CPUE standardization of albacore (*Thunnus alalunga*) caught by Taiwanese large-scale longline fishery in the Indian Ocean

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ABSTRACT

The cluster analysis was adopted to explore the targeting of fishing operations of vessels operating in the albacore fishing areas of the Indian Ocean. In addition, the CPUE standardizations were conducted using the regular generalized linear model (GLM) and delta-GLM for accounting for the trend in the zero catches. In general, the clustering approach was able to explicitly and clearly identify the targeting of each set. Based on the diagnostic statistics and trend of model fits, the standardized CPUE series obtained based on the regular GLM with gamma error distribution would be recommended by this study.

INTRODUCTION

Albacore tuna are currently caught almost exclusively using drifting longlines (accounting for over 90% of the total catches), with remaining catches recorded using purse seines and other gears. Longliners from Japan and Taiwan have been operating in the Indian Ocean since the early 1950s. Catches by Taiwanese longliners increased steadily from the 1950’s to average around 10,000 t by the mid-1970s. Between 1998 and 2002 catches ranged between 20,000 t to 26,000 t, equating to just over 55% of the total Indian Ocean albacore catch. Since 2006 albacore catches by Taiwanese longliners have been between 1,500 and 5,000 t, with the lowest catches recorded in 2012 (IOTC, 2019a).

Based on the historical patterns of Taiwanese longline fishery in the Indian Ocean (Wang, 2019), the catch composition in the southern Indian Ocean mainly consisted of albacore and other species, and the catches of albacore were more than 50% of total catches before 1990s. However, the species composition in the southwestern Indian Ocean became complex after 1990s and the catches of swordfish, yellowfin tuna, bigeye tuna and other species gradually increased, while the catch and CPUE of albacore obviously decreased. The catches of oilfish and other species substantially increased in the southern waters of 10S since 2005 (there was no column for recording the catch of oilfish before 2009 but the catches of other species should mainly consist of oilfishes). In addition, vessels operated in the southern Indian Ocean also tended to use deep sets since early 2000s.

Although the relative abundance index derived from joint CPUE analysis based on Japanese, Korean and Taiwanese data has been used for the stock assessment for albacore in the Indian Ocean, this study conducted the CPUE standardization of albacore caught by Taiwanese large-scale longline fishery in the Indian Ocean for providing auxiliary information of the relative abundance indices solely derived from Taiwanese data.

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).

As the discussions and suggestions from previous IOTC meetings (Hoyle et al., 2015a; Hoyle et al., 2015b; Hoyle et al., 2016; 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 data problem might not only influence the misreport for the catches of major tropical tunas but also lead to uncertainties in the catch and effort data for other species. Therefore, CPUE standardizations were conducted using the data from 2005 to 2020 as suggested in previous meetings. Based on the agreement for the trilateral collaborative study of Japan, Korea and Taiwan, the data were aggregated by 10-days duration (1st-10th, 11th-20th, and 21st~ for each month) for conducting the cluster analysis and also the CPUE standardizations (Kitakado et al., 2021).

The analyses of this study were conducted based on the data of vessels operating in the albacore fishing areas (Fig. 1)

2.1. Cluster analysis

The details of the procedures of cluster analysis were described in Wang et al.

(2021). This study adopted a direct hierarchical clustering with agglomerative algorithm, which brings a fast and efficient implementation through features of memory-saving routines in hierarchical clustering of vector data (Müllner, 2013). The trials conducted using R function “hculst.vector” of package “fastcluster” (Müllner 2021) with Ward's minimum variance linkage methods (“ward.D” for the argument “method” in “hclust.vector” of R function) applied to the squared Euclidean distances between data points calculated based on the species composition.

The number of clusters was selected based on the elbow method, i.e. the change in deviance between/within clusters against different numbers of clusters. The number of clusters was determined when the improvement in the sum of within-cluster variations was less than 10%. The diagnostics of the homogeneity of centroids between clusters were also conducted using the nonparametric comparison of multivariate samples with permutation test. In addition, the visual diagnostic for multivariate dispersions of the centroids by clusters was conducted based on the plots from PCA derived with the variance-covariance matrix of species compositions by clusters.

2.3. CPUE Standardization

Wang (2019) attempted to conduct the CPUE standardization using a generalized linear mixed model (GLMM) and the vessel ID was treated as a random effect. However, the standardized CPUE series revealed very little difference from those obtained from the regular generalized linear model (GLM) with fixed effects. In addition, IOTC (2019b) suggested that the delta-lognormal model may be better for accounting for the trend in the zero catches. Therefore, regular GLM and two-step delta-GLM were adopted in this study. In addition, the CPUE standardizations were conducted by incorporating the year-quarter effect (e.g. 20051, …, 20054, 20061, …, 20064, etc.) to produce annual and year-quarter trends of standardized CPUE series.

Regular GLM and delta-GLM for positive catches:
Annual model:

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

Year-quarter model:

$$Catch = \mu + YQ + CT + Lon + Lat + T + offset(\log(Hooks)) + \varepsilon^c$$

delta model:

Annual model:

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

Year-quarter model:

$$PA = \mu + YQ + CT + Lon + Lat + T + \varepsilon^{Bin}$$

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^{c}	is the error term assumed based on various distribution,
	ε^{Bin}	is the error term, ε^{Bin} ~ Binomial distribution.

To examine the appropriateness of the assumption of error distribution for the regular GLM and delta-GLM for positive catches, this study applied normal and gamma distributions to the error assumption and specified “log” for the model link function. 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. 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 series were calculated based on the estimates of least square means of Y and YQ effects. The products of the CPUE from the model for the positive catches and the catch probability from the delta model were calculated to produce the standardized CPUE series for delta-GLM:

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

where DL^{index} is the standardized CPUE

RESULTS AND DISCUSSION

3.1. Fishing trends

Fig 2. shows the distributions of species compositions aggregated by 5 years. The catches of albacore were mainly made in the southern waters of 15˚S but other species became the main targeting species in the SW area. Although a large amount of fish was also caught in the subtropical and tropical waters with contributions of fishing efforts, the distribution of high CPUE over the years mainly occurred around the southern waters of 30˚S (Figs. 3 and 4).

Albacore catches were mainly made with high effort in the southern waters (SW and SE areas). The catches in the northwestern Indian Ocean gradually decreased before 2018 but slightly increased in recent years (Figs. 5 and 6).

The trend in CPUE of main species by the number of hooks between float (NHBF) of vessels operating in the albacore fishing areas was shown in Fig. 7. High CPUE of albacore, swordfish and other species mainly made by shallow fishing sets, while bigeye and yellowfin tunas were obviously caught by deep fishing sets. However, NHBF significantly increased in the NW and NE areas after 2010, while the shallow fishing sets also gradually decreased in the SW and SE areas through the years (Fig. 8).

3.2. Cluster analysis

Based on the patterns from the elbow method, the determined numbers of clusters were 4 for areas NE, NW and SE, 3 for area SW (Figs. 9 and 10). The global and detailed tests of nonparametric comparisons indicated statistical significance in the hypothesis of equality of multivariate distributions among and between clusters for all areas.

The species compositions by clusters indicated that clustering can not only identify the groups for the main target species but also can explicitly provide groups for other species in a particular area (Fig. 11). For instance, the fishing sets targeted the other species (oilfish) in area SW and southern bluefin tuna in area SE can be explicitly identified by clustering. The annual trends of catches of albacore and fishing efforts were shown in Figs. 12.

3.3. CPUE standardization

IOTC (2019b) suggested that only the main clusters associated with the species of interest were retained in the standardization except in NE area where all clusters were included as there is little albacore catches since 2010. Based on the species compositions and catches of albacore by clusters (Figs. 11 and 12), the clusters contained very few catches of albacore were excluded when doing the CPUE standardizations. Clusters 2 and 4 was excluded for NW area, cluster 3 was excluded for SW area, while all clusters were remained for NE and SE. Although most of the albacore catches were grouped into cluster 1 for NE area, the data of all clusters were used for further CPUE standardization because very few albacore catches occurred the after the early 2000s even the cluster 1, and too many missing values may occur when removing data from some clusters.

Tables 1 and 2 show the diagnostic statistics for the CPUE standardizations using regular GLM and delta-GLM for positive catches for year-quarter and annual models. The models with gamma error distribution would be the optimal models for all areas based on the values of AIC, BIC and Pearson dispersion statistics although R^2 may not be higher than other models. Take the regular GLM for SW area as an instance, diagnostic plots for residuals also indicated that the models with gamma error distribution (Fig. 13) should be most appropriate than other models because there were less increasing or decreasing trends in the range of predicted values when assuming a gamma error distribution (plots for other models by areas were not shown here but the residuals revealed obvious patterns with predicted values).

For the delta model for standardizing the catch probability, the warning occurred that the predicted probabilities were indistinguishable from 0 or 1, especially for NE and SE areas where very little or abundant catches of albacore were distributed. In addition, the standardized CPUE series obtained from delta-GLM somehow deviated from those of nominal CPUE in some years, even for the NW and SW areas (Figs. 14 and 15). Therefore, the standardized CPUE series obtained based on the regular GLM with gamma error distribution would be recommended by this study.

The ANOVA tables for selected models are shown in Tables 3 and 4. The results indicate that the effects of *T* (clusters) provided the most significant contributions to the explanation of the variance of CPUE for both annual and year-quarterly models for all areas.

The standardized CPUE series with confidence intervals obtained from the selected model are shown in Figs. 16 and 17. The CPUE series in the northern areas (NW and NE) revealed decreasing trends around 2015-2017 and increased in recent years. For the southern areas (SW and SE), annual standardized CPUE series revealed increasing trends since 2005, while more fluctuations were observed from the year-quarterly standardized CPUE series.

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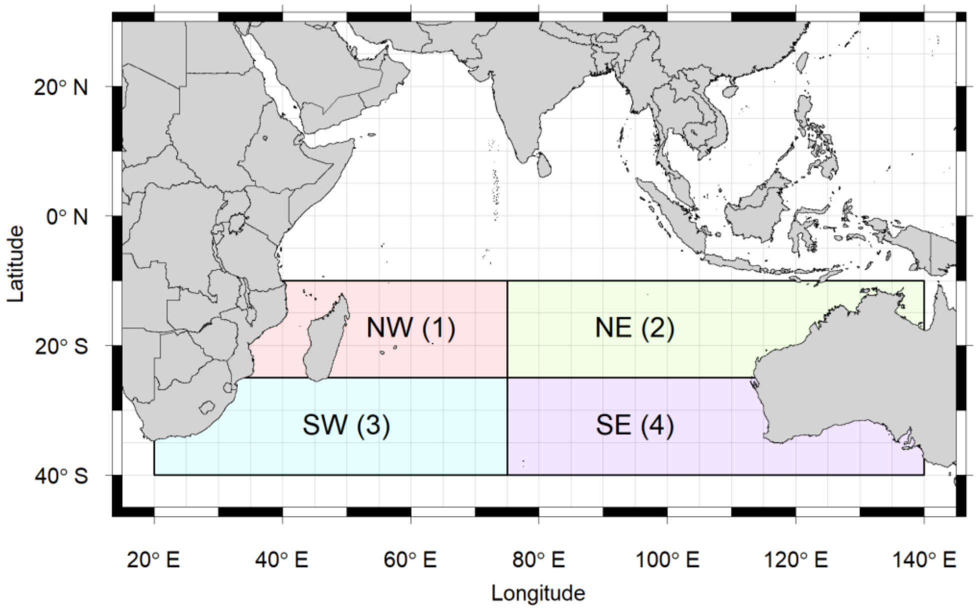


Fig. 1. Area stratification for albacore in the Indian Ocean.

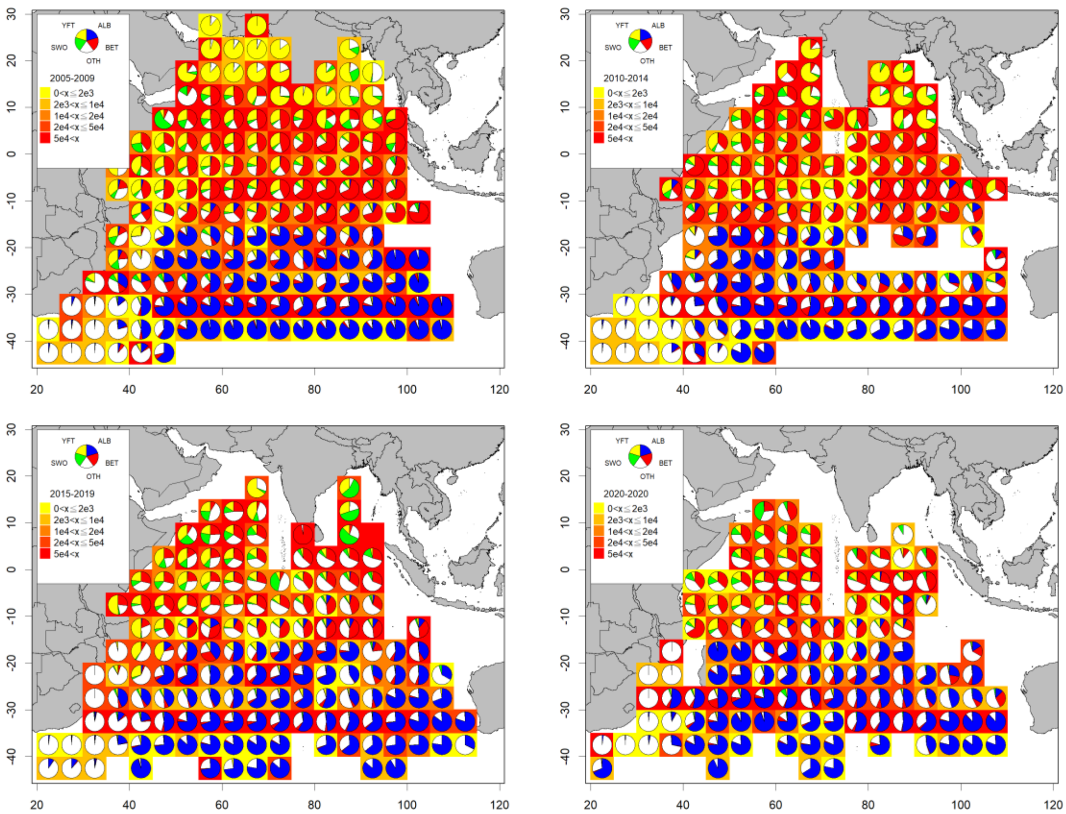


Fig. 2. Species composition distribution of Taiwanese large-scale longline fishery in the Indian Ocean.

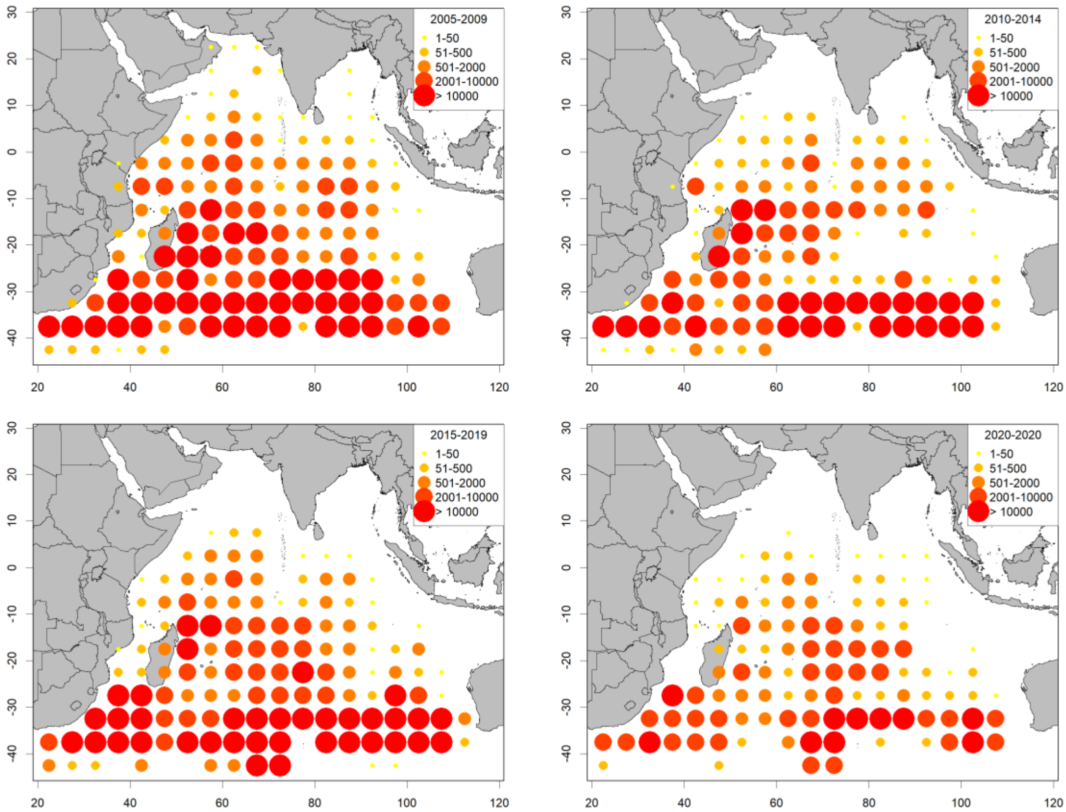


Fig. 3. Albacore catch distribution of Taiwanese large-scale longline fishery in the Indian Ocean.

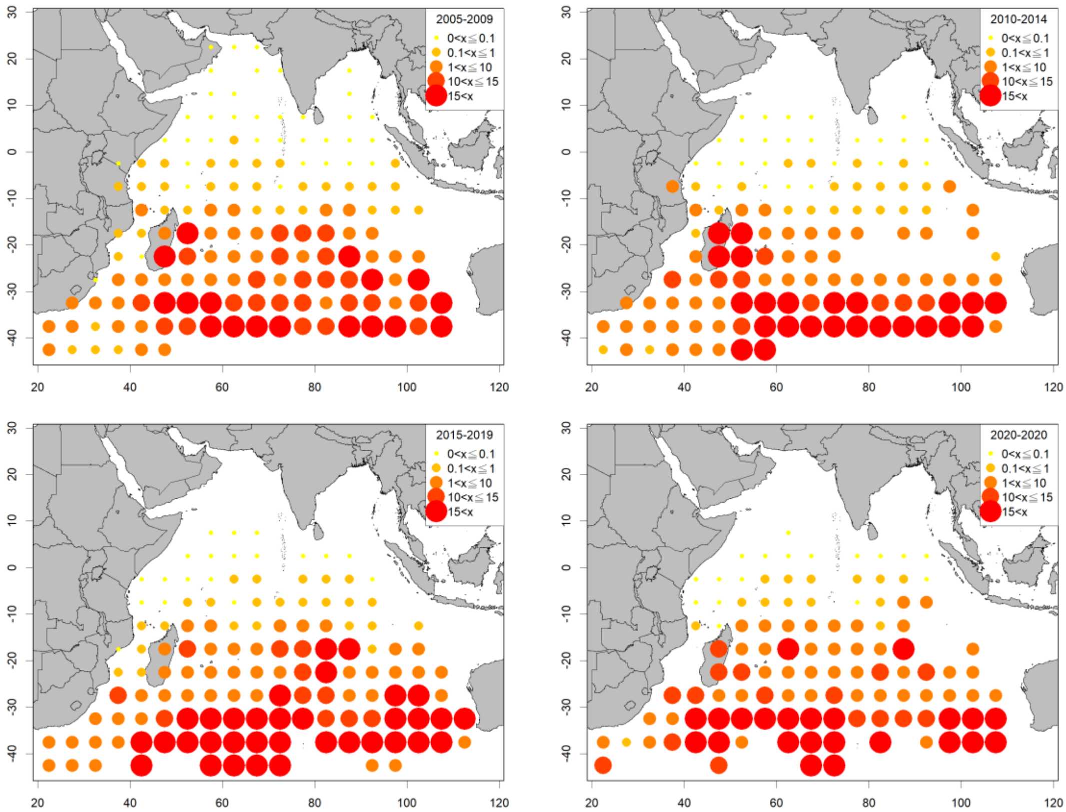


Fig. 4. Albacore CPUE distribution of Taiwanese large-scale longline fishery in the Indian Ocean.

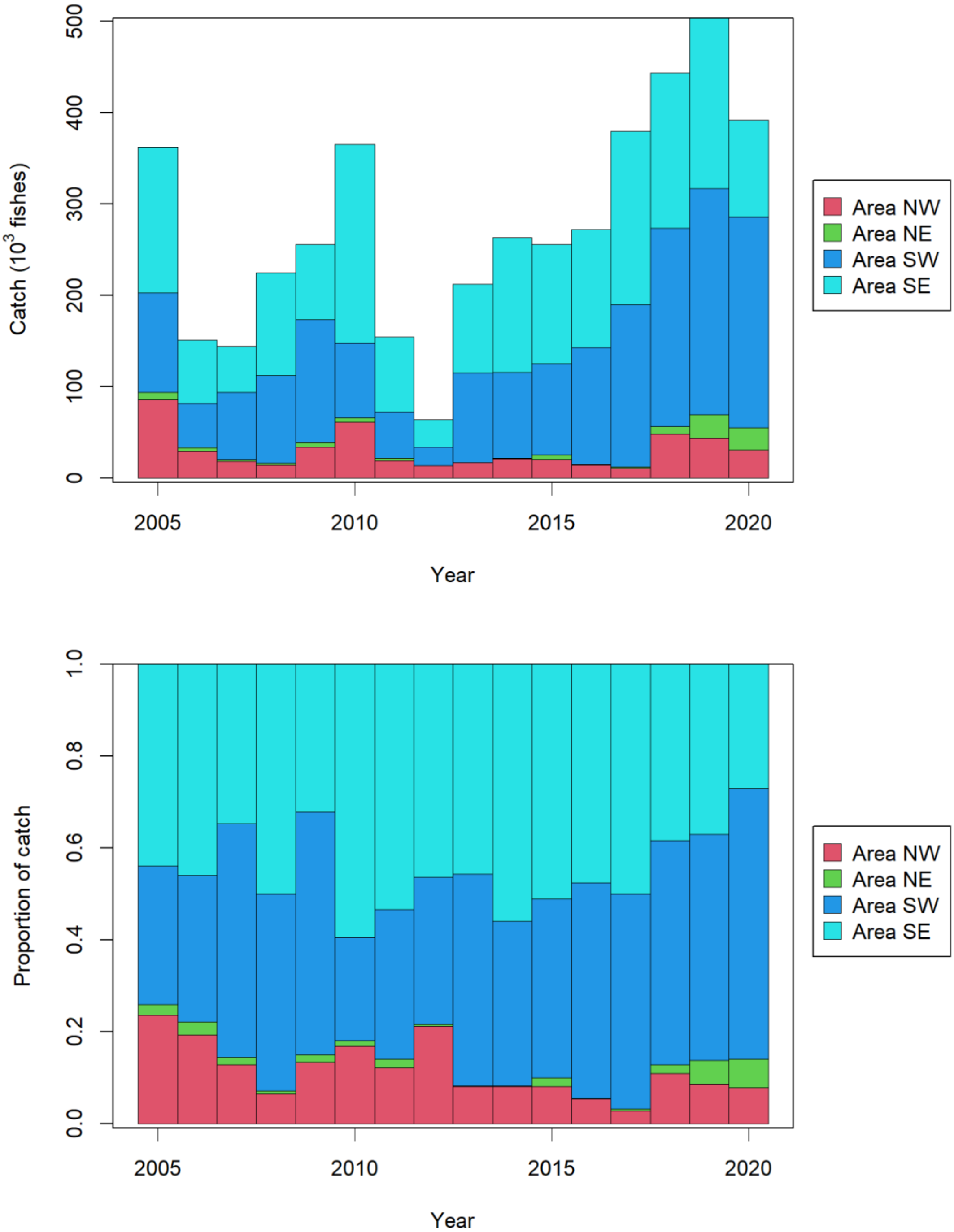
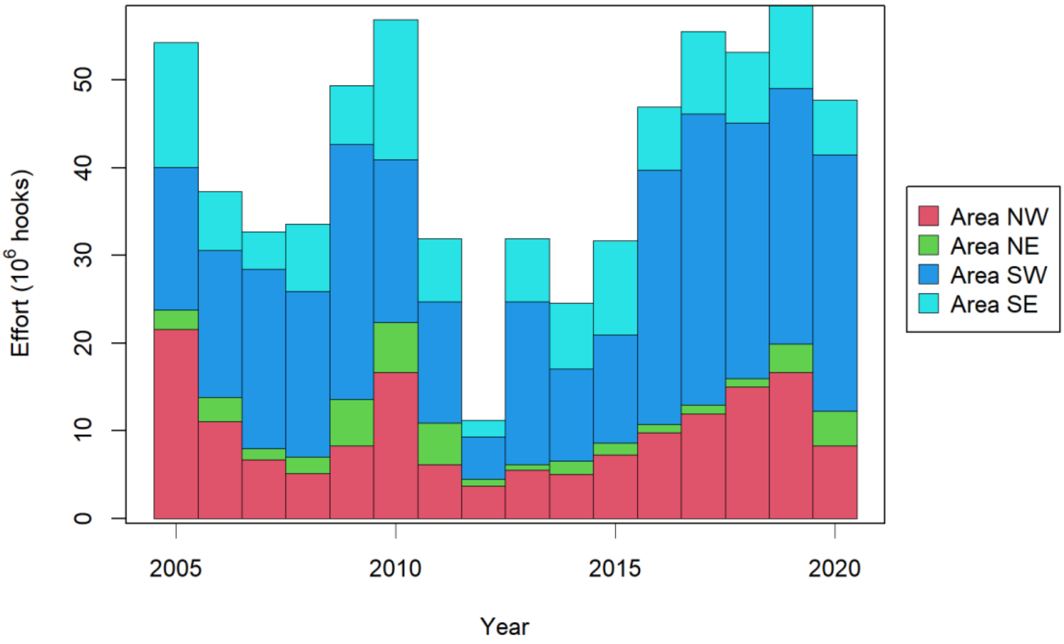


Fig. 53. Annual albacore catches of Taiwanese large-scale longline fishery in the Indian Ocean.



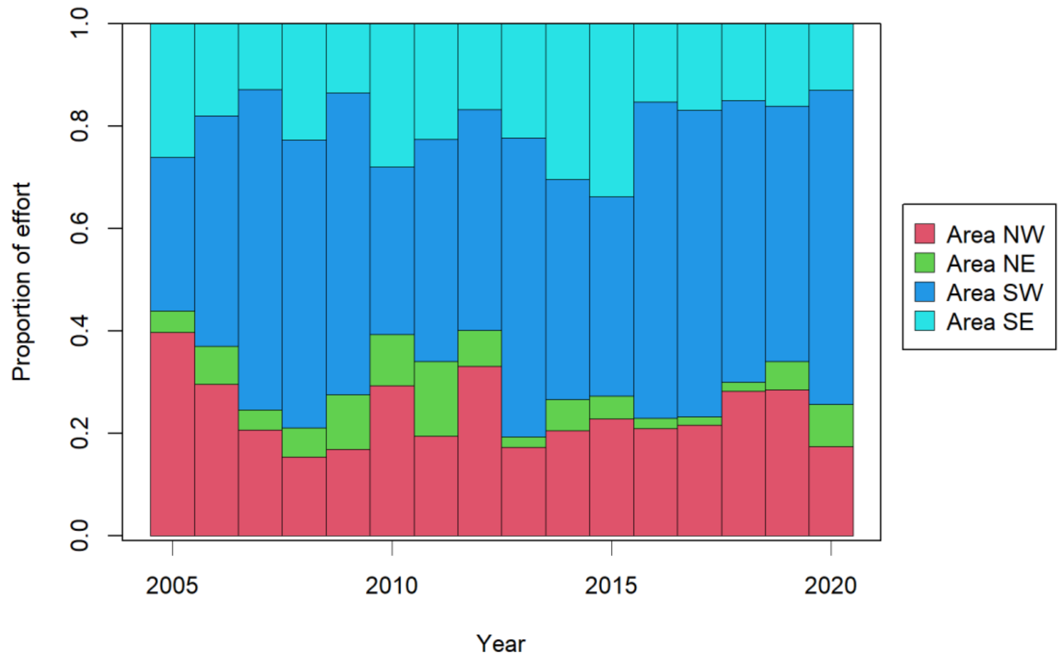


Fig. 6. Annual efforts (number of hooks) of Taiwanese large-scale longline fishery in the Indian Ocean.

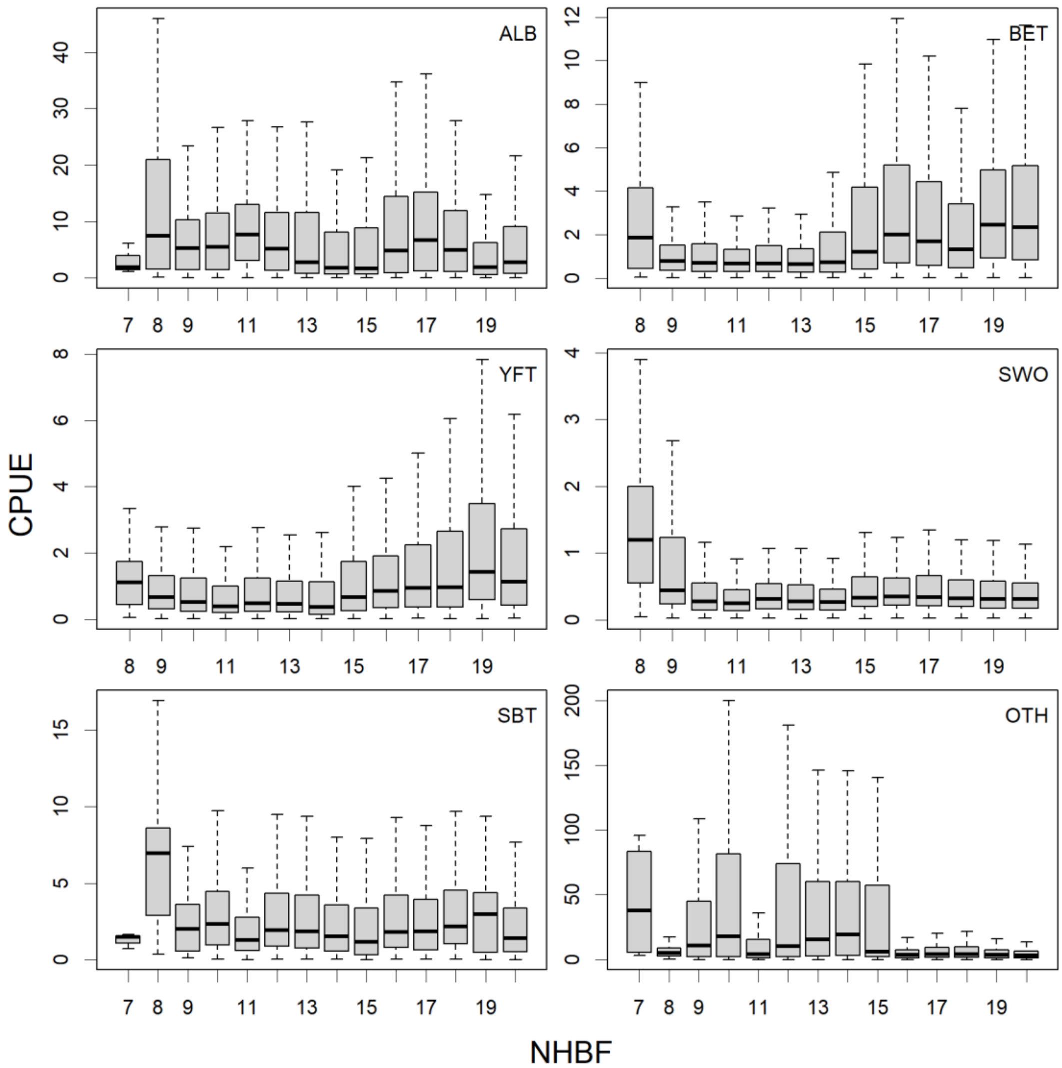
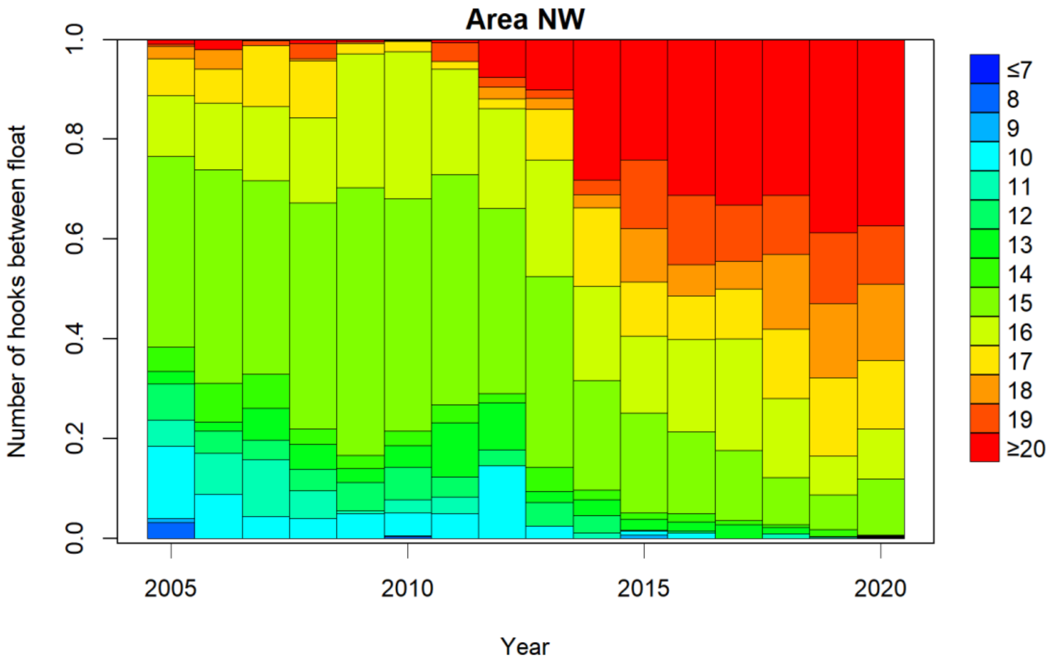


Fig. 7. CPUE of main species by the number of hooks between float (NHBF) of Taiwanese large-scale longline fishery in the Indian Ocean.



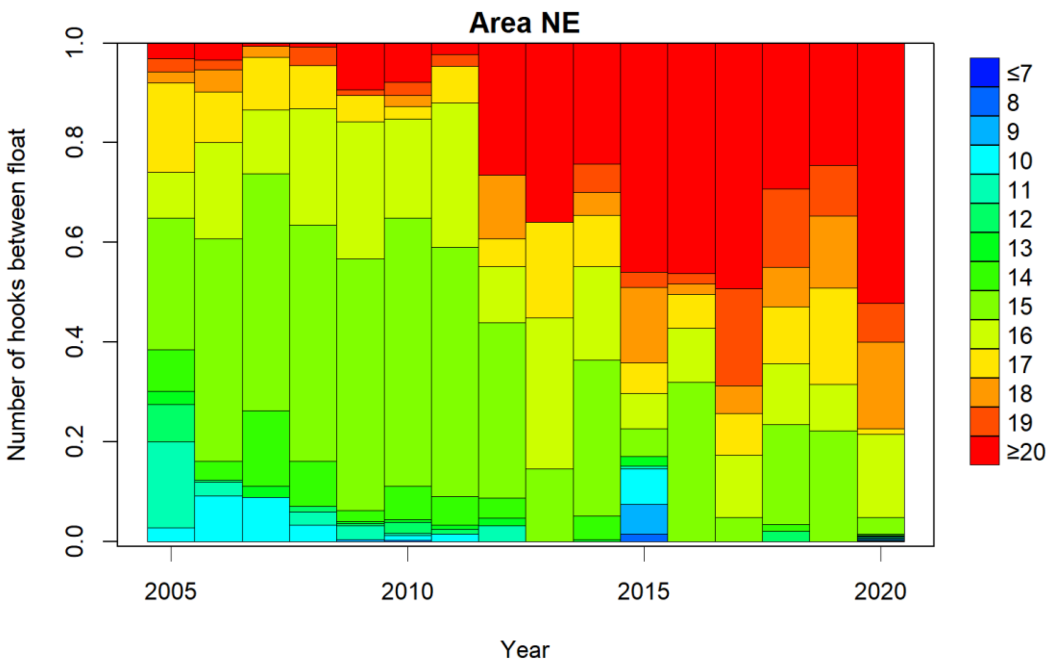


Fig. 8. Annual trend in the compositions of number of hooks between float of Taiwanese large-scale longline fishery in the Indian Ocean.

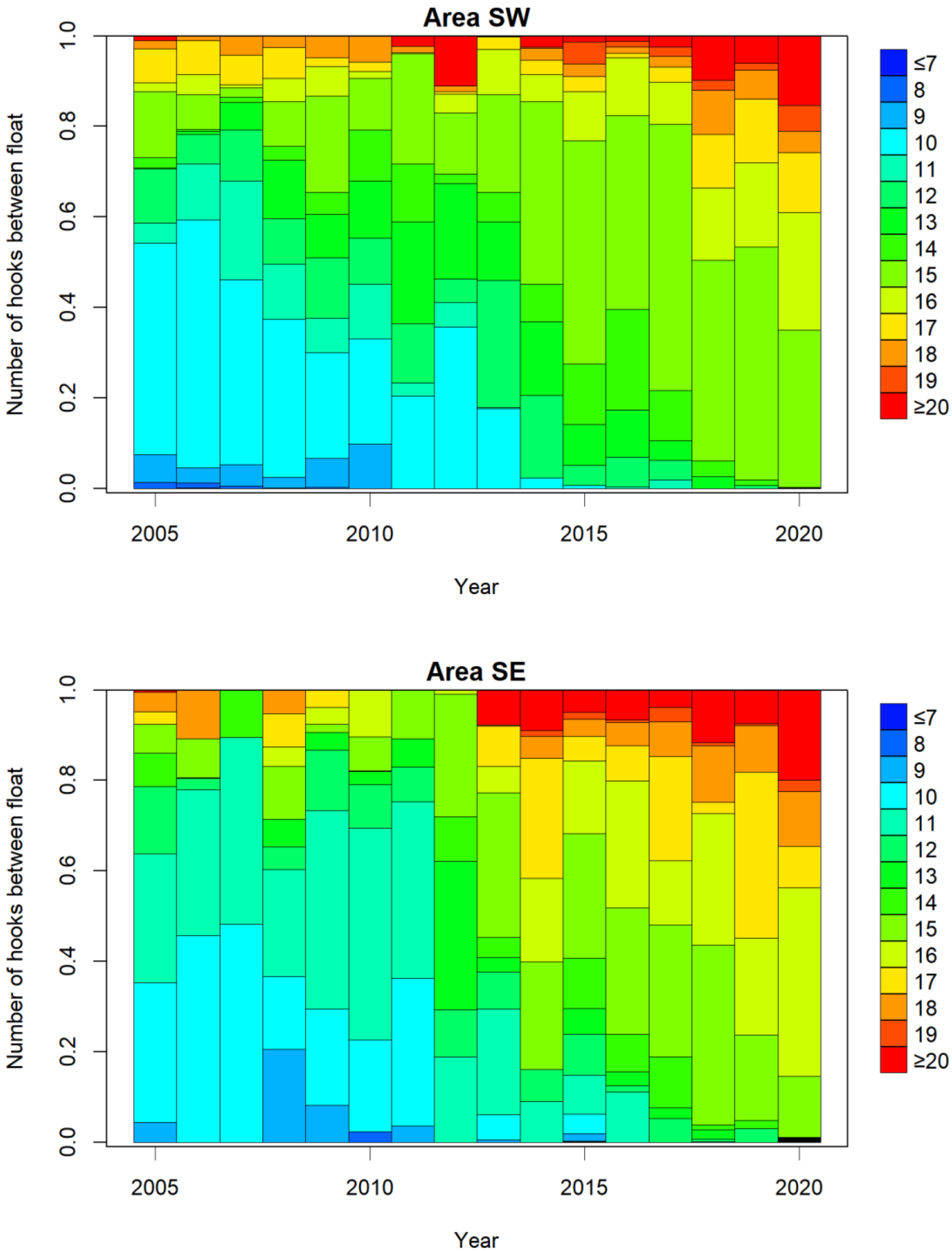
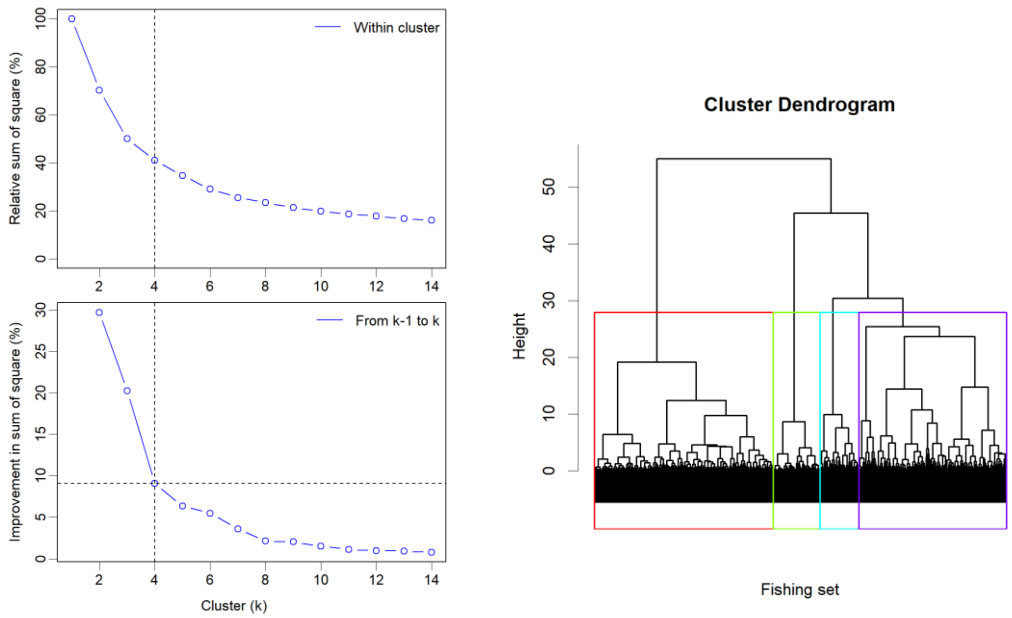


Fig. 8. (Continued).

NW



NE

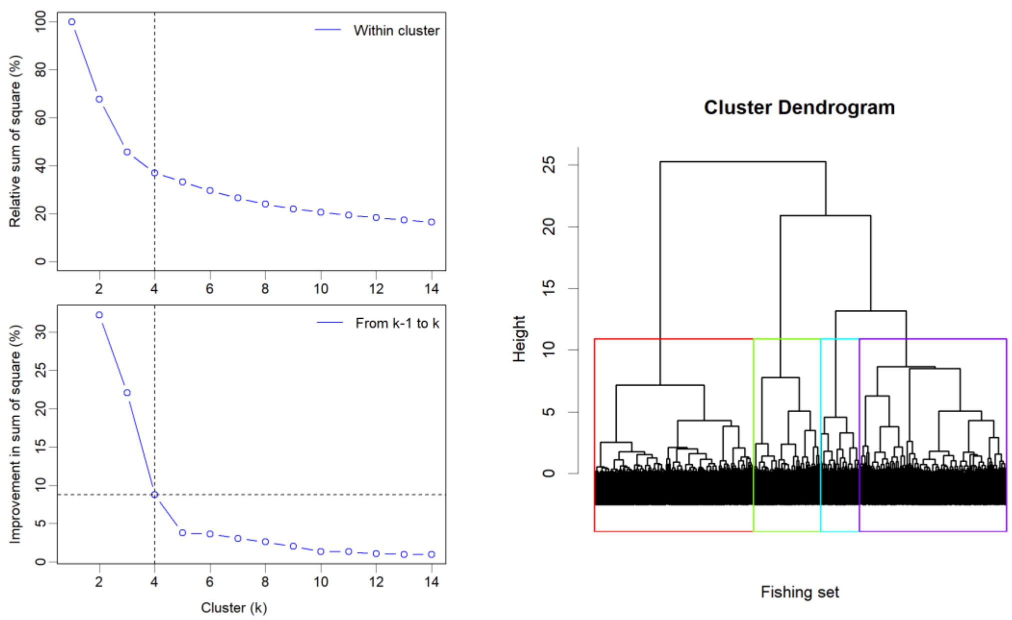
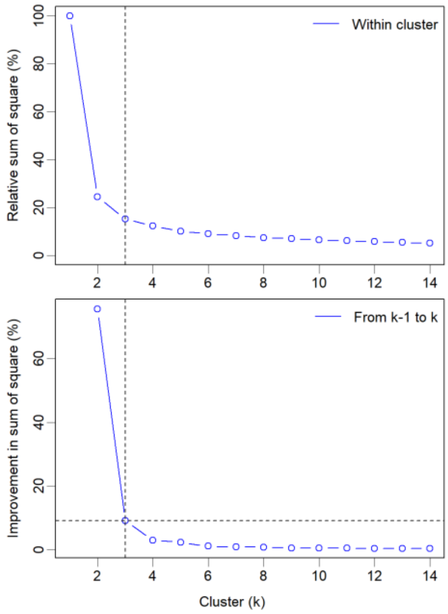
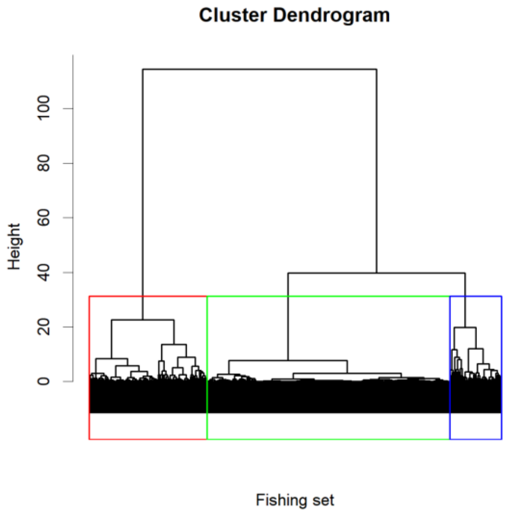


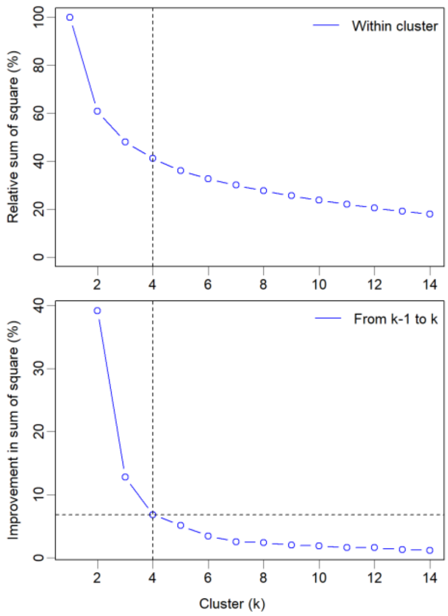
Fig. 9. Sum of squares within clusters for the data of Taiwanese large-scale longline fishery in albacore area of the Indian Ocean.

SW





SE



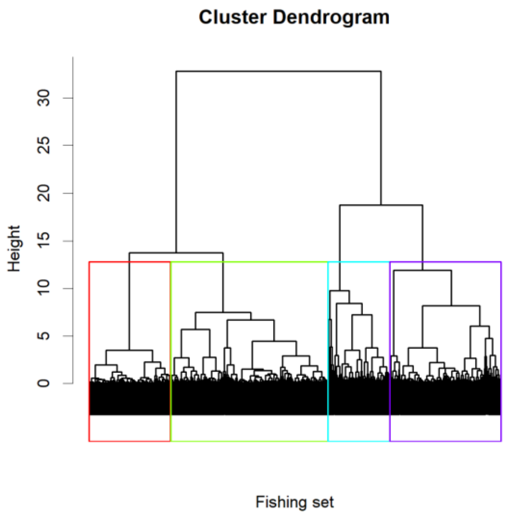


Fig. 9. (Continued).

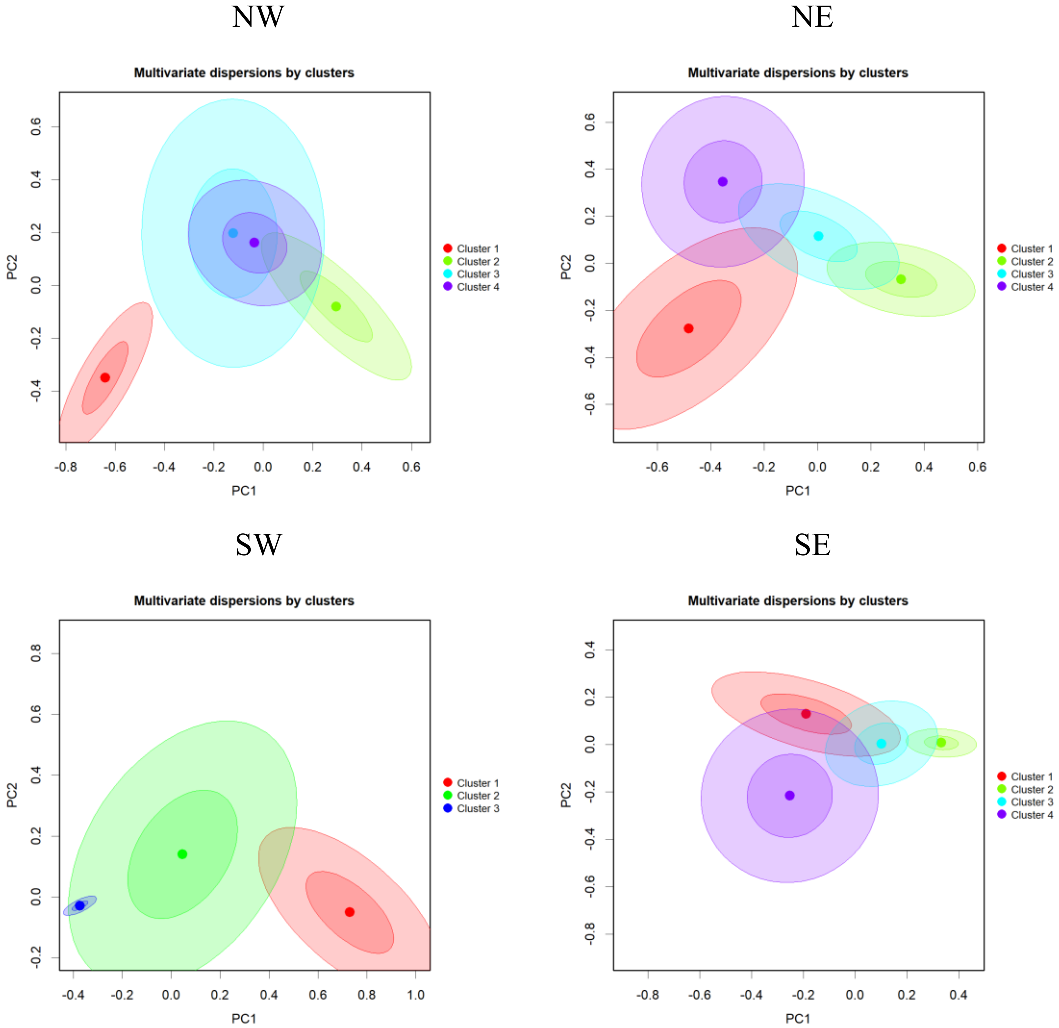


Fig. 10. Multivariate dispersions of the centroids by clusters derived from PCA for the data of Taiwanese large-scale longline fishery in albacore area of the Indian Ocean.

NW

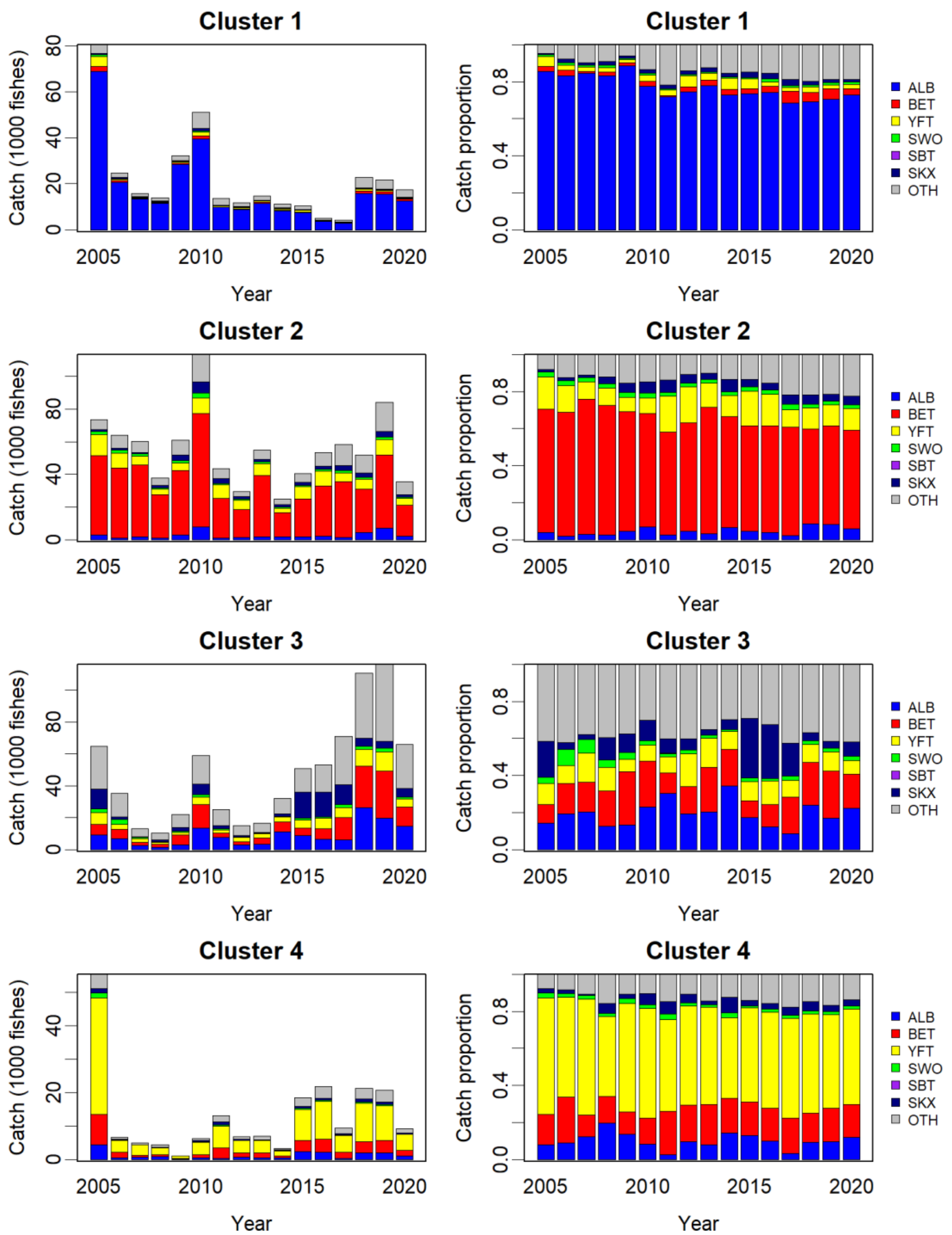


Fig. 11. Annual catches and compositions by species for each cluster of Taiwanese large-scale longline fishery in albacore area of the Indian Ocean.

NE

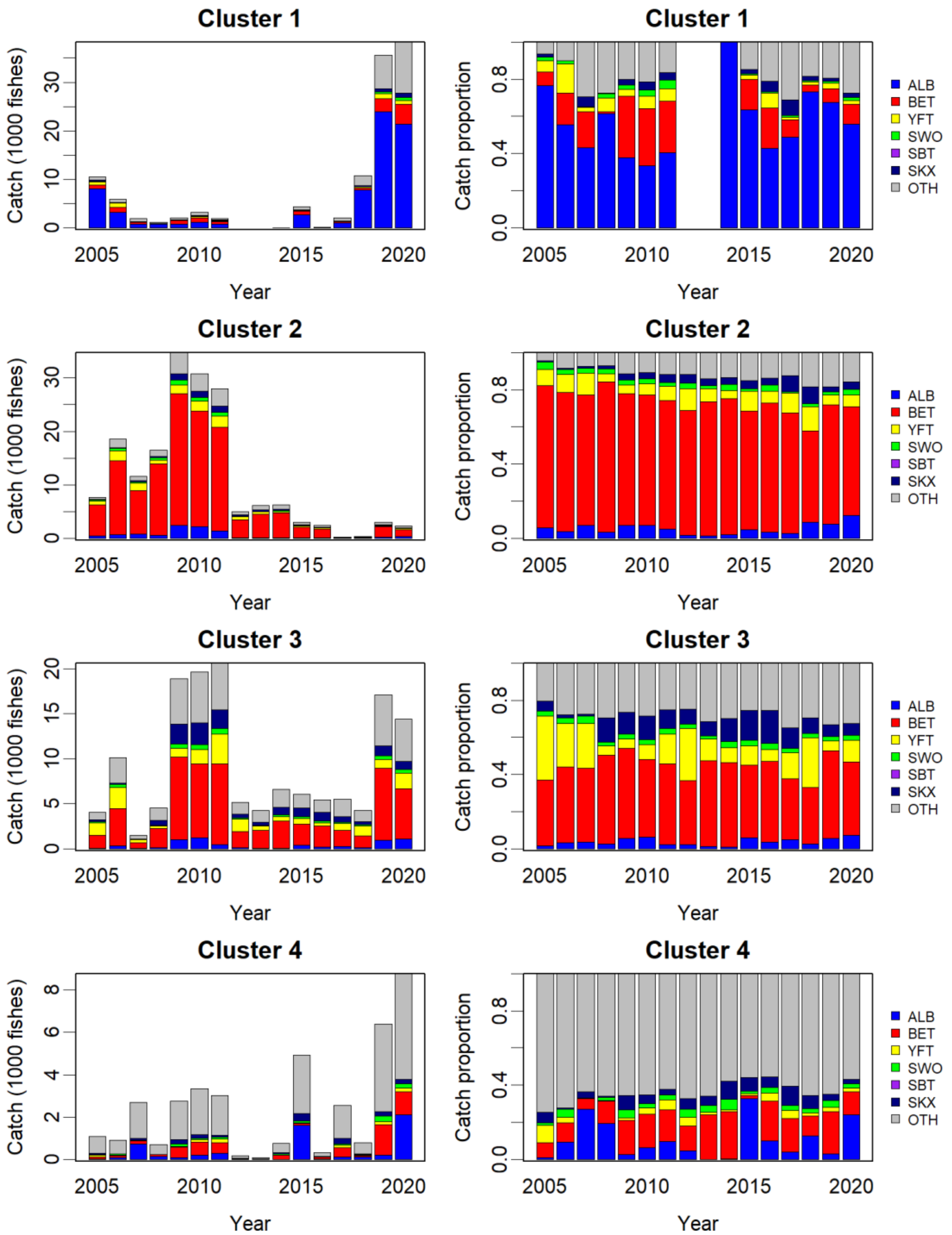


Fig. 11. (Continued).

SW

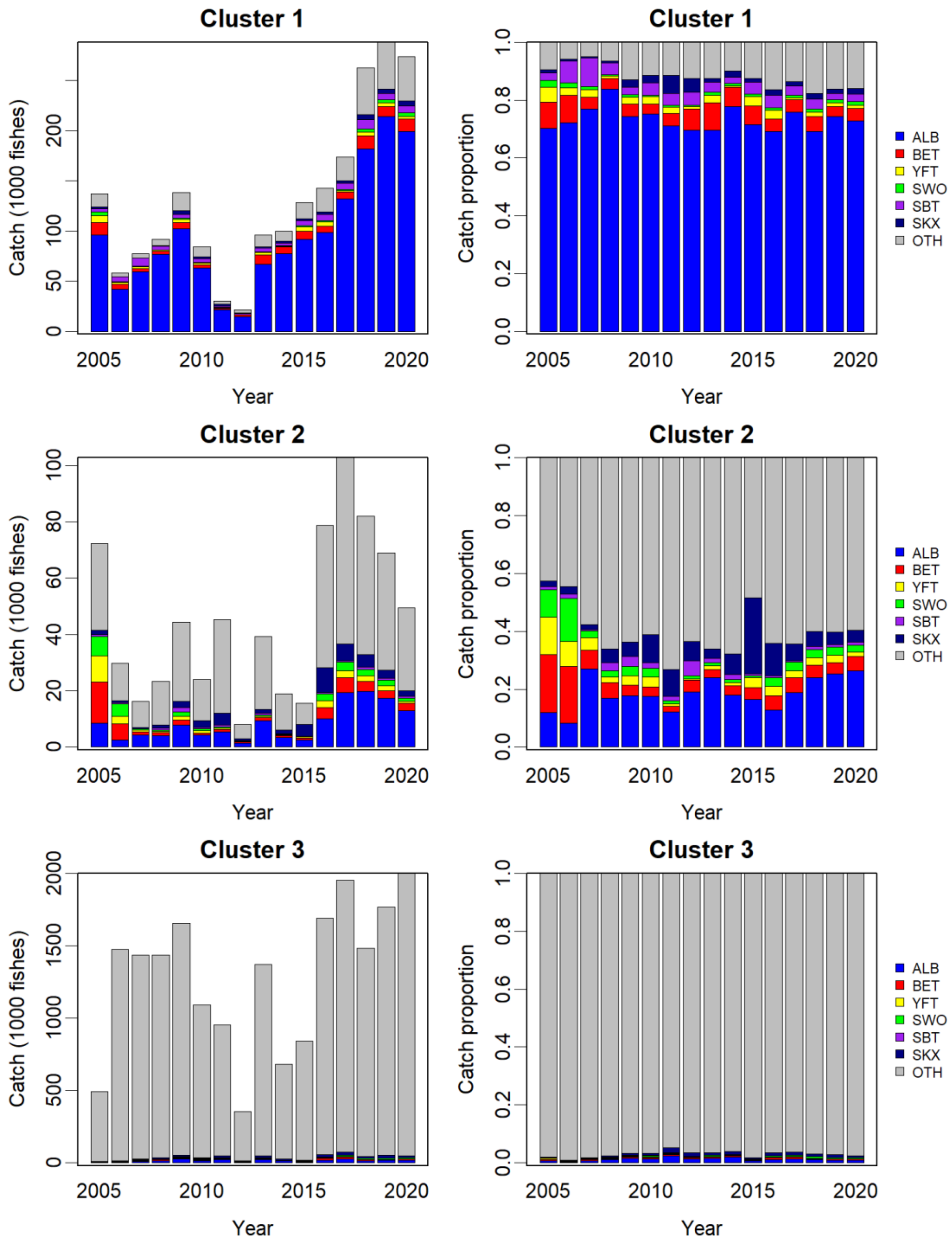


Fig. 11. (Continued).

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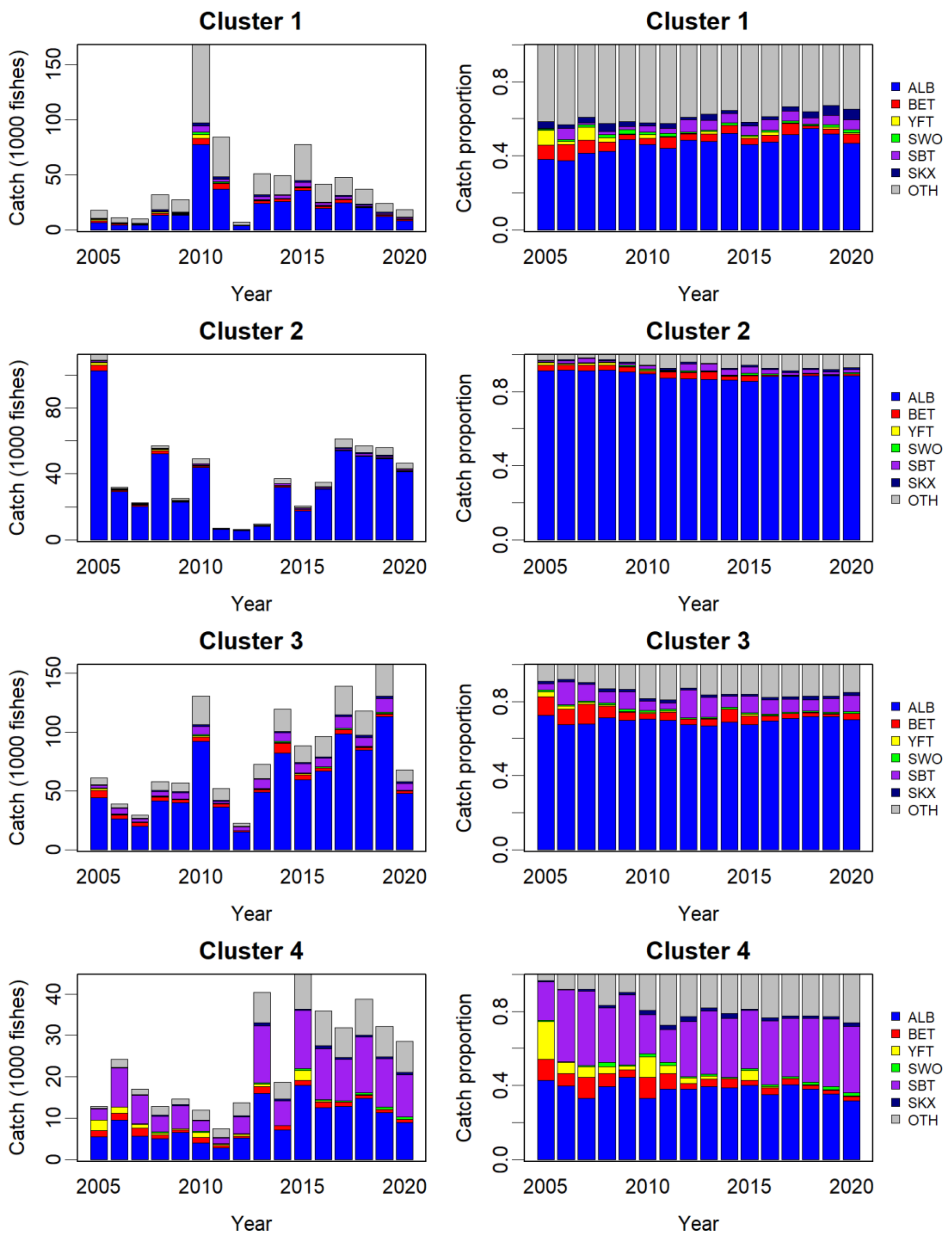

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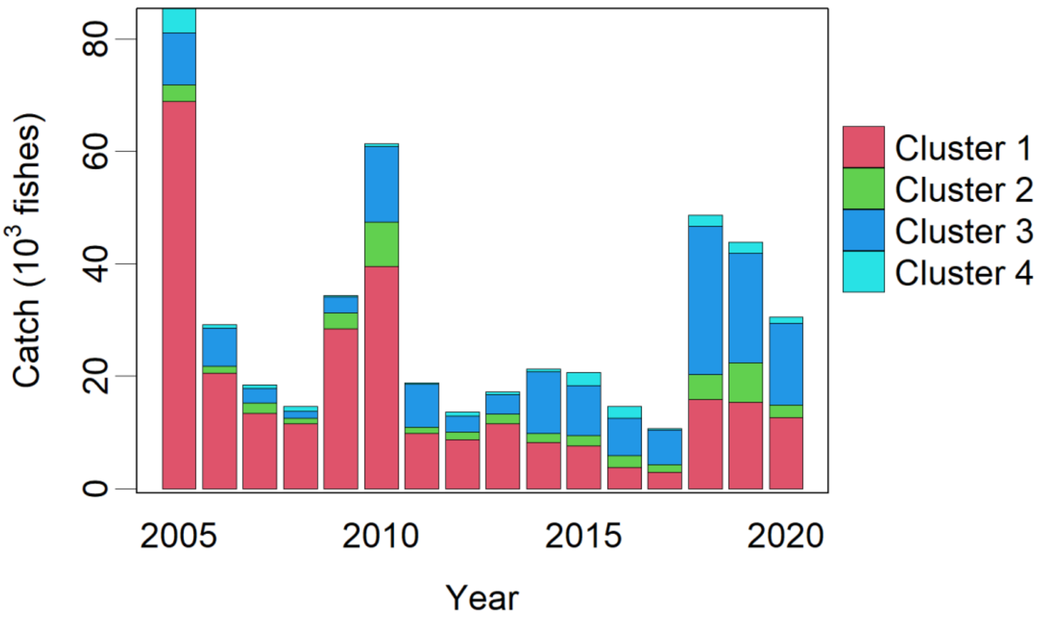
NW



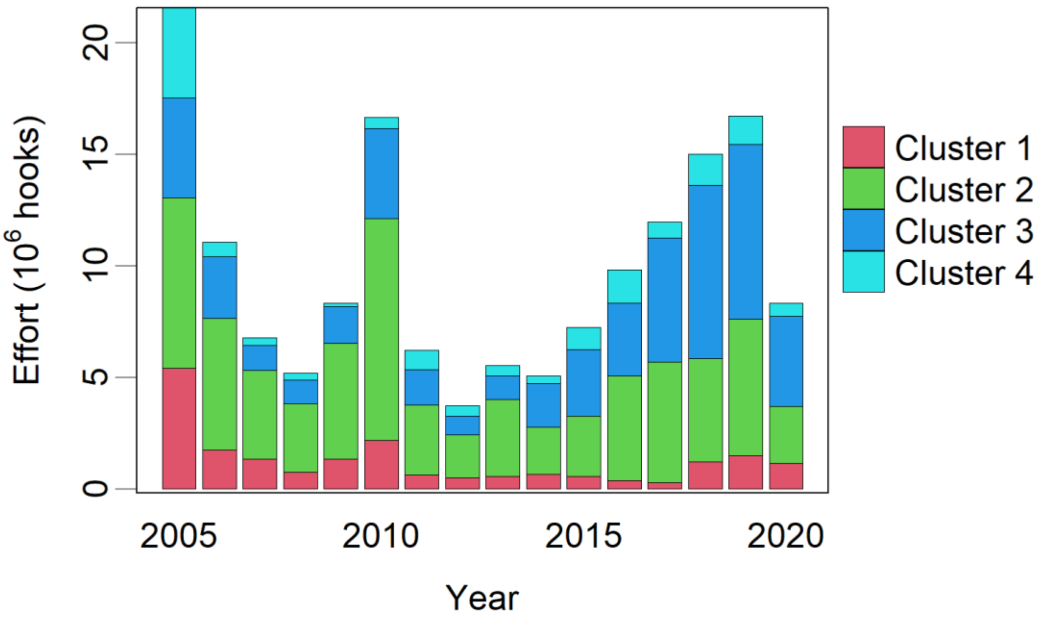
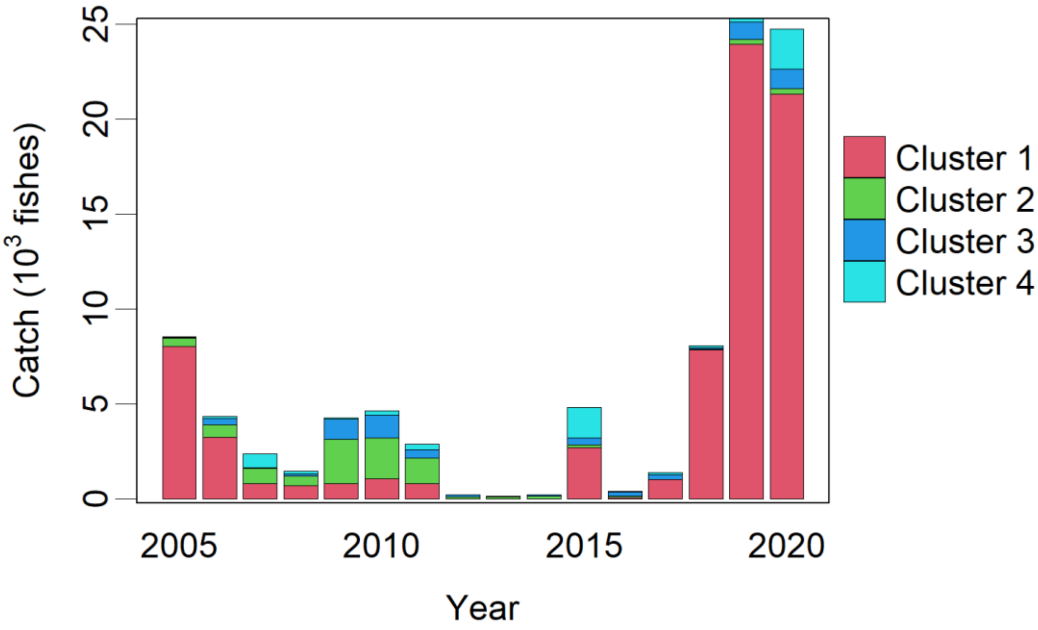
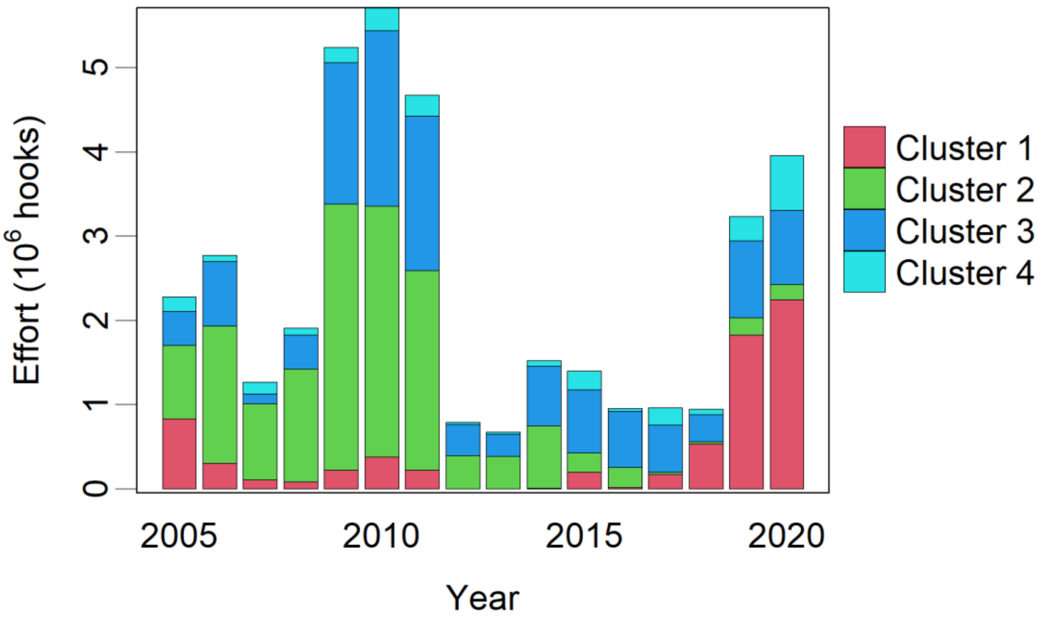


Fig. 12. Annual albacore catches and efforts for each cluster of Taiwanese large-scale longline fishery in albacore area of the Indian Ocean.

NE





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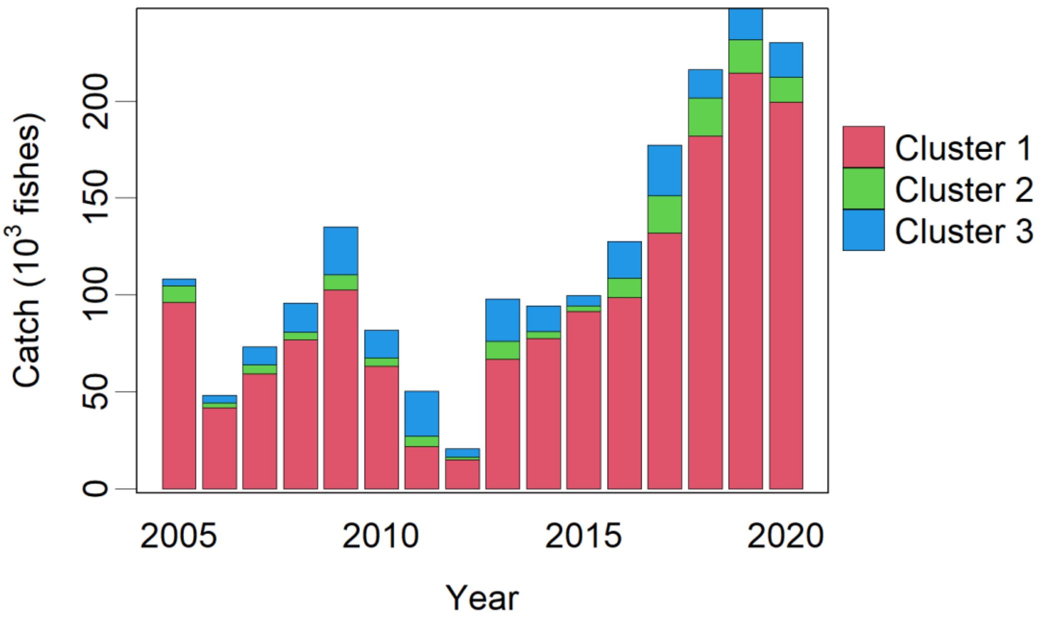
SW



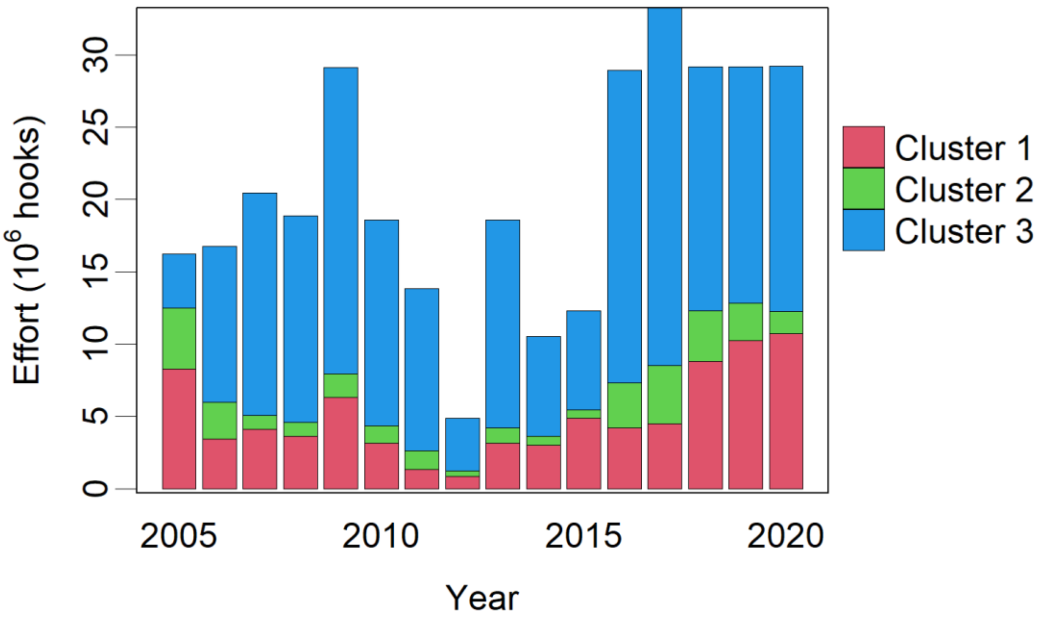
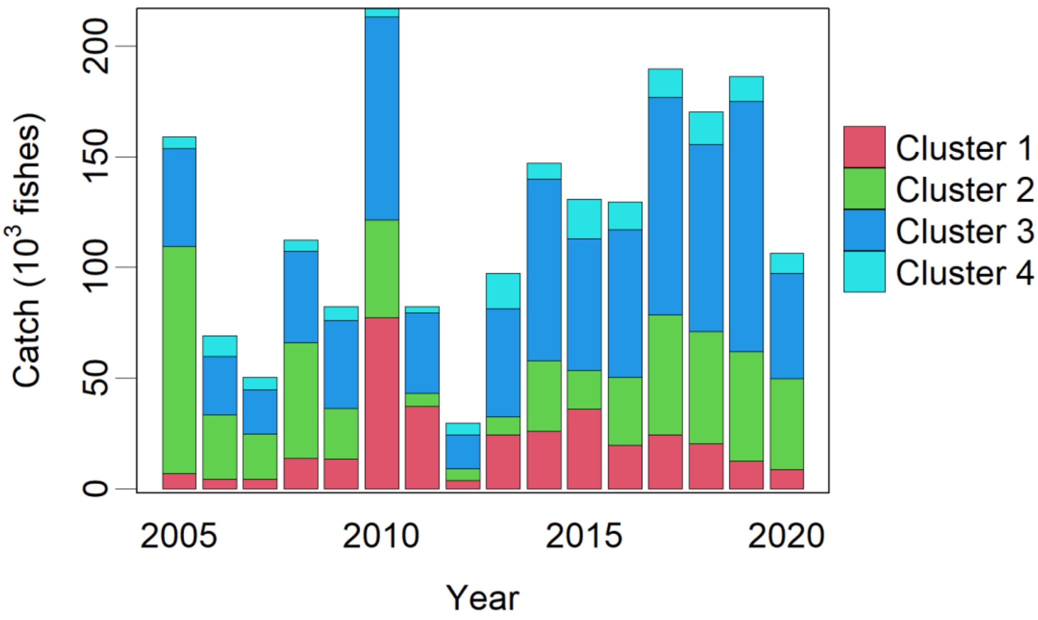


Fig. 12. (Continued).

SE



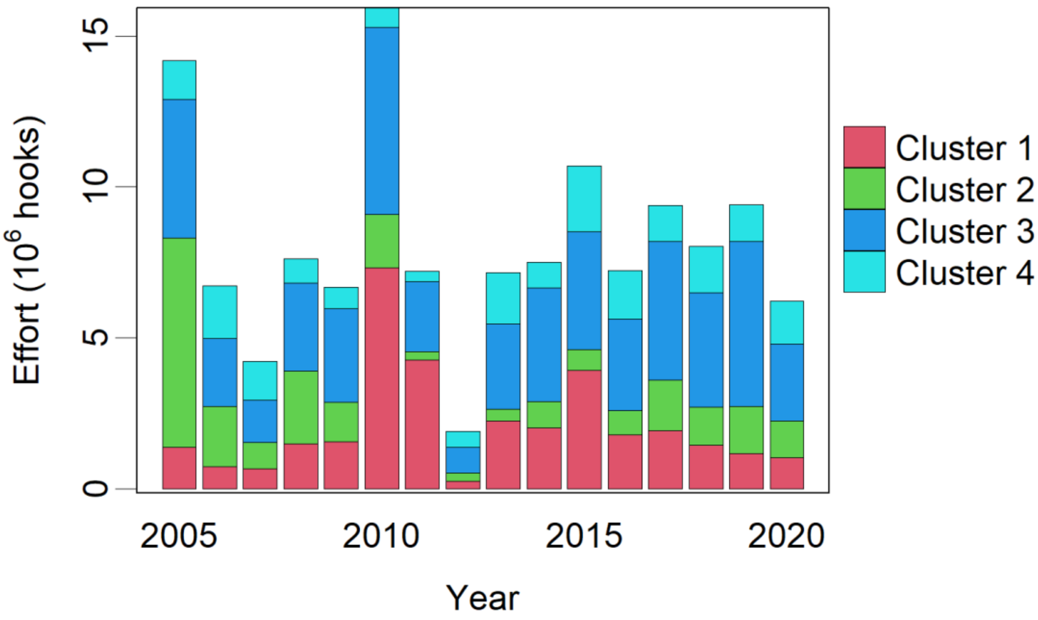


Fig. 12. (Continued).

Lognormal model

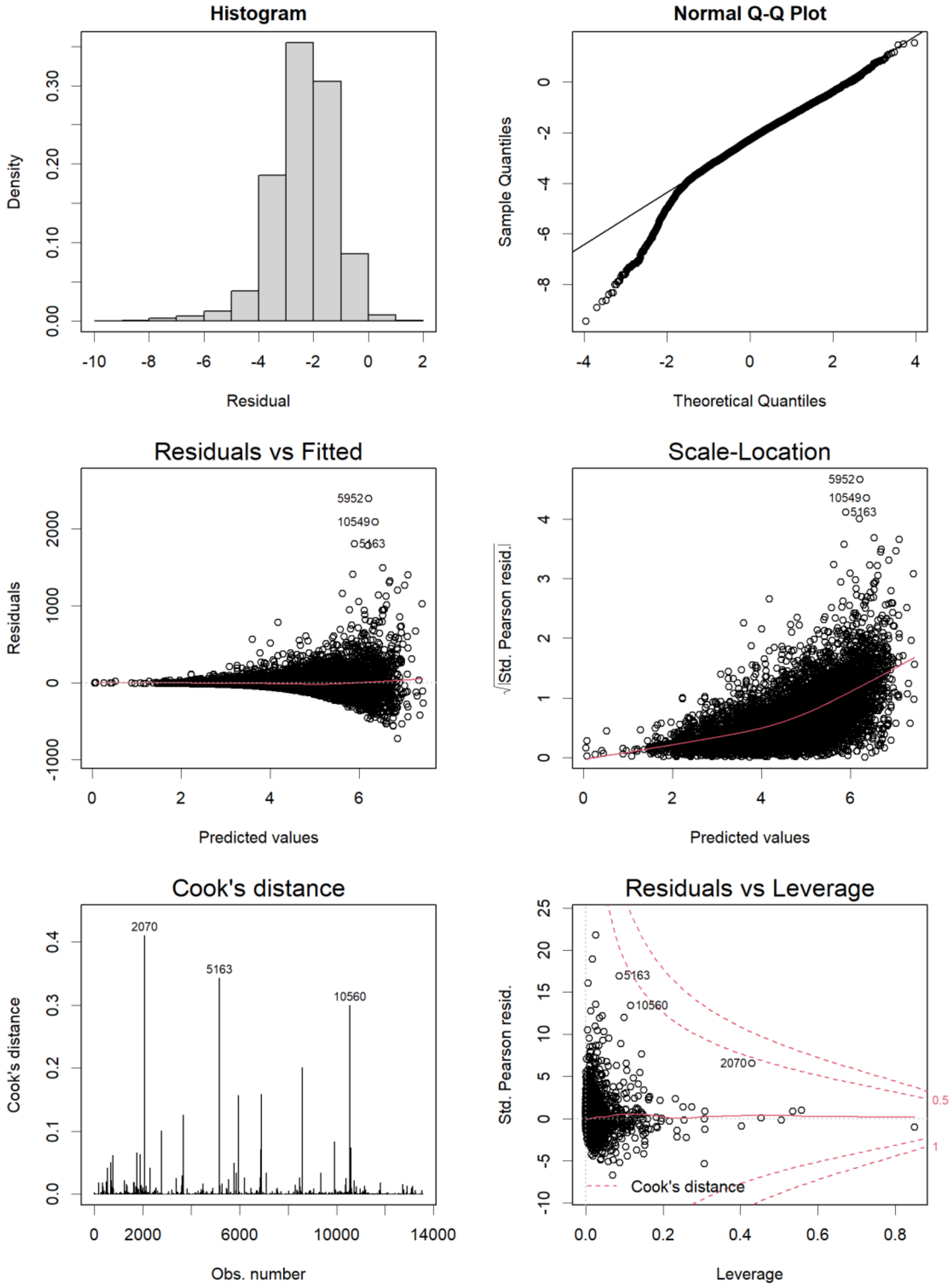


Fig. 13. Diagnostic plots for regular GLM with lognormal and gamma error distribution assumptions for albacore caught by Taiwanese large-scale longline fishery in the Indian Ocean.

Gamma model

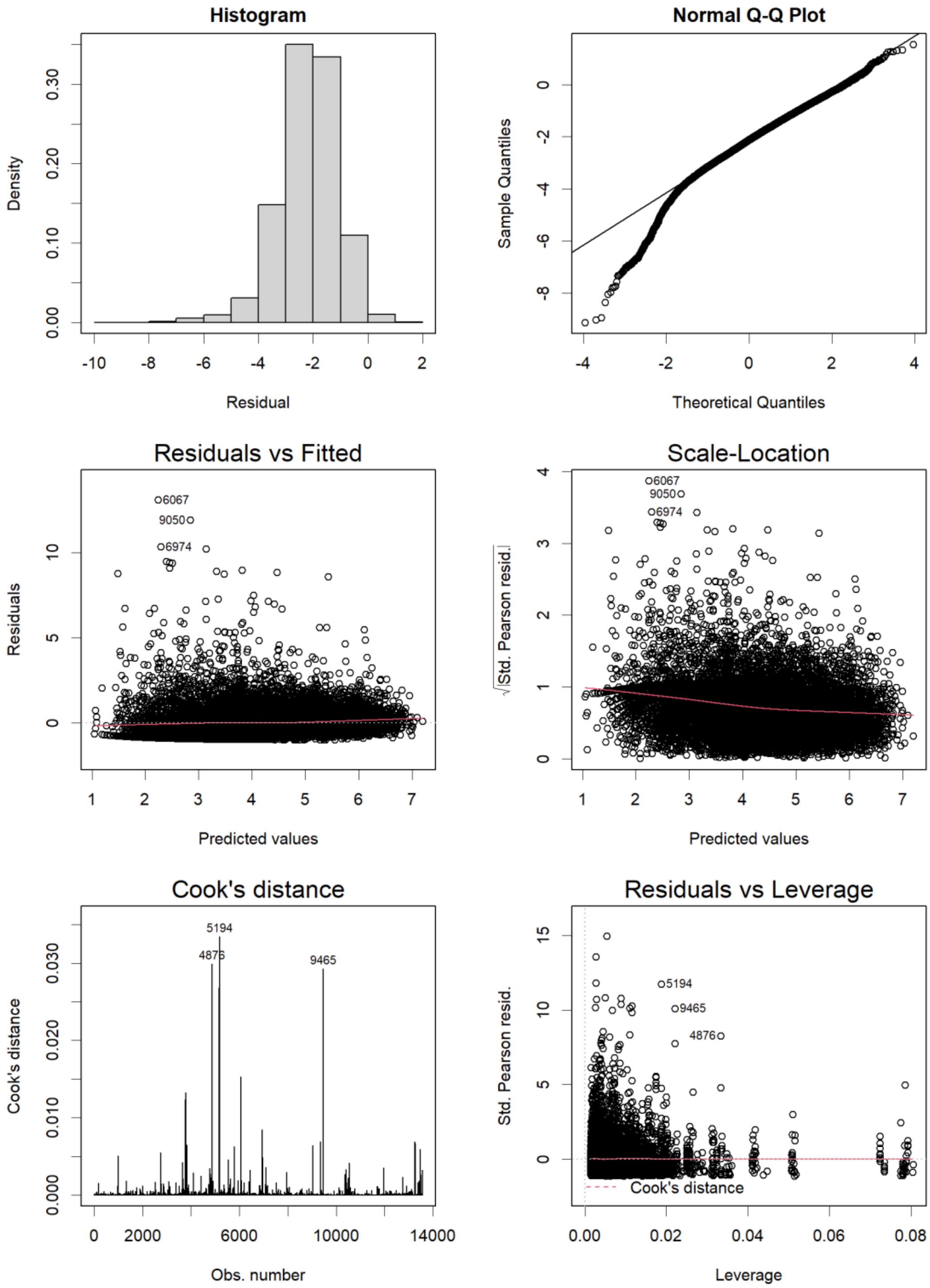


Fig. 13. (continued).

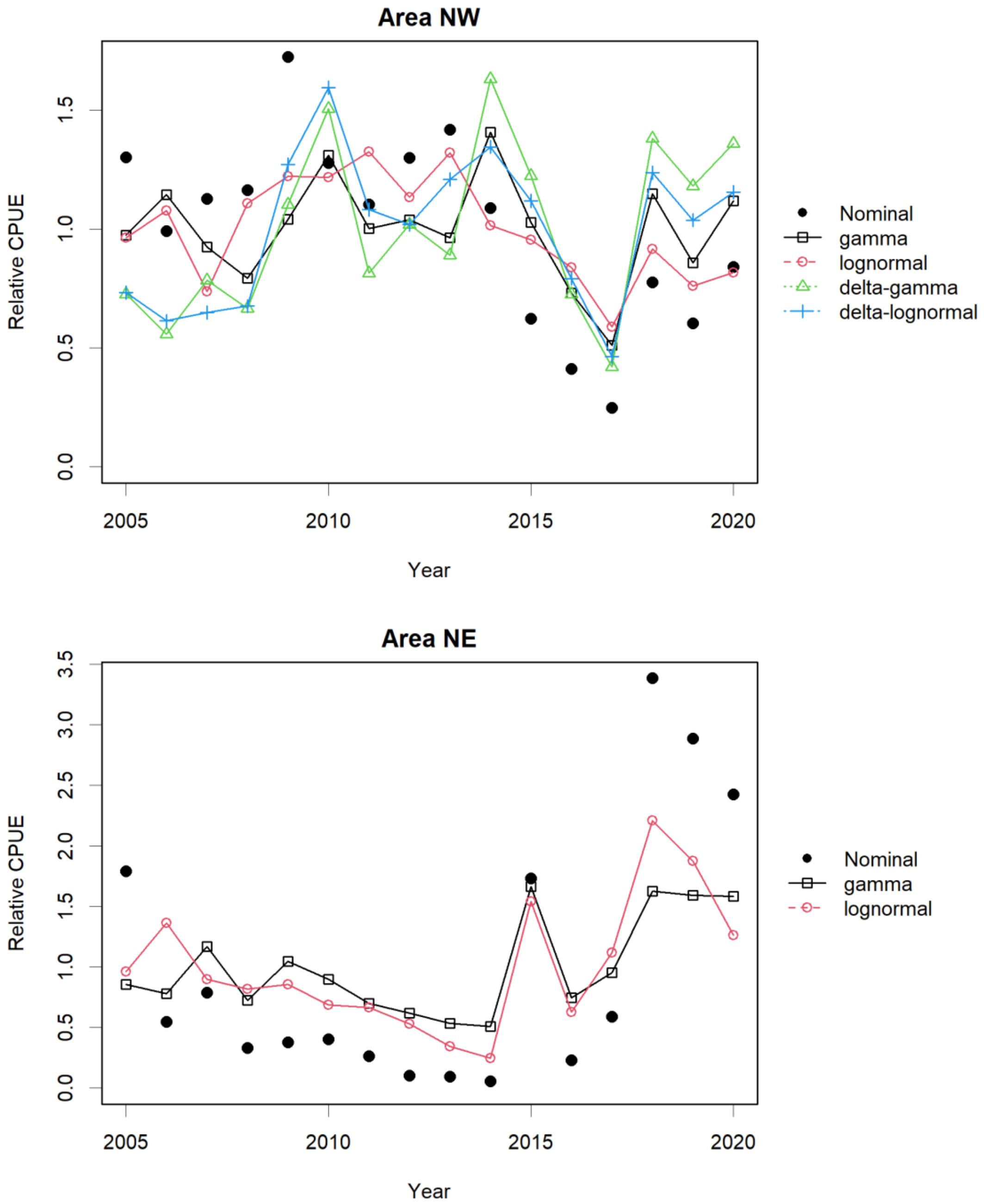
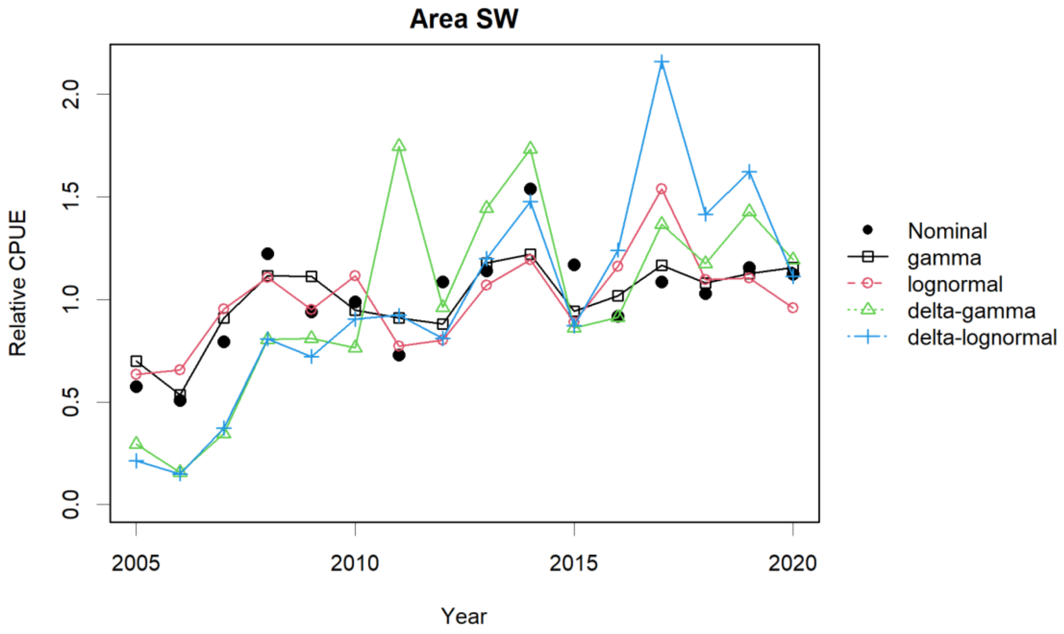


Fig. 14. Annual standardized CPUE series based on regular GLM and delta-GLM for albacore caught by Taiwanese large-scale longline fishery in the Indian Ocean from.



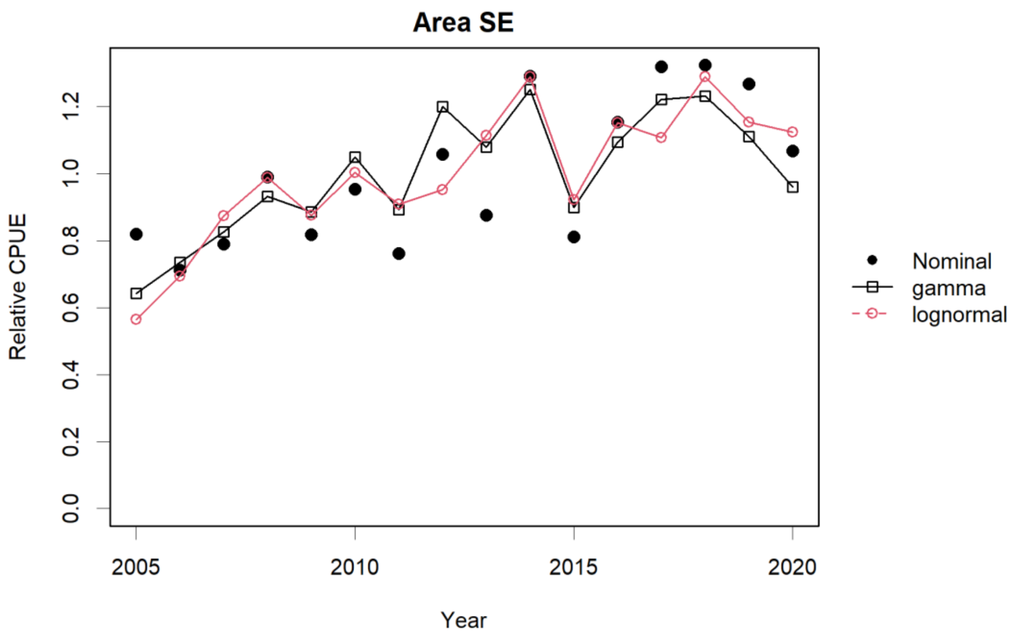


Fig. 14. (Continued).

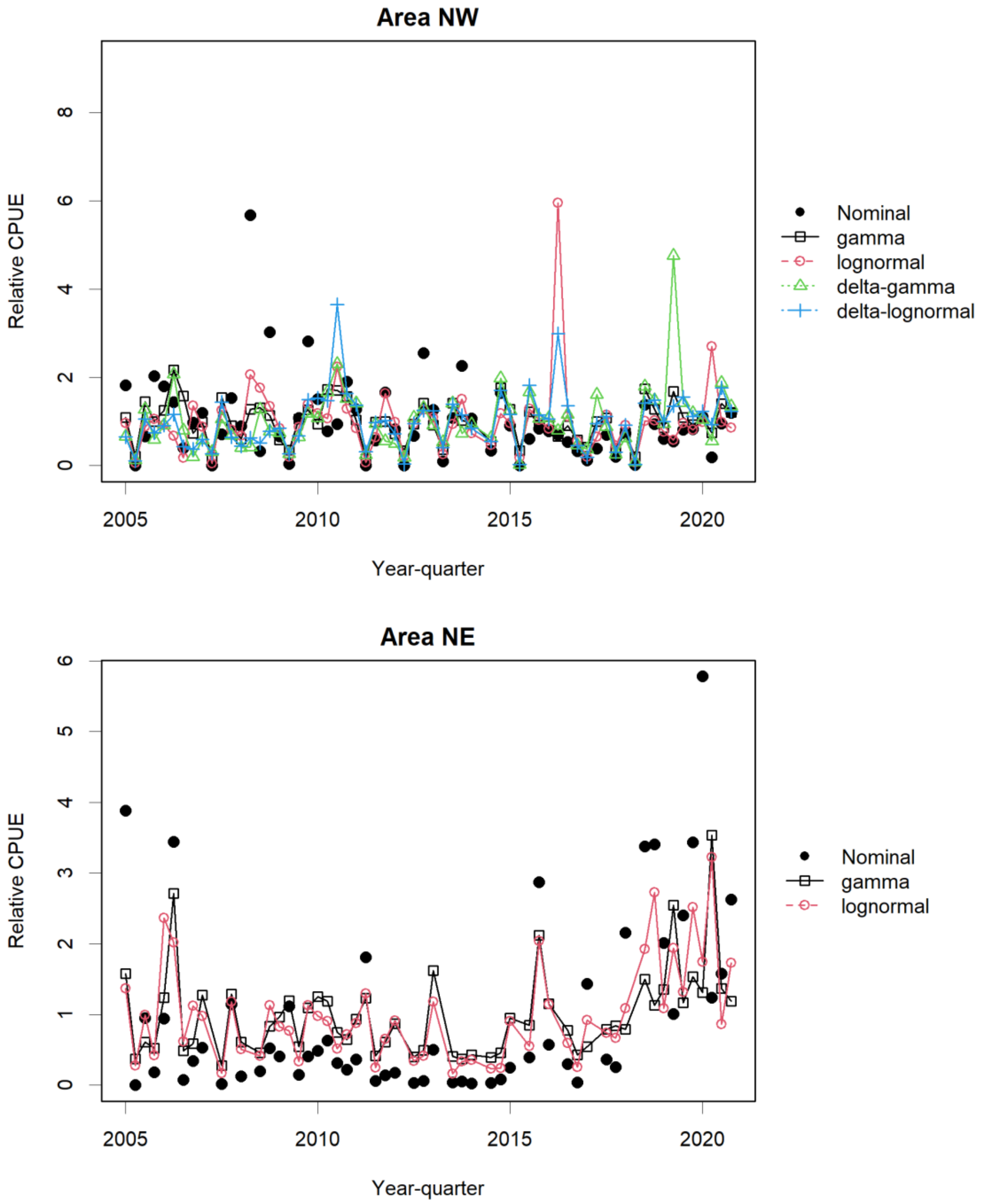
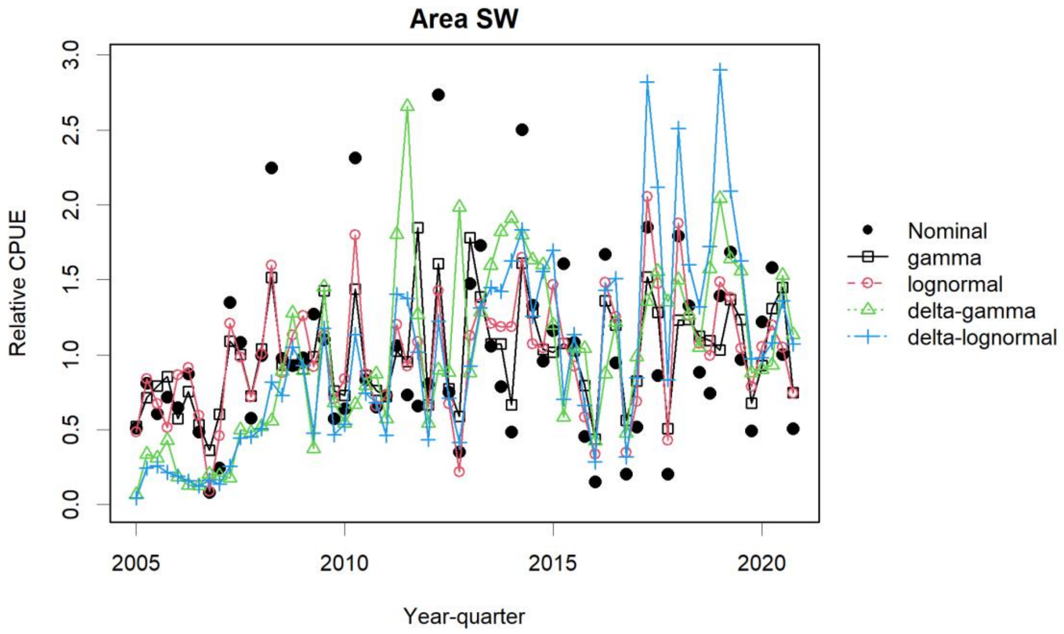


Fig. 15. Year-quarterly standardized CPUE series based on regular GLM and delta-GLM for albacore caught by Taiwanese large-scale longline fishery in the Indian Ocean from.



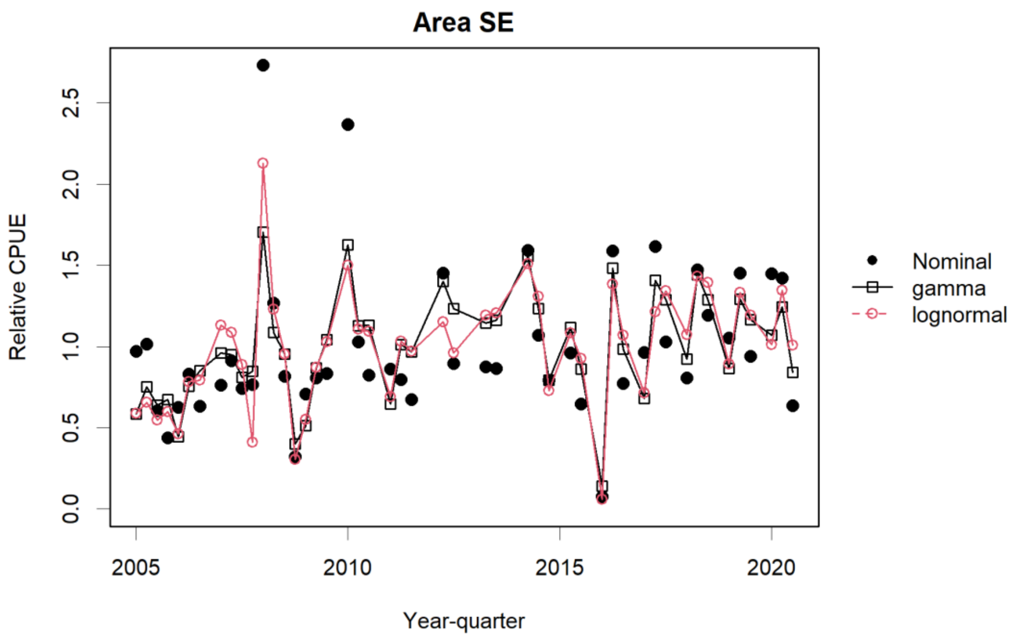


Fig. 15. (Continued).

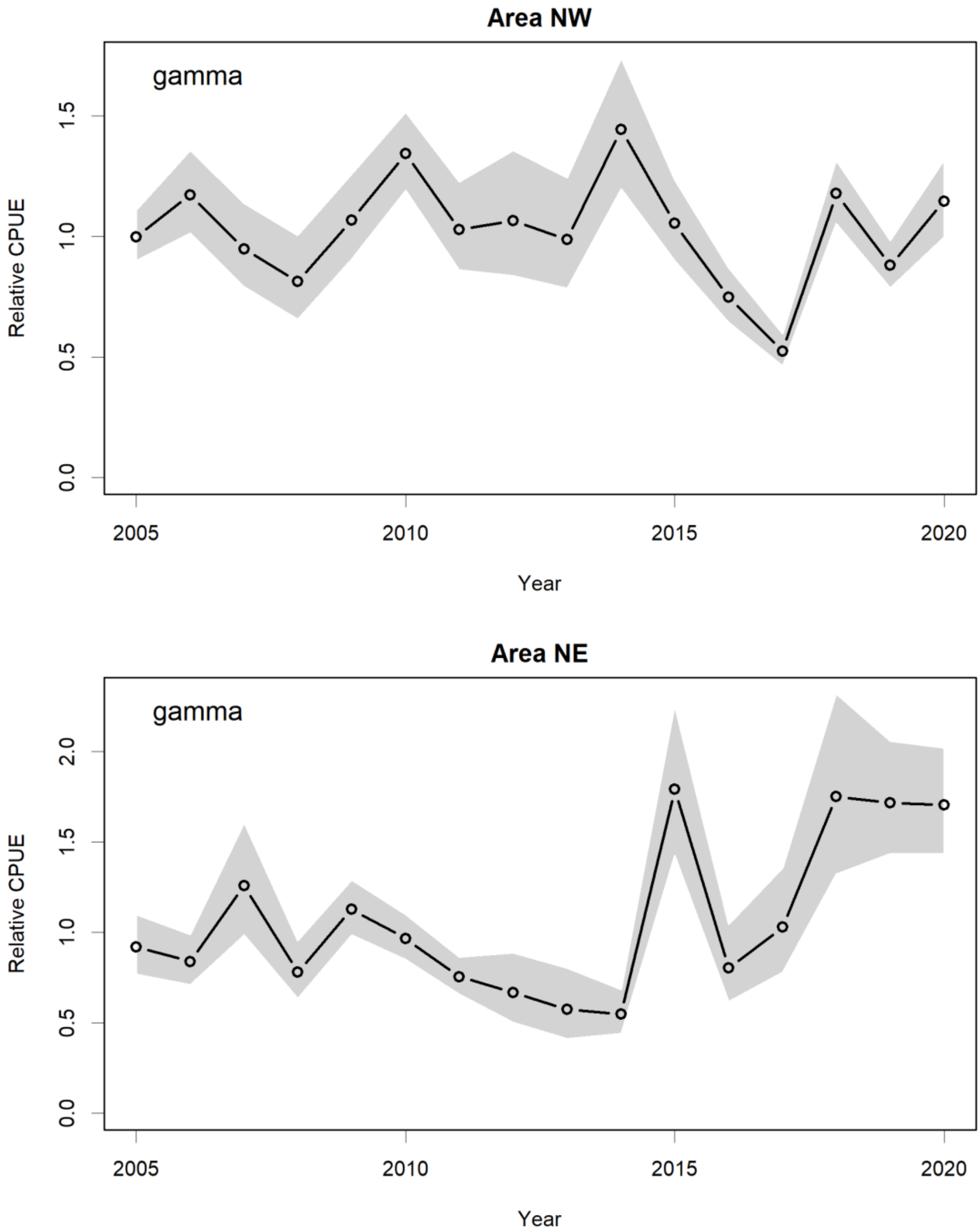
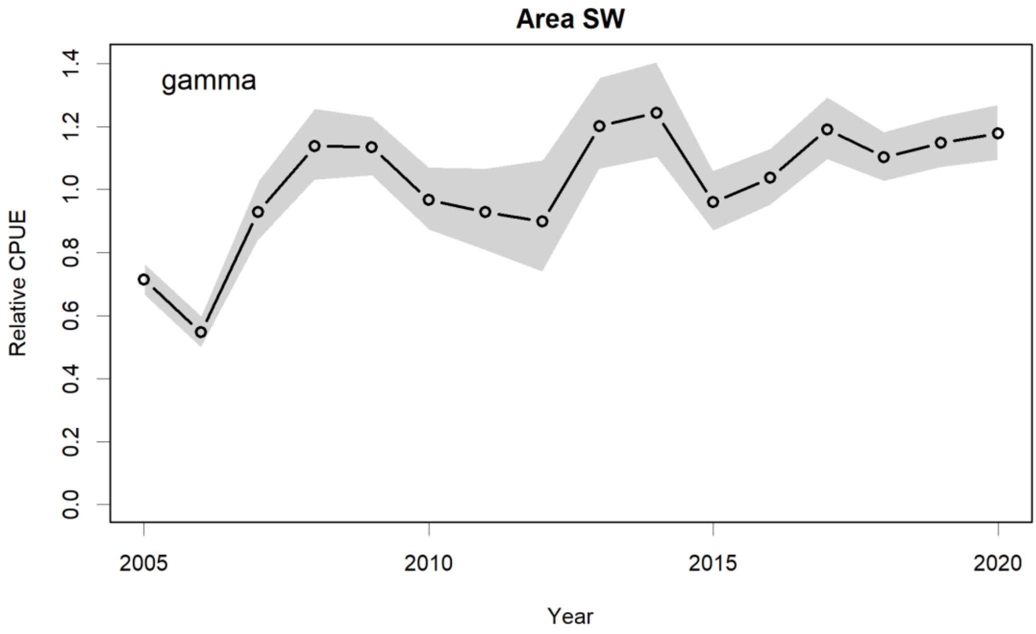


Fig. 16. Annual standardized CPUE series based on regular GLM and delta-GLM for albacore caught by Taiwanese large-scale longline fishery in the Indian Ocean from.



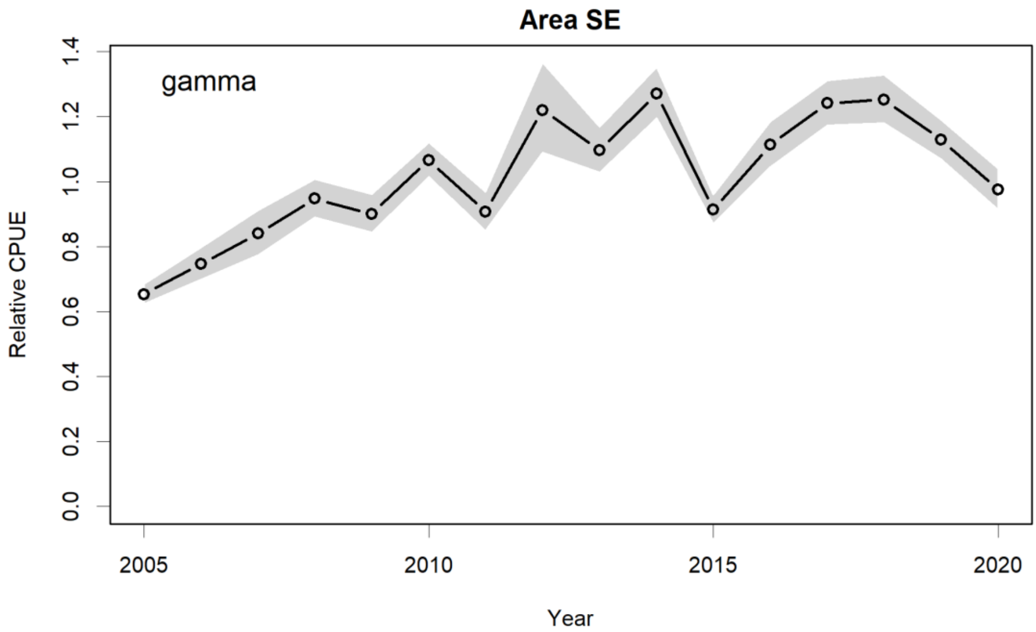


Fig. 16. (Continued).

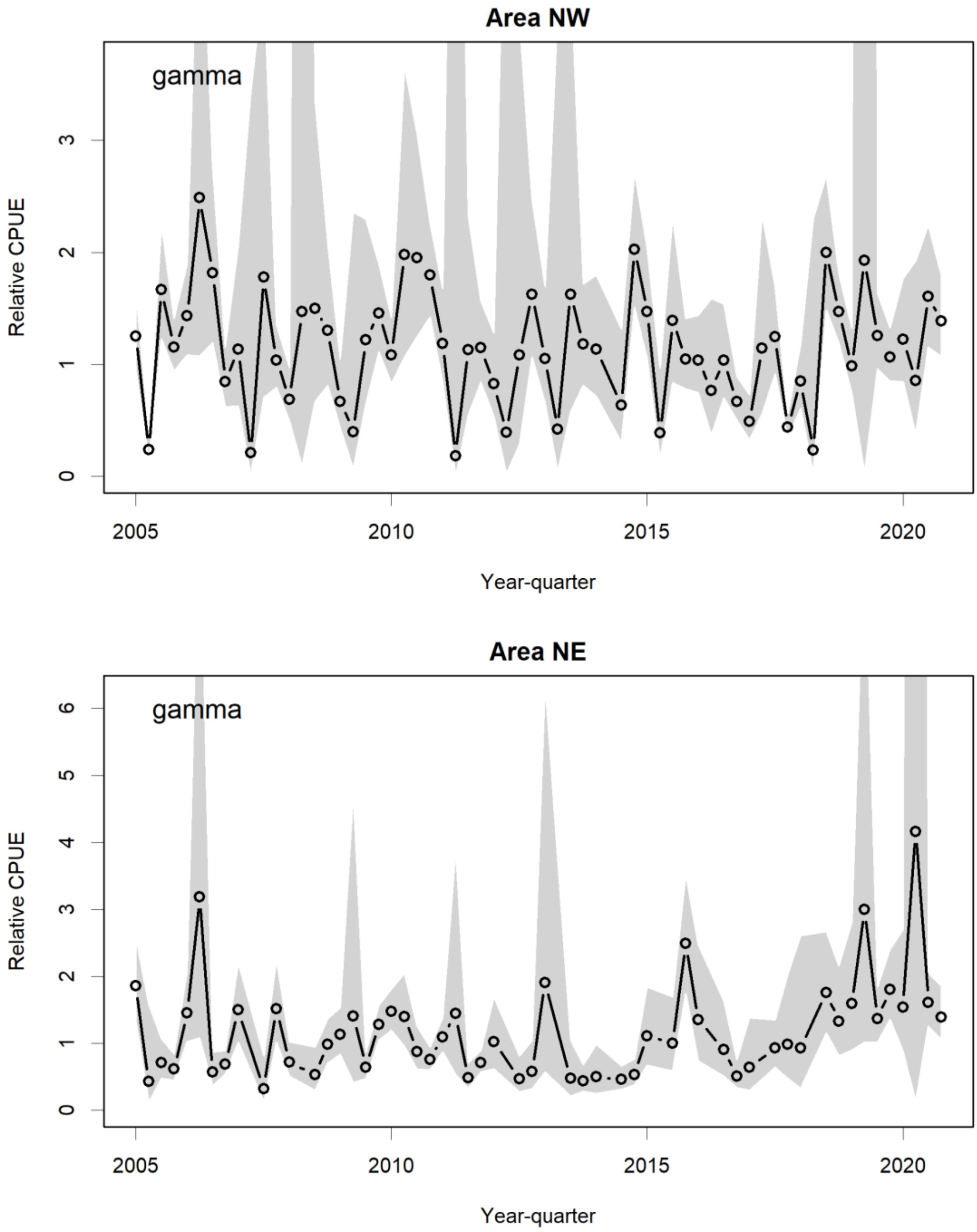
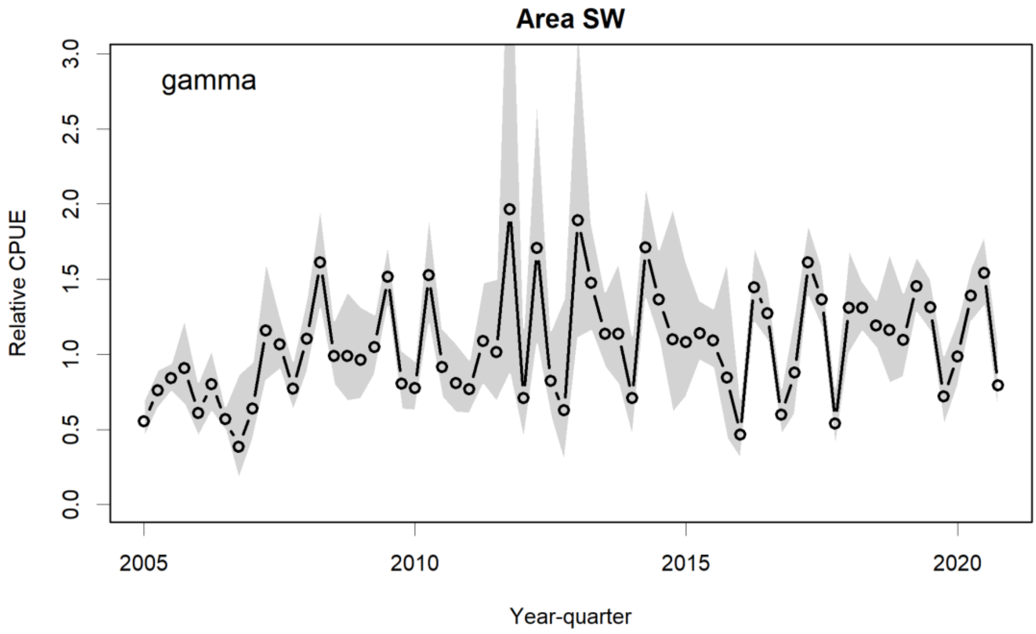


Fig. 17. Year-quarterly standardized CPUE series based on regular GLM and delta-GLM for albacore caught by Taiwanese large-scale longline fishery in the Indian Ocean from.



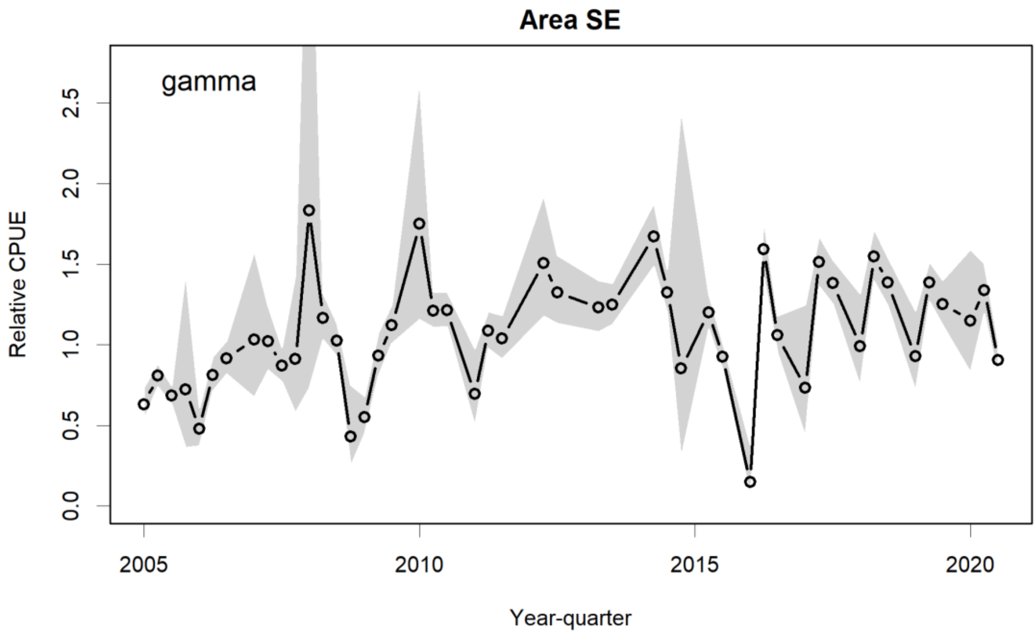


Fig. 17. (Continued).

Table 1. Diagnostic statistics for CPUE standardization based on regular GLM and delta-GLM for annual model for albacore caught by Taiwanese large-scale longline fishery in the Indian Ocean.

Regular GLM

Area	Model	R^2	AIC	BIC	Dispersion
NW	lognormal	0.55	110,270	110,509	2.77
NW	gamma	0.48	79,791	80,031	2.58
NE	lognormal	0.79	49,359	49,577	3.75
NE	gamma	0.64	30,082	30,286	3.91
SW	lognormal	0.45	167,219	167,482	1.54
SW	gamma	0.41	139,688	139,951	1.41
SE	lognormal	0.54	156,694	156,948	1.18
SE	gamma	0.36	140,262	140,517	1.13

delta-GLM for positive catches

Area	Model	R^2	AIC	BIC	Dispersion
NW	lognormal	0.63	139,372	139,627	2.50
NW	gamma	0.55	102,615	102,870	2.45
NE	lognormal	0.77	30,289	30,488	2.55
NE	gamma	0.62	21,819	22,006	2.60
SW	lognormal	0.69	323,122	323,418	2.18
SW	gamma	0.66	238,320	238,616	2.22
SE	lognormal	0.53	154,262	154,516	1.15
SE	gamma	0.39	136,500	136,754	1.09

Table 2. Diagnostic statistics for CPUE standardization based on regular GLM and delta-GLM for year-quarter model for albacore caught by Taiwanese large-scale longline fishery in the Indian Ocean.

Regular GLM

Area	Model	R^2	AIC	BIC	Dispersion
NW	lognormal	0.57	109,943	110,501	2.52
NW	gamma	0.50	79,257	79,816	2.60
NE	lognormal	0.80	49,082	49,537	3.72
NE	gamma	0.66	29,741	30,183	3.94
SW	lognormal	0.48	166,530	167,131	1.52
SW	gamma	0.43	139,328	139,930	1.41
SE	lognormal	0.55	156,435	156,906	1.18
SE	gamma	0.38	139,992	140,463	1.13

delta-GLM for positive catches

Area	Model	R^2	AIC	BIC	Dispersion
NW	lognormal	0.64	139,008	139,594	2.50
NW	gamma	0.56	102,262	102,848	2.46
NE	lognormal	0.79	30,159	30,571	2.58
NE	gamma	0.65	21,648	22,048	2.62
SW	lognormal	0.70	321,673	322,340	2.16
SW	gamma	0.67	237,472	238,139	2.21
SE	lognormal	0.54	154,015	154,485	1.15
SE	gamma	0.41	136,157	136,627	1.09

Table 3. ANOVA table for selected CPUE standardization based on selected GLM for annual model for albacore caught by Taiwanese large-scale longline fishery in the Indian Ocean.

NW

	Sum Sq	Df	F values	Pr(>F)
Y	539.1	15	24.08	< 2.2e-16 ***
Q	187.6	3	41.90	< 2.2e-16 ***
CT	248.2	2	83.15	< 2.2e-16 ***
Lon	1289.8	8	108.02	< 2.2e-16 ***
Lat	1151.1	2	385.60	< 2.2e-16 ***
T	1753.6	1	1174.90	< 2.2e-16 ***
Residuals	15476.2	10369		

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

NE

	Sum Sq	Df	F values	Pr(>F)
Y	441.9	15	23.72	< 2.2e-16 ***
Q	187.1	3	50.22	< 2.2e-16 ***
Lon	120.7	6	16.20	< 2.2e-16 ***
Lat	287.0	2	115.55	< 2.2e-16 ***
T	1288.8	3	345.87	< 2.2e-16 ***
Residuals	6683.7	5381		

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

Table 3. (Continued).

SW

	Sum Sq	Df	F values	Pr(>F)
Y	517.2	15	43.06	< 2.2e-16 ***
Q	195.7	3	81.44	< 2.2e-16 ***
CT	75.7	2	47.28	< 2.2e-16 ***
Lon	205.9	10	25.72	< 2.2e-16 ***
Lat	263.2	2	164.31	< 2.2e-16 ***
T	2943.4	1	3675.50	< 2.2e-16 ***
Residuals	10841.4	13538		

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

SE

	Sum Sq	Df	F values	Pr(>F)
Y	430.7	15	86.90	< 2.2e-16 ***
Q	76.2	3	76.84	< 2.2e-16 ***
CT	76.3	2	115.42	< 2.2e-16 ***
Lon	89.0	7	38.46	< 2.2e-16 ***
Lat	22.1	2	33.37	3.50E-15 ***
T	1315.6	3	1327.32	< 2.2e-16 ***
Residuals	4317.0	13066		

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

Table 4. ANOVA table for selected CPUE standardization based on selected GLM for year-quarterly model for albacore caught by Taiwanese large-scale longline fishery in the Indian Ocean.

NW

	Sum Sq	Df	F values	Pr(>F)
YQ	1253.3	62	14.17	< 2.2e-16 ***
CT	229.1	2	80.33	< 2.2e-16 ***
Lon	1010.4	8	88.55	< 2.2e-16 ***
Lat	1200.3	2	420.77	< 2.2e-16 ***
T	1463.4	1	1026.03	< 2.2e-16 ***
Residuals	14726.3	10325		

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

NE

	Sum Sq	Df	F values	Pr(>F)
YQ	832.4	54	14.19	< 2.2e-16 ***
Lon	87.9	6	13.49	3.01E-15 ***
Lat	305.8	2	140.76	< 2.2e-16 ***
T	974.1	3	298.96	< 2.2e-16 ***
Residuals	5805.4	5345		

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

Table 4. (Continued).

SW

	Sum Sq	Df	F values	Pr(>F)
YQ	1046.6	63	21.55	< 2.2e-16 ***
CT	63.4	2	41.15	< 2.2e-16 ***
Lon	162.6	10	21.09	< 2.2e-16 ***
Lat	245.0	2	158.90	< 2.2e-16 ***
T	2688.4	1	3487.45	< 2.2e-16 ***
Residuals	10401.5	13493		

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

SE

	Sum Sq	Df	F values	Pr(>F)
YQ	655.5	47	42.94	< 2.2e-16 ***
CT	74.5	2	114.70	< 2.2e-16 ***
Lon	82.3	7	36.22	< 2.2e-16 ***
Lat	20.9	2	32.24	1.08E-14 ***
T	1256.3	3	1289.35	< 2.2e-16 ***
Residuals	4234.2	13037		

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