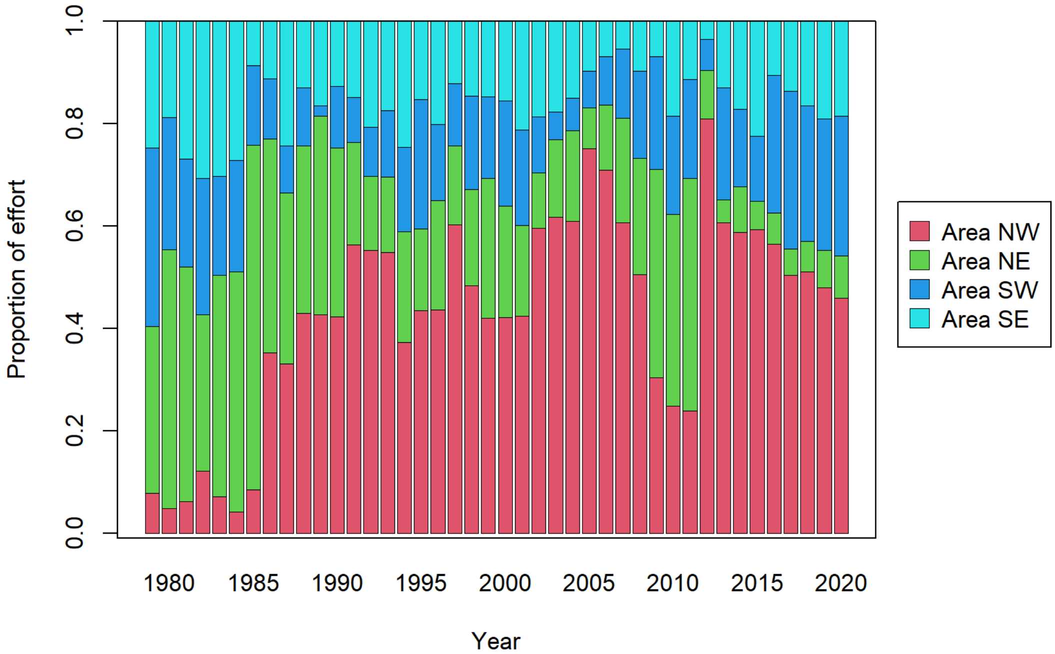


Fig. 5. Annual efforts (number of hooks) of Taiwanese large scale longline fishery in the defined billfish area the Indian Ocean.

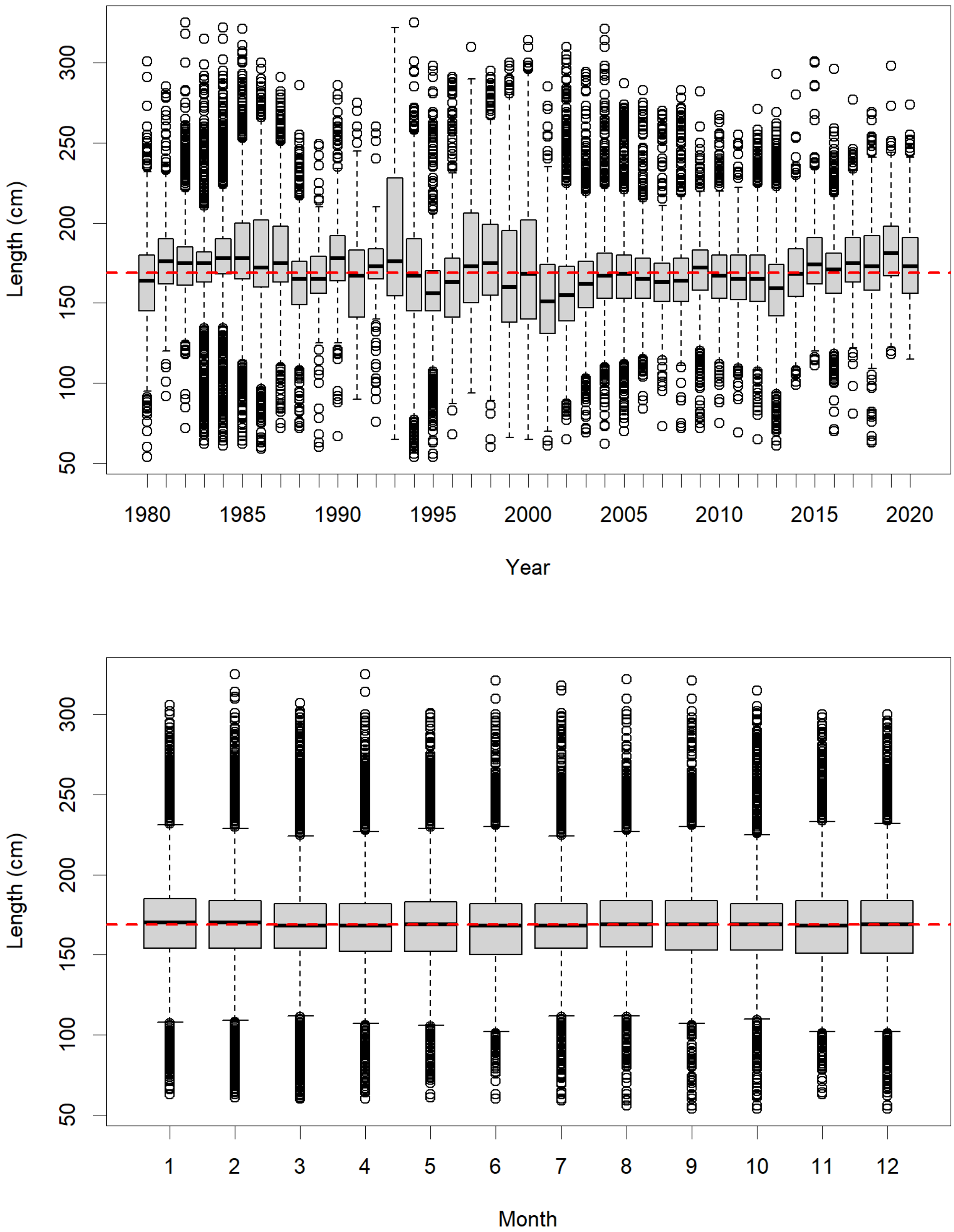
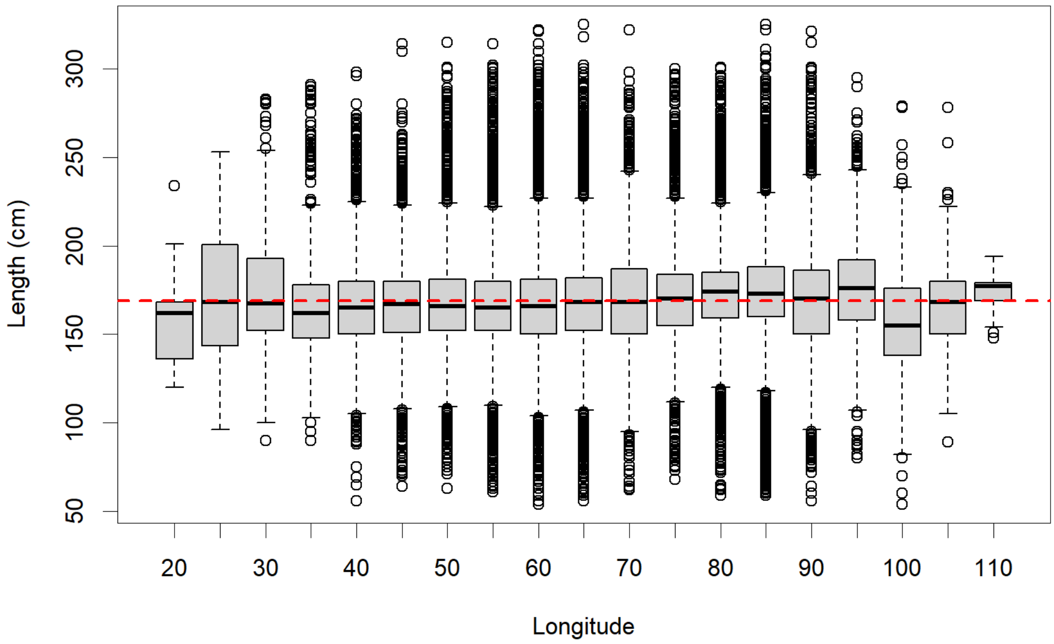


Fig. 6. The trend of the boxplot for the length data of striped marlin of Taiwanese large scale longline fishery in the Indian Ocean.



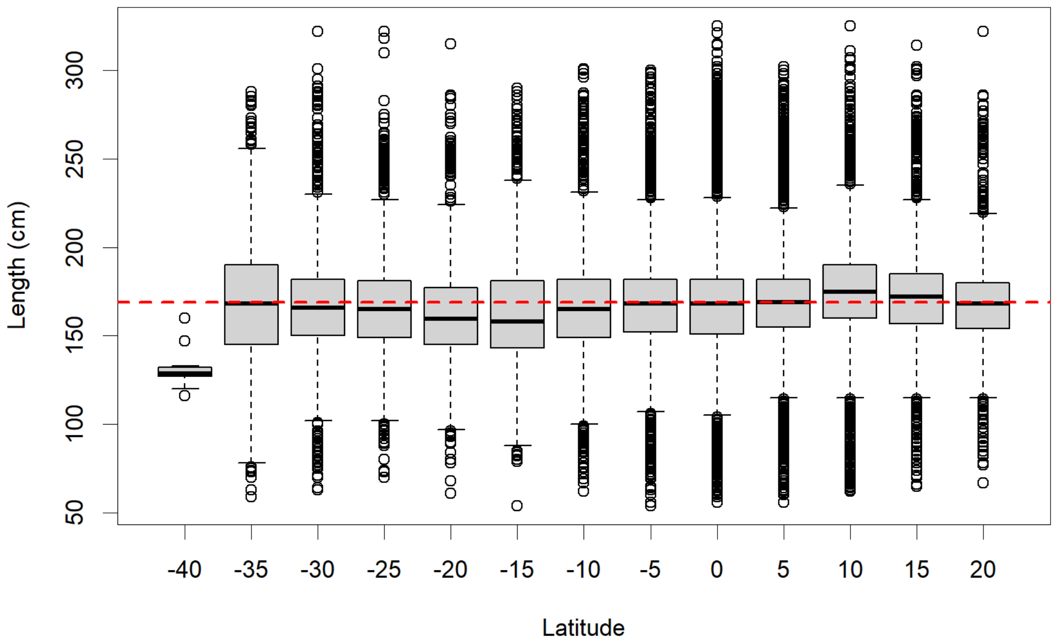


Fig. 6. (continued).

NW

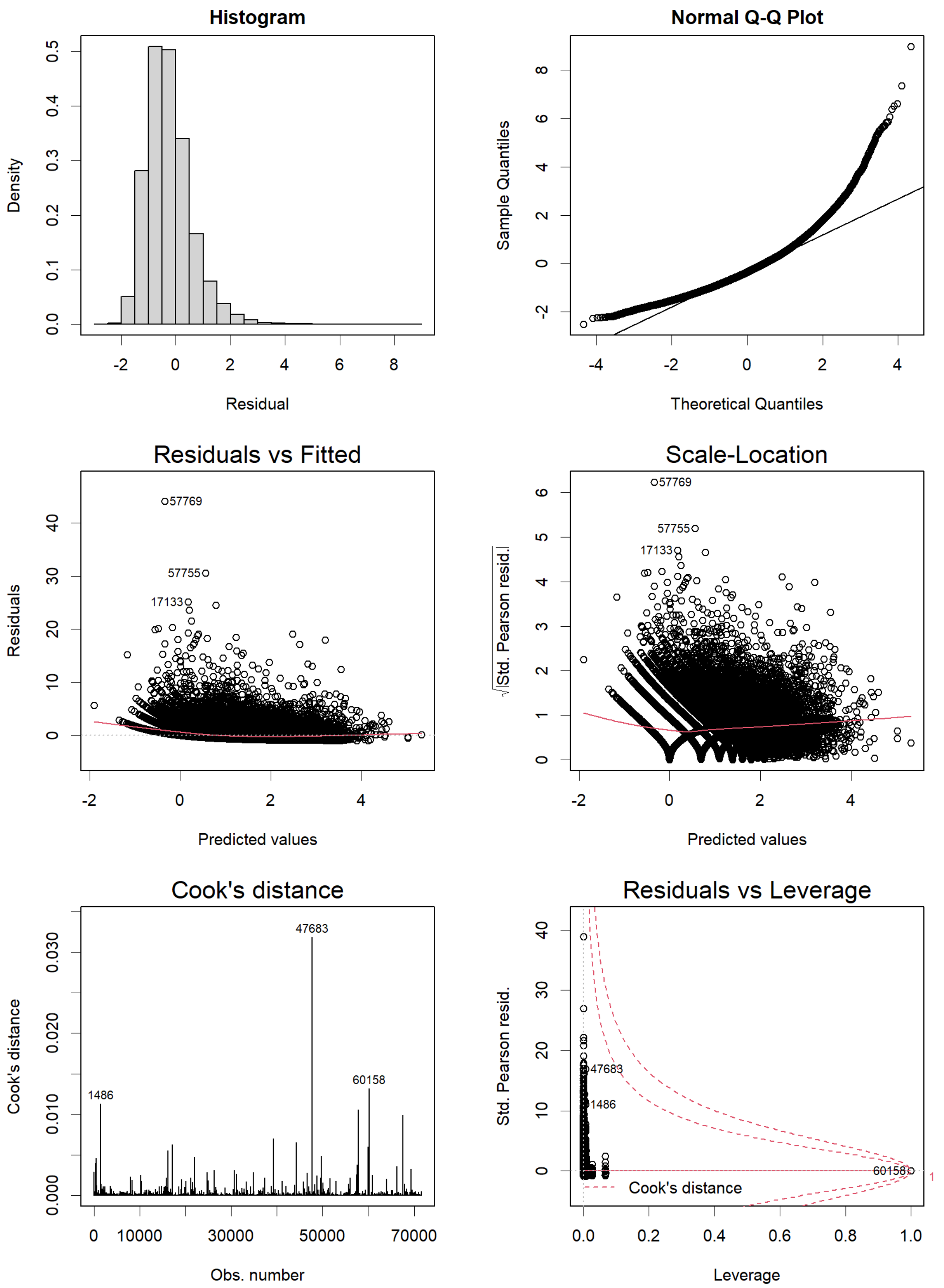


Fig. 7. Diagnostic plots for GLMs with gamma error distribution assumption for striped marlin caught by Taiwanese large scale longline fishery in the Indian Ocean from 1979 to 2020.

NE

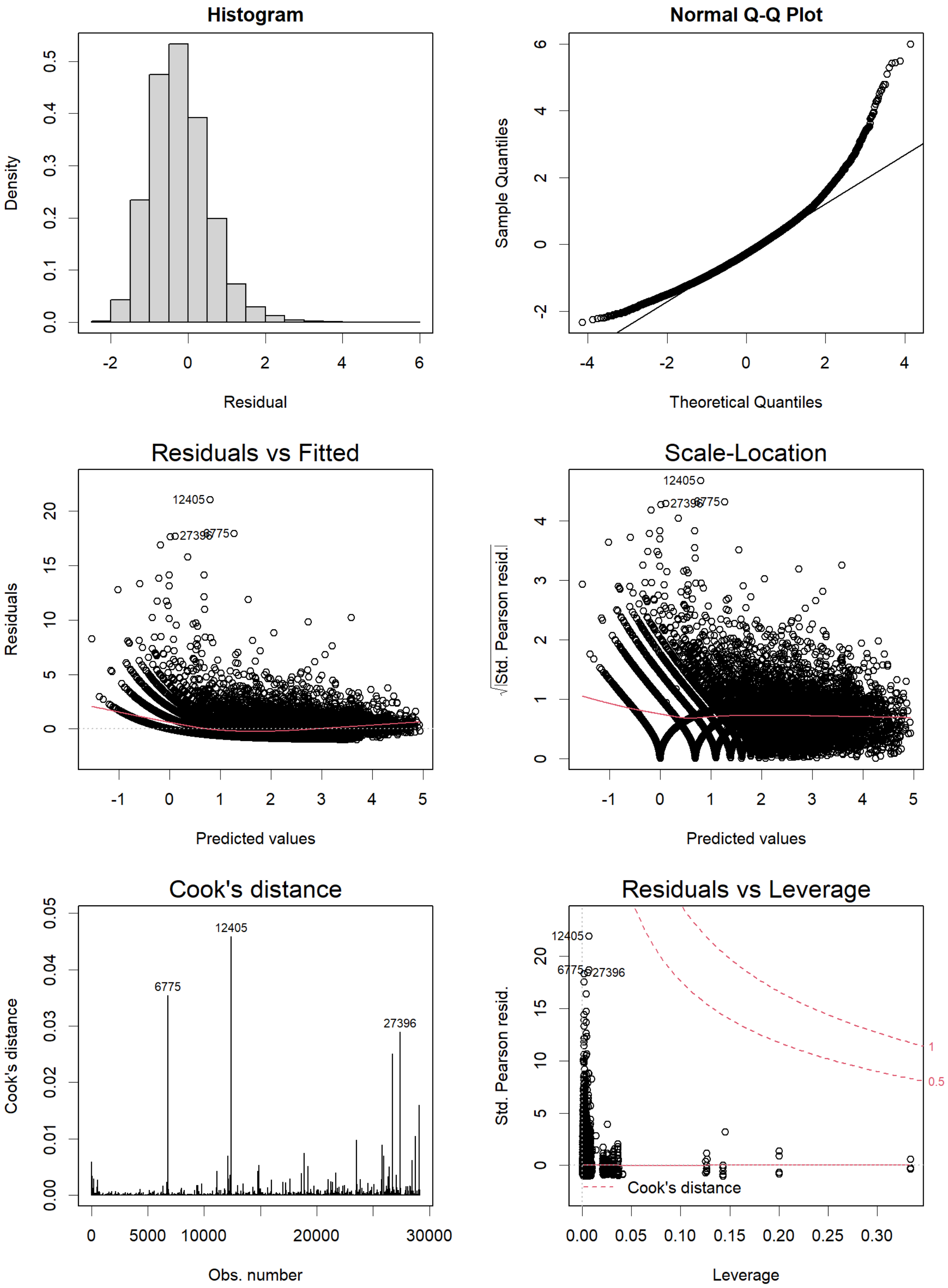
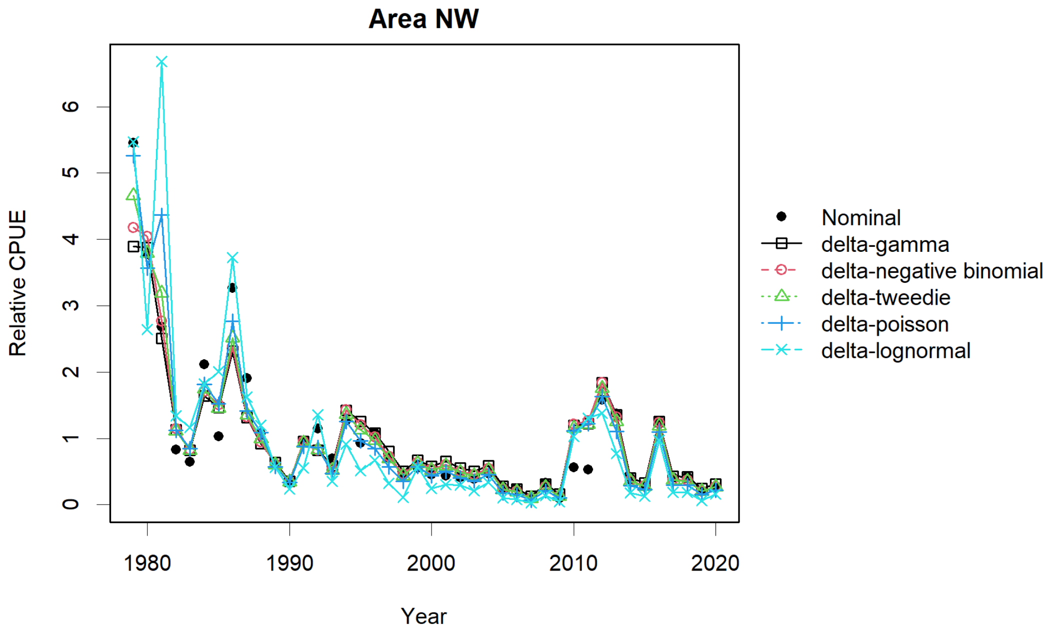


Fig. 7. (continued).



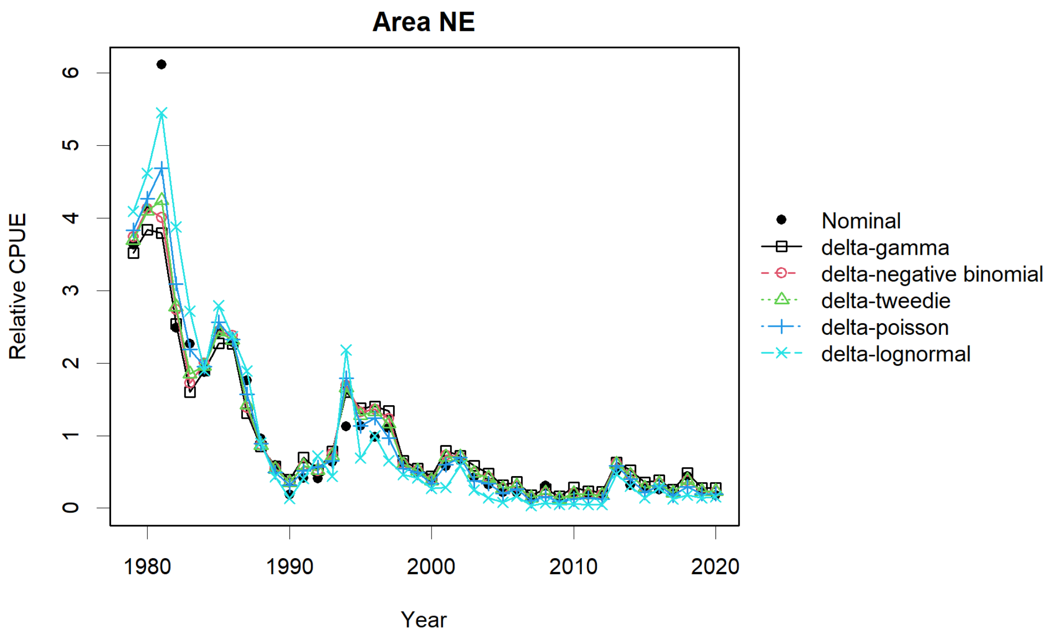
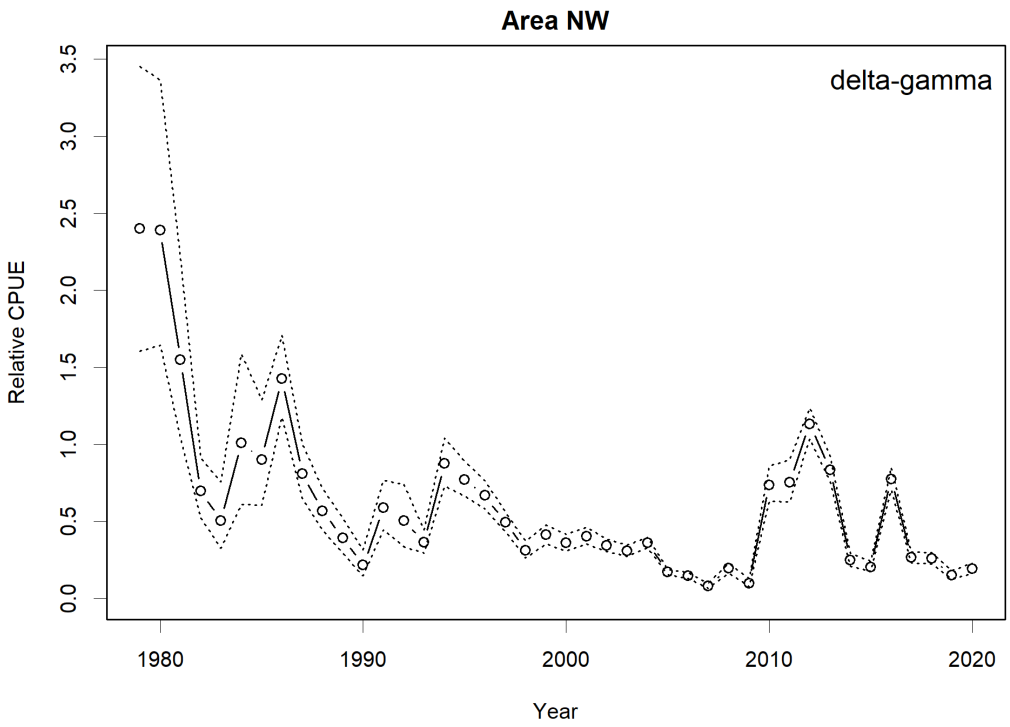


Fig. 8. Standardized CPUE series based on various GLMs for striped marlin caught by Taiwanese large scale longline fishery in the Indian Ocean from 1979 to 2020.



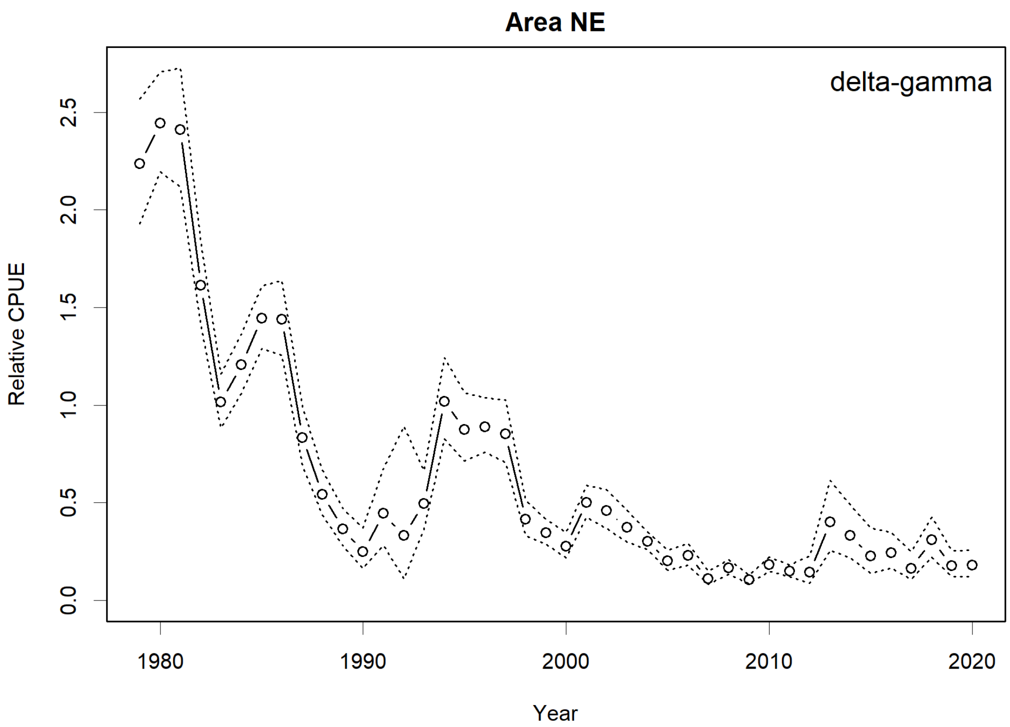


Fig. 9. Standardized CPUE series based on selected GLMs for striped marlin caught by Taiwanese large scale longline fishery in the Indian Ocean from 1979 to 2020.

NW

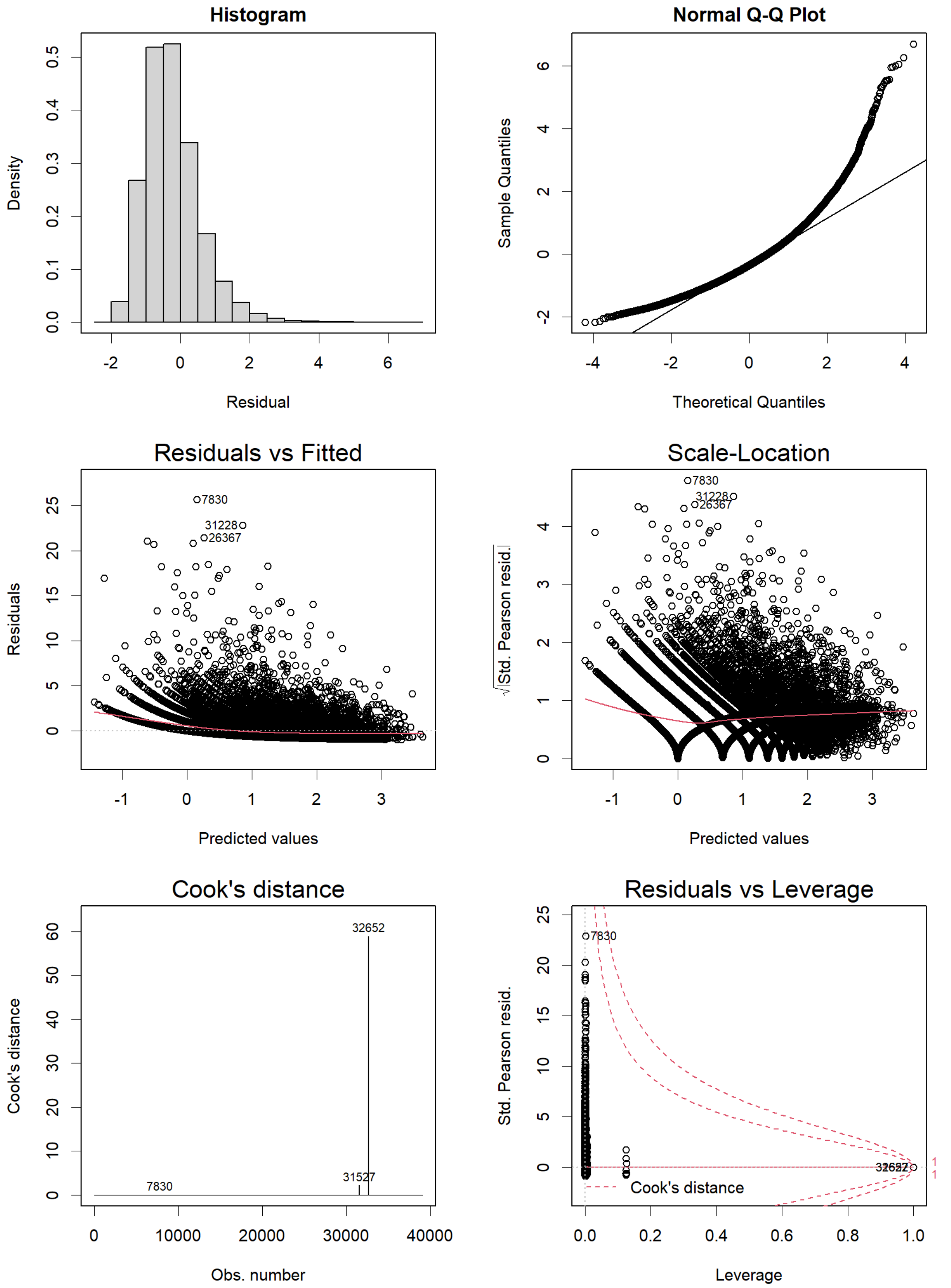


Fig. 10. Diagnostic plots for GLMs with gamma error distribution assumption for striped marlin caught by Taiwanese large scale longline fishery in the Indian Ocean from 2005 to 2020.

NE

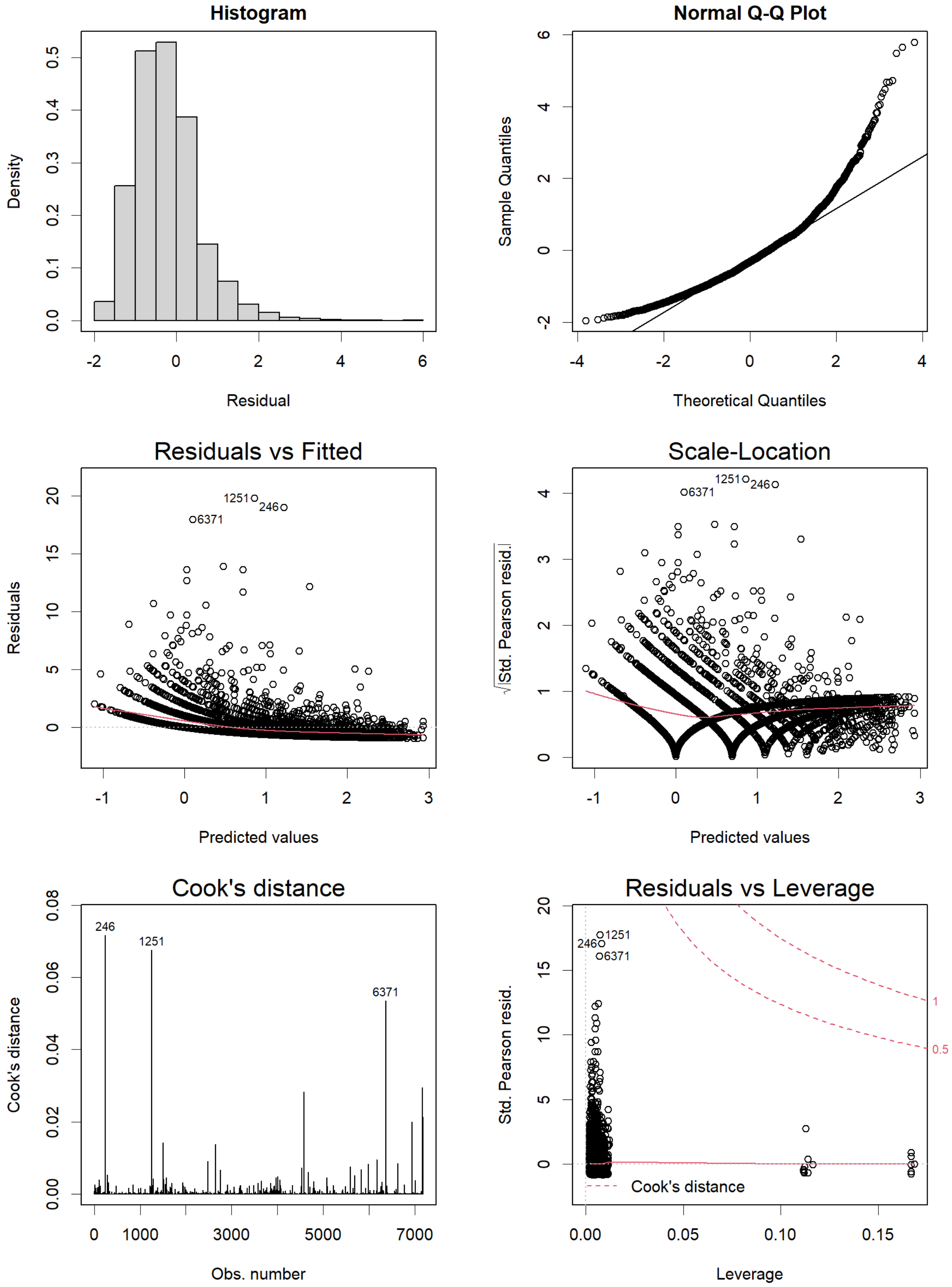
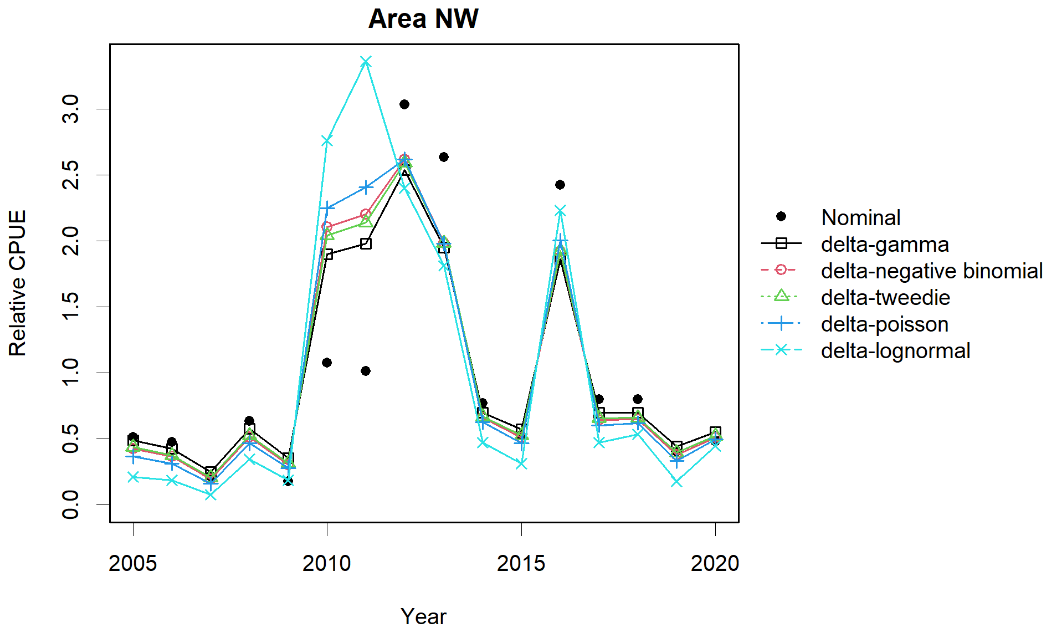


Fig. 10. (continued).



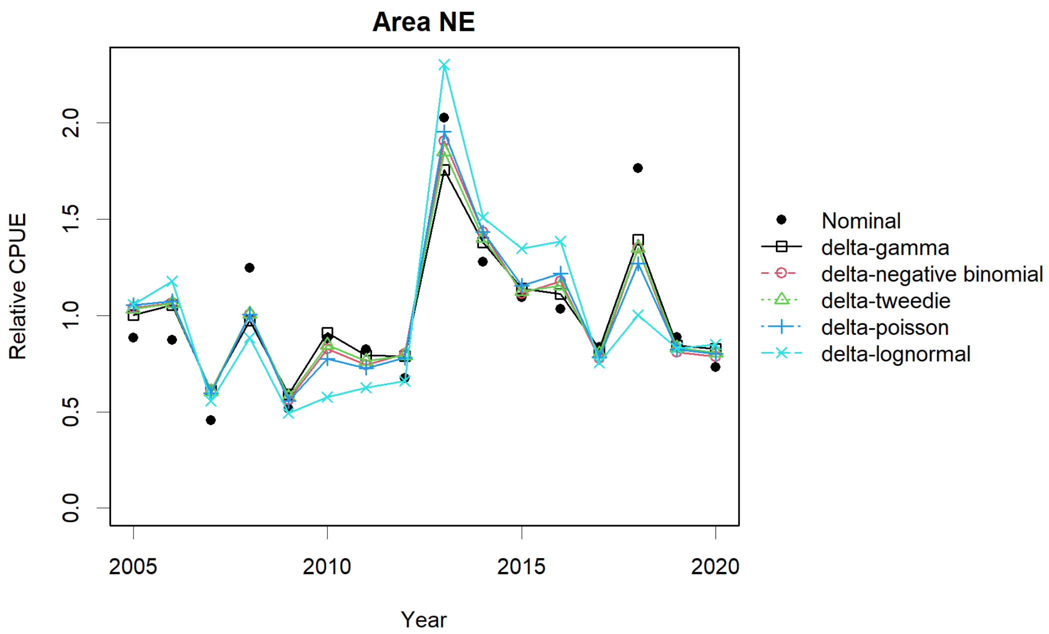
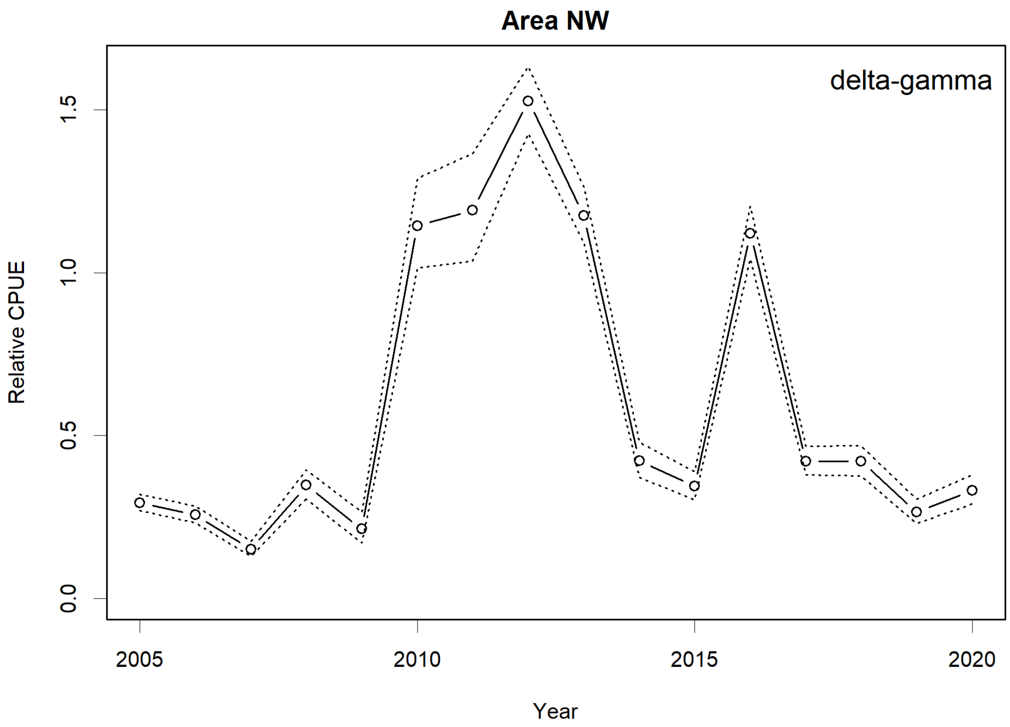


Fig. 11. Standardized CPUE series based on various GLMs for striped marlin caught by Taiwanese large scale longline fishery in the Indian Ocean from 2005 to 2020.



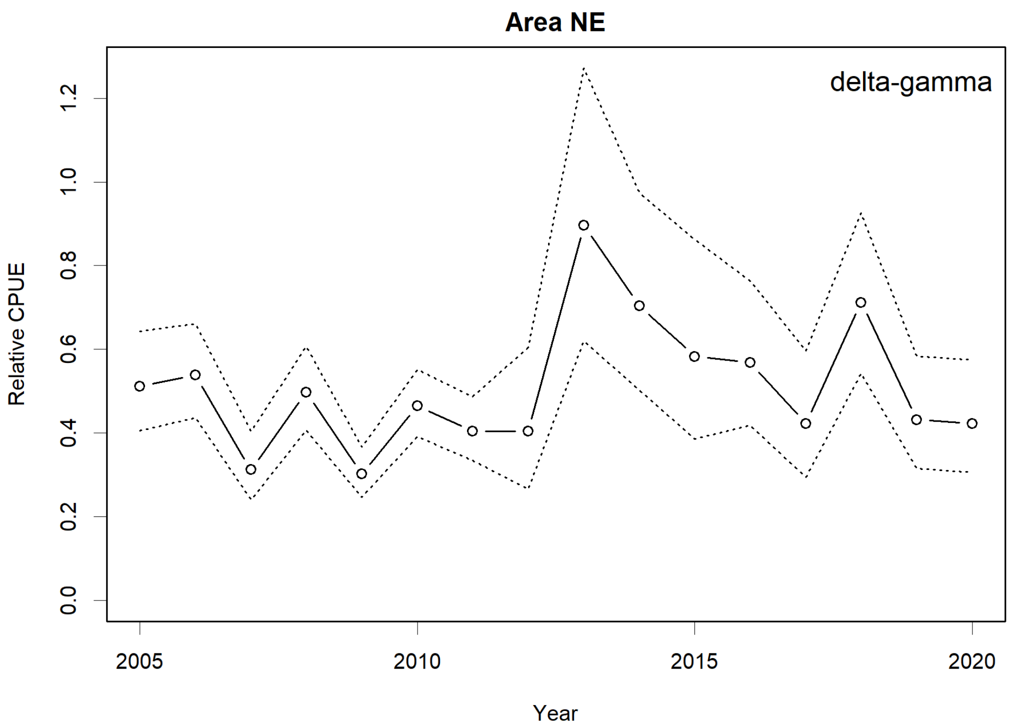


Fig. 12. Standardized CPUE series based on selected GLMs for striped marlin caught by Taiwanese large scale longline fishery in the Indian Ocean from 1979 to 2020.

Table 1. Diagnostic statistics for standardized CPUE series based on various GLMs for striped marlin caught by Taiwanese large scale longline fishery in the Indian Ocean from 1979 to 2020.

Area	Model	R2	AIC	BIC	Dispersion
NE	gamma	0.496	135338	135917	0.929
NE	negative.binomial	0.597	140392	140971	1.388
NE	tweedie	0.623	143088	143667	1.965
NE	poisson	0.716	186550	187122	4.735
NE	lognormal	0.738	208805	209385	75.475
NW	gamma	0.266	292592	293217	1.287
NW	negative.binomial	0.314	311204	311828	1.549
NW	tweedie	0.319	321987	322611	2.505
NW	poisson	0.364	422811	423426	5.309
NW	lognormal	0.412	477621	478245	46.195

Table 2. ANOVA table for selected standardized CPUE series based on selected GLMs for striped marlin caught by Taiwanese large scale longline fishery in the Indian Ocean from 1979 to 2020.

NW

Positive catch model:

	Sum Sq	Df	F values	Pr(>F)
Y	7918	41	150.025	< 2.2e-16 ***
Q	241	3	62.366	< 2.2e-16 ***
CT	82	3	21.196	1.02E-13 ***
Lon	1310	8	127.167	< 2.2e-16 ***
Lat	1622	8	157.509	< 2.2e-16 ***
T	4050	3	1048.626	< 2.2e-16 ***
Residuals	92068	71522		

Delta model

	LR Chisq	Df	Pr(>Chisq)
Y	18548.1	41	< 2.2e-16 ***
Q	614.6	3	< 2.2e-16 ***
CT	100.0	4	< 2.2e-16 ***
Lon	1307.6	8	< 2.2e-16 ***
Lat	4714.9	8	< 2.2e-16 ***
T	483.3	3	< 2.2e-16 ***

Table 2. (continued).

NE

Positive catch model:

	Sum Sq	Df	F values	Pr(>F)
Y	4042.4	41	106.1258	< 2.2e-16 ***
Q	222.1	3	79.6967	< 2.2e-16 ***
CT	38.5	5	8.2811	7.87E-08 ***
Lon	408	9	48.7957	< 2.2e-16 ***
Lat	856.9	7	131.7639	< 2.2e-16 ***
T	2013.3	3	722.3706	< 2.2e-16 ***
Residuals	27013.7	29077		

Delta model

	LR Chisq	Df	Pr(>Chisq)
Y	13079.3	41	13079.3 ***
Q	87.8	3	87.8 ***
CT	129.2	6	129.2 ***
Lon	51.1	9	51.1 ***
Lat	2682.5	7	2682.5 ***
T	88.3	3	88.3 ***

Table 3. Diagnostic statistics for standardized CPUE series based on various GLMs for striped marlin caught by Taiwanese large scale longline fishery in the Indian Ocean from 2005 to 2020.

Area	Model	R2	AIC	BIC	Dispersion
NE	gamma	0.097	24565	24806	1.252
NE	negative.binomial	0.109	26665	26871	1.683
NE	tweedie	0.105	26692	26947	2.096
NE	poisson	0.102	29307	29507	3.241
NE	lognormal	0.081	34254	34495	6.857
NW	gamma	0.300	151133	151485	1.259
NW	negative.binomial	0.349	161697	162049	1.551
NW	tweedie	0.339	164881	165232	2.247
NW	poisson	0.354	197342	197685	4.076
NW	lognormal	0.283	223793	224145	17.976

Table 4. ANOVA table for selected standardized CPUE series based on selected GLMs for striped marlin caught by Taiwanese large scale longline fishery in the Indian Ocean from 2005 to 2020.

NW

Positive catch model:

	Sum Sq	Df	F values	Pr(>F)
Y	5500	15	291.343	< 2.2e-16 ***
Q	128	3	34.012	< 2.2e-16 ***
CT	55	2	21.674	3.91E-10 ***
Lon	1171	8	116.256	< 2.2e-16 ***
Lat	856	8	84.972	< 2.2e-16 ***
T	1970	3	521.708	< 2.2e-16 ***
Residuals	49123	39030		

Delta model

	LR Chisq	Df	Pr(>Chisq)
Y	12471.0	15	12471.0 ***
Q	300.5	3	300.5 ***
CT	51.1	2	51.1 ***
Lon	2032.5	8	2032.5 ***
Lat	3249.8	8	3249.8 ***
T	344.0	3	344.0 ***

Table 4. (continued).

NE

Positive catch model:

	Sum Sq	Df	F values	Pr(>F)
Y	102.2	15	5.4423	4.13E-11 ***
Q	8.6	3	2.2833	0.07693 .
Lon	13.2	5	2.1118	0.06099 .
Lat	72.5	7	8.2685	4.41E-10 ***
T	225.8	3	60.1121	< 2.2e-16 ***
Residuals	8952.6	7150		

Delta model

	LR Chisq	Df	Pr(>Chisq)
Y	708.8	15	< 2.2e-16 ***
Q	47.3	3	3.00E-10 ***
CT	24.7	2	4.32E-06 ***
Lat	1345.4	7	< 2.2e-16 ***
T	16.3	3	0.0009672 ***