CPUE standardization analyses for southern bluefin tuna based on the Taiwanese longline fishery data from 2002 to 2024

Ching-Ping Lu[1], Sheng-Ping Wang[1], Shu-Ting Chang[2], Jia-Hao Chang[3], I-Lu Lai[3]

[1] Department of Environmental Biology and Fisheries Science,
National Taiwan Ocean University, Taiwan
[2] Overseas Fisheries Development Council, Taiwan
[3] Fisheries Agency, Ministry of Agriculture, Taiwan

ABSTRACT

The CPUE standardization analyses were conducted with the statistical information of Taiwanese longline fleets, and the period of temporal data was from 2002 to 2024. The operating water of the large-scale Taiwanese longliner were distributed the south of 20°S of the Indian Ocean. The fishing areas of the Indian Ocean were separated to the central-eastern area (Area E: main fishing area) and the western area (Area W: secondary fishing area) with the boundary 60°E for the CPUE standardization analyses. Followed the steps of CPUE standardization analyses for each area, the cluster analysis was initially processed to explore the targeting of fishing operations and to produce the data filter for selecting the data for the next step. Weekly-aggregated data was applied for clarifying various styles of the targeting of fishing operations. Then, the simple delta-lognormal model without interactions was adopted to avoid the confounding from interactions for the CPUE standardizations analyses. As the results CPUE standardizations, the pattern of CPUE trends in area E were relatively increasing trend with updated data in 2024 and the pattern of CPUE trends in area W were presented decreasing trend with the updated information of 2024. The pattern of the CPUE trends in both fishing areas remained similar as the past with retrospect analysis using updated data.

1. INTRODUCTION

Before the 1990s, albacore was one of the target species of Taiwanese tuna longline fishery, at that time, Southern bluefin tuna (*Thunnus maccoyii*; SBT) was the bycatch species in the Indian Ocean. Since the 1990s, some Taiwanese fishing vessels equipment deep-frozen freezers started the seasonal targeting SBT fishery in the Indian Ocean. For the purpose of improving the quality of the related SBT fishing information, Taiwanese SBT statistics system was reformed for the data collection in 2002. And the reporting rate of SBT catch data had substantially improved since then (Anon, 2014). It is helpful for further understanding of the SBT fishery indicators with the improved Taiwanese SBT statistics fishing information. Therefore, the main goal of this study is to explore the variation of temporal and spatial patterns of SBT using the major species of catch and effort data of Taiwanese longline fishery operated in the waters of the south of 20°S of the Indian Ocean. Here, we presented the temporal pattern and the results of the CPUE standardization of Taiwanese SBT fishery using the updated statistics fishing information from 2002 to 2024.

2. MATERIALS AND METHODS

2.1. Catch and Effort data

The operational catch and effort data of large scale Taiwanese longline fisheries from 2002 to 2024 provided by the Overseas Fisheries Development Council (OFDC) of Taiwan were applied for the CPUE standardization in this study. The resolution of the dataset was compiled by 5×5 degree fishing location grids from Taiwanese longline fleets fishing information.

According to the suggestions of the previous studies (Wang et al., 2015; 2017; 2018.), the SBT fishing ground of Taiwanese longline fisheries was divided into the central-eastern area (Area E) and western area (Area W) by the boundary at the 60°E (Fig. 1). Also, it is suitable for the CPUE standardization analyses of the SBT caught by large scale Taiwanese longline fishery. Here, all of the analyses were conducted with this area stratification with the boundary at the 60°E in the Indian Ocean.

2.2. Cluster analysis

Following the methodology of the previous study (Wang et al. 2015) and the suggestions by the experts of CCSBT ESC meetings in 2015 and 2016, we applied the cluster analysis (He et al., 1997) as first step to explore the targeting of fishing operations and to produce the data filter for selecting the data for the further CPUE standardization of the Area E and Area W defined in this study. Cluster analyses were processed using the major species composition of the catches in both areas. There were six major species were used including albacore (ALB), bigeye tuna (BET), yellowfin tuna (YFT), swordfish (SWO), southern bluefin tuna (SBT) and other species (OTH, the majority of the catches is composed by the oilfish). According to the recommendation of CCSBT ESC meeting in 2016, the clustering operational set-by-set data might contain large amount noise that because most of SBT caught by Taiwanese vessels was bycatches and only part of vessels targeted SBT for some fishing operations during the SBT fishing seasons. Therefore, ESC suggested that the cluster analysis could be processed using the aggregated data rather than the operational set-by-set data. Based on all the suggestions and considerations, we conducted the cluster analyses with both monthly and weekly aggregated data and then merged the clusters with operational data sets to identify the SBT fishing operations. However, while applying the cluster analysis with the monthly-aggregated data, the proportion of SBT catches decreased substantially and the difficulties were increased to identify the cluster contained SBT fishing operations (Wang et al., 2017). Then, we decided to conduct the cluster analyses using weekly-aggregated data in this study.

The hierarchical cluster analysis with Ward's minimum variance method was performed to the squared Euclidean distances calculated from the aggregated data sets. The analyses were conducted using R (R Core Team (2019) with functions "hclust" and "cutree". The number of clusters was strongly influenced by the subjective choice (He et al. 1997). Here, there were at least two clusters (SBT sets and other tuna sets) as it expected. There were more than two clusters were produced to allow other possible categories to emerge. Additional clusters were considered until the smallest cluster contained very few efforts. Here, we kept the SBT catch proportions of a specific cluster as large as possible and the proportion of data sets of the smallest cluster was larger than 5%.

2.3. CPUE standardization

Because there was large amount of SBT zero catch ("0") occurred in the fishing data sets, we applied the delta-lognormal models for the CPUE standardization of SBT caught by Taiwanese longline fishery. The main effects of year (Y), month (M), 5x5 grid (G), cluster (C) and number of hooks between floats (NHBF) were suggested by the previous ESC and all included in both of lognormal and delta models. The effects of latitude and longitude were replaced by the effect of 5x5 grid. Additionally, the effects of cluster and NHBF were also included because various catch compositions can be observed in a cluster (Wang et al., 2017). The interactions between main effects were not considered in the models to avoid the confounding resulted from interactions. The models were conducted as below:

$$\begin{array}{ll} \text{lognormal model:} & \log(CPUE) \\ \text{delta model:} & PA \end{array} = \mu + Y + M + G + C + NHBF + \varepsilon$$

where	*CPUE*	is the nominal CPUE of SBT (catch in number/1,000 hooks) from data sets with positive SBT catch,
	PA	is the presence and absence of SBT catch,
	μ	is the intercept,
	Y	is the effect of year,
	M	is the effect of month,
	G	is the effect of 5x5 grid,
	C	is the effect of cluster,
	NHBF	is the effect of number of hooks between floats,
	ε	is the error term, $\varepsilon \sim N(0, \sigma^2)$.

The effects of year, month, cluster and 5x5 grid were treated as categorical variables. The effect of NHBF was treated as three categories with various hooks including regular (≤9 hooks), deep (10-14 hooks), and ultra-deep (≥15 hooks) (Wang and Nishida, 2011).

The standardized CPUE trends were estimated with the exponentiations of the adjusted means (least square means) of the effect of year (Butterworth, 1996; Maunder and Punt, 2004). The model was selected based on the value of Akaike information criterion (AIC) and the estimations of the models were performed using R (R Core Team (2019) with functions “glm” and “lsmeans”.

The standardized CPUE was calculated by the product of the CPUE of positive catch and the probability of positive catches:

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

where	$\tilde{C}PUE$	is the least square means of the effect of year from the lognormal model,
	$\tilde{P}$	is the least square means of the effect of year from the delta model.

3. RESULTS AND DISCUSSIONS

3.1. Cluster analysis

Cluster analysis was performed with the major species composition of the catches of Taiwanese large-scale longliners in the Indian Ocean. The annually composition of the catches of six major species from 2002 to 2024 were presented in Fig. 2 and Fig. 3. The ALB catch was the majority of the catch of Taiwanese large-scale longline fisheries excluded other species (OTH). The cluster analyses were conducted for the Area E and Area W separately with the boundary at the 60°E of Taiwanese SBT fishing area in the Indian Ocean. The Area E as the main fishing area, four clusters were identified in Figure 4. And according to the catch proportion by species of each cluster, multiple species were observed in the Cluster 1, the majority of components in the Cluster 1 were contributed by the ALB, BET, SBT and OTH operations, and the rest of operations with less proportion of YFT and SWO were also composed in this Cluster. For the Cluster 2, the ALB operation was the majority of this Cluster and the catch proportions were almost over 0.8 each year, also included relatively fewer operations for BET, SBT and OTH. Similar pattern of the catch proportions was also observed in Cluster 3, the ALB operation took the majority, the OTH operation showed the higher catch proportions than the rest of fewer operations for BET and SBT. And in the Cluster 4, it was mainly and clearly contributed by the SBT operations (Figs. 5 and 6). Although the highest SBT catch proportion was occurred in Cluster 4, most of the SBT catches were contained in Cluster 1 and Cluster 2 (Fig. 7). For SBT operation Cluster (Cluster 4), several fishing characteristics were observed and described by the main effects as bellowed and shown in Fig. 8 and Fig. 9: (1) the data mainly consisted of the data in the early 2000s; (2) the majority of fishing operations were concentrated from June to September; (3) the NHBF concentrated at around 10 hooks; and (4) the operations also concentrated in the waters between 30°S and 35°S. The spatial distribution of SBT catch proportion was illustrated that the SBT catch proportion of Cluster 4 was obviously higher than the rest of others clusters.

For the Area W, the cluster analysis was conducted and two clusters were selected in this Area (Fig. 10). According to the result, the ALB operations was found as the majority parts of composition in Cluster 1 and contained the rest of operations such as BET, YFT, SBT, SWO and OTH. The OTH operations was belonged to Cluster 2 where mostly composed by oilfish (Figs. 11 and 12). Most of SBT catches were found in Cluster 1. (Fig. 13). For the fishing characteristics with various factors were described: (1) For the factor of year, Cluster 1 broadly consisted of the data period between 2006 and 202, while the majority data of Cluster 2 were concentrated between 2010 and 2018; (2) NHBF of Cluster 1 was distributed wider than Cluster 2; And the NHBF of Cluster 2 was concentrated at the deep (10-14 hooks) category; (3) Fishing areas by longitude and latitude were different between two Clusters (Fig. 14). The SBT catch proportion of two cluster were illustrated by the spatial distribution and there were no obvious differences in the Area W. (Fig. 15).

3.2 CPUE standardization

For both of Areas E and W, the final models were selected with the models with the lowest value of AIC. The results of ANOVA analysis for the lognormal models are shown in Table 1. All of the effects were statistically significant for both areas. About 28.1% and 35.9% of CPUE variances were explained by the models for Area E and Area W, respectively. The distributions of standardized residuals and the Quantile-Quantile Plots indicated that the distributions of residuals fitted to the assumption of the normal distribution (Fig. 16). For delta models, all of the main effects were also statistically significant for both areas (Table 2) and about 34.0% and 22.0% of CPUE variances were explained by the models for Area E and Area W, respectively.

Standardized CPUE series of Area E and Area W demonstrated quite different patterns (Fig. 17). In the Area E, the standardized CPUE series gradually showed the increasing trend after 2004, and revealed variation in the period of 2004 to 2011, then substantially increased in 2012 and reached the highest peak. After that the trend gradually decreased until 2015. And in recent years it remained higher and relatively stable increasing pattern and reached the highest in 2022. This year, with the updated data of 2024, it presented the increased status. Moreover, for Area W, the standardized CPUE series generally revealed a decreasing trend with a fluctuation since 2002 and after 2013 stayed stable low pattern until 2019, after that it presented increasing trend and presented the highest in 2021 then back to lower value as the past. And with the updated data of 2024, it revealed slightly decreased and back to the similar level of 2019. The pattern of CPUE trends in area E were relatively increasing trend with updated data in 2024 and the pattern of CPUE trends in area W were presented decreasing trend with the updated information of 2024.

3.3 Retrospect analysis

The retrospect analyses were performed to understand the influence while using the updated data to 2024 on the CPUE standardization of both Area E and Area W. The analysis was performed by removing the data from 2024 to 2012. The results indicated that the influence of adding the updated data on the CPUE standardization was negligible for both two areas. Although the index values of standardized CPUE series slightly changed while applying updated data into CPUE standardization, however, the pattern of the CPUE trends remained high similarity of variation patterns (Fig. 18).

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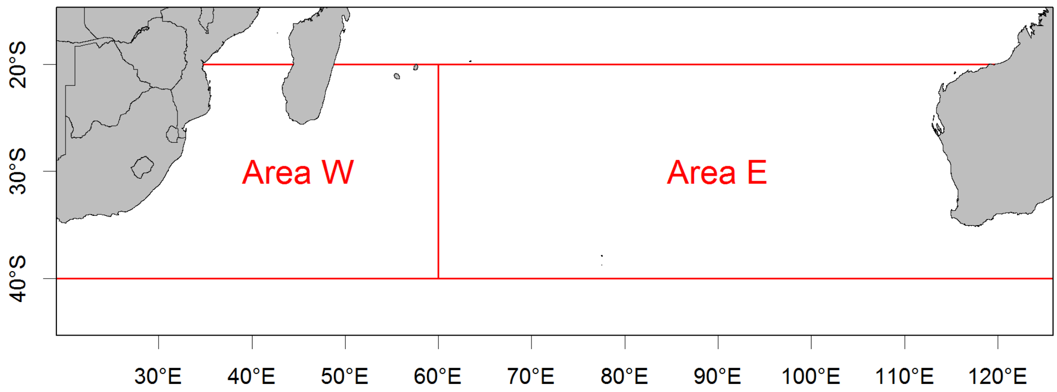


Fig. 1. Fishing area stratification for southern bluefin tuna of Taiwanese large scale longline fishery in the Indian Ocean.

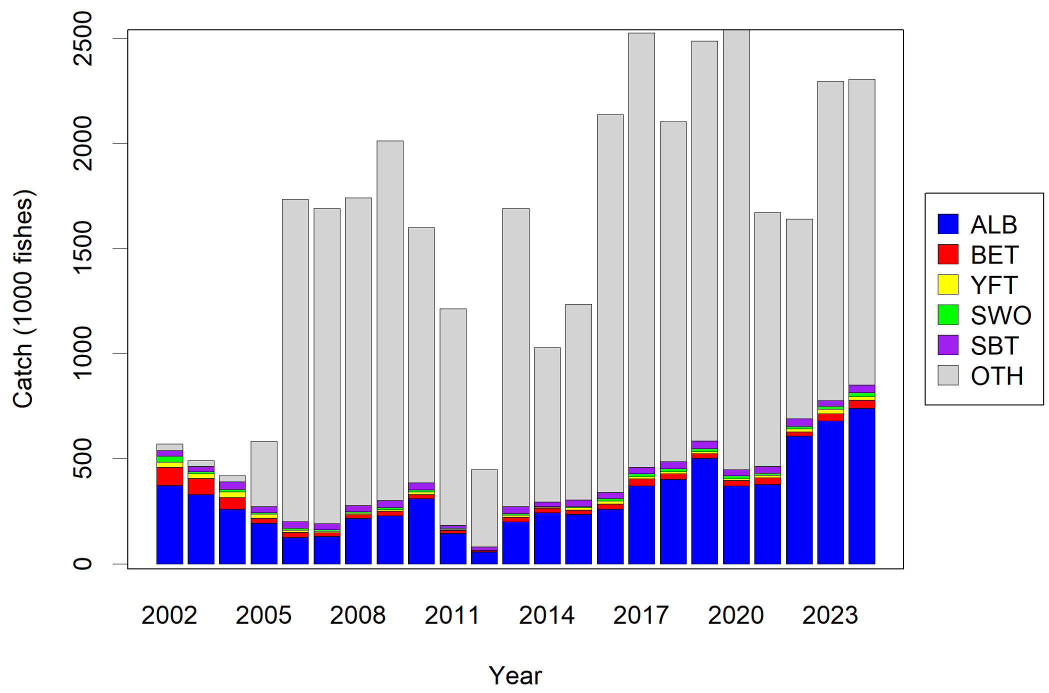


Fig. 2. Annual catch composition of the major species caught by Taiwanese longline fleets operated in the waters of south of 20°S in the Indian Ocean from 2002 to 2024.

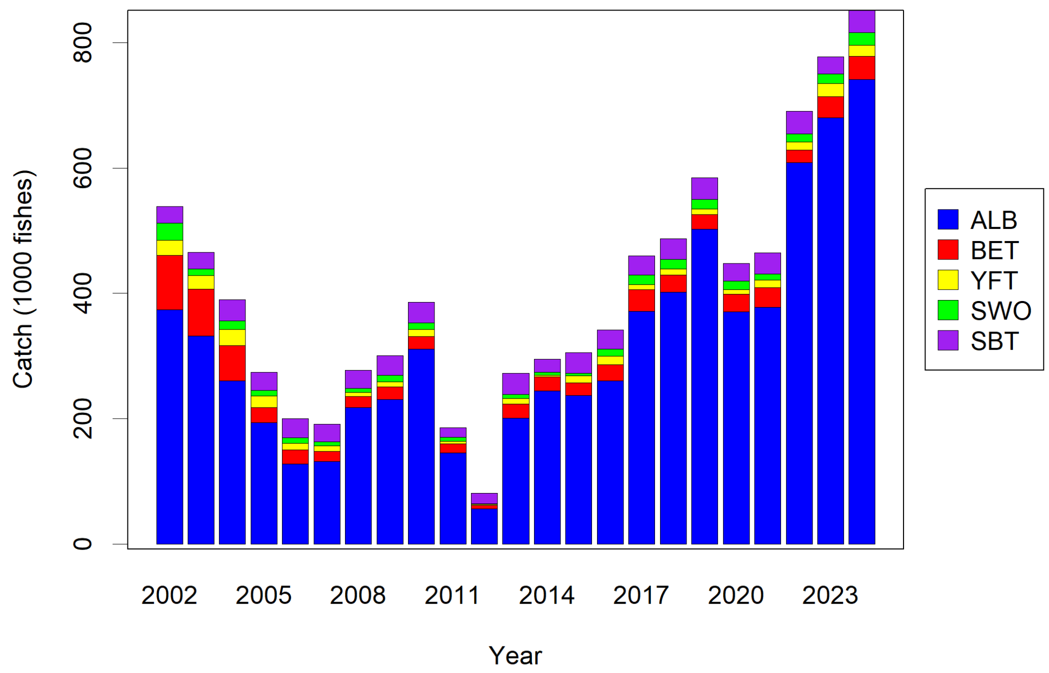


Fig. 3. Annual catch composition of the major species caught by Taiwanese longline fleets operated in the waters of south of 20°S in the Indian Ocean from 2002 to 2024. The catches of OTH are excluded.

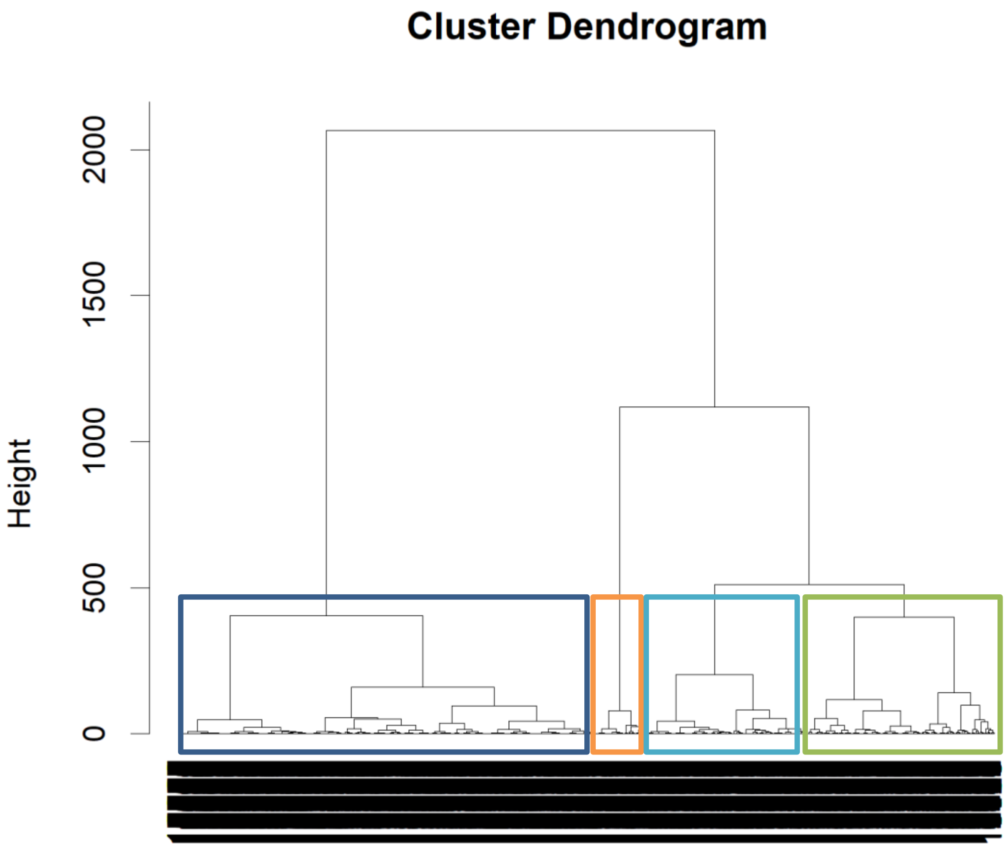


Fig. 4. The tree of cluster analysis using the data of Taiwanese large scale longline fishery in Southern Bluefin Tuna (SBT) Area E of the Indian Ocean.

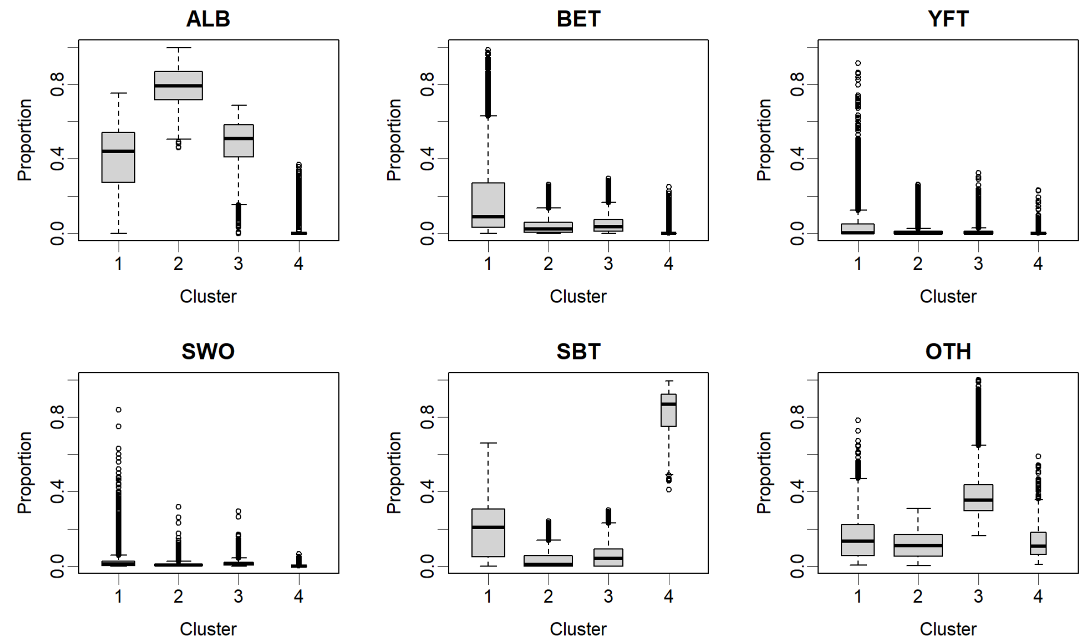


Fig. 5. Catch proportion by species for each cluster of Taiwanese large scale longline fishery in SBT Area E of the Indian Ocean.

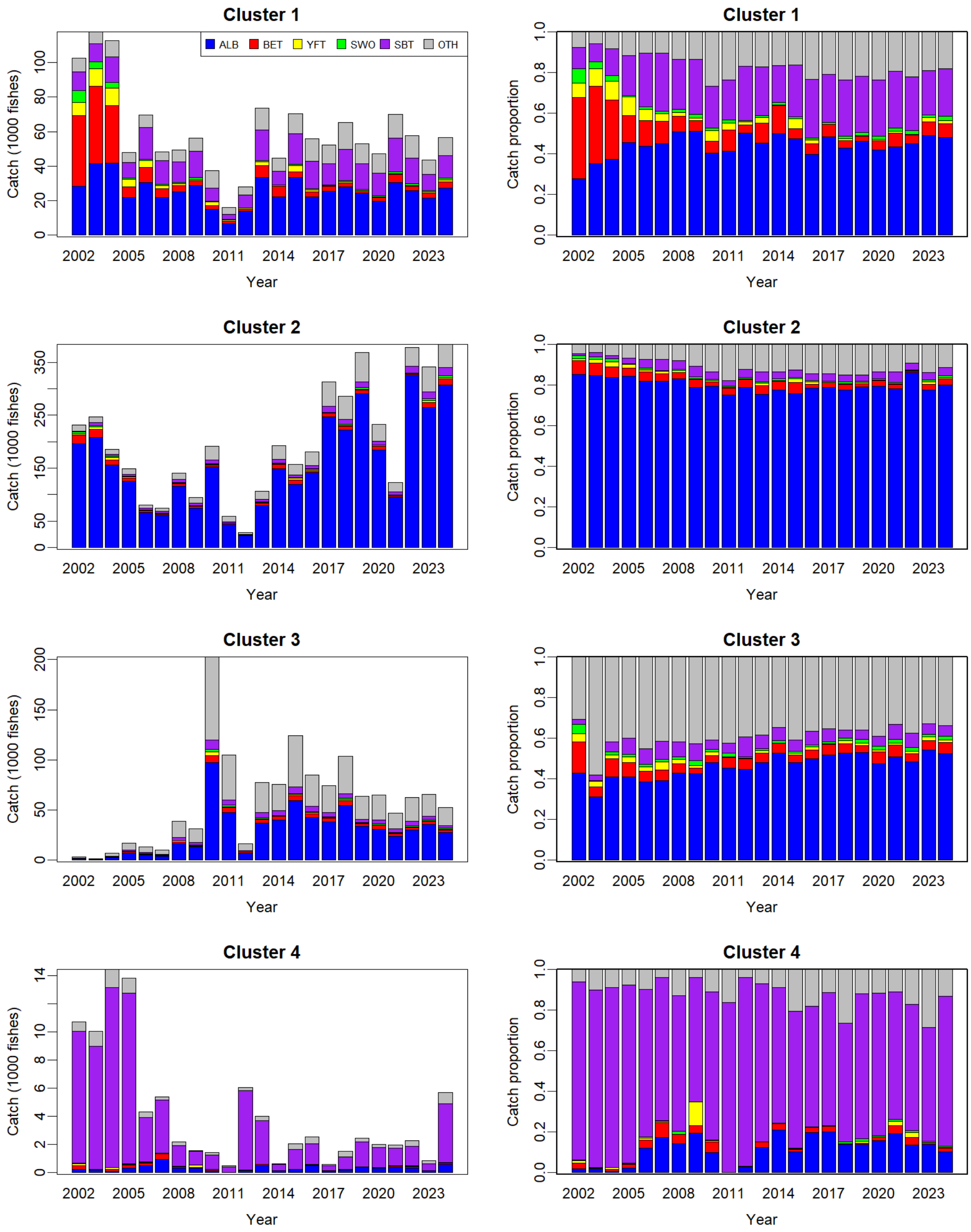


Fig. 6. Annual catch and catch proportion by species for each cluster of Taiwanese large scale longline fishery in SBT Area E of the Indian Ocean.

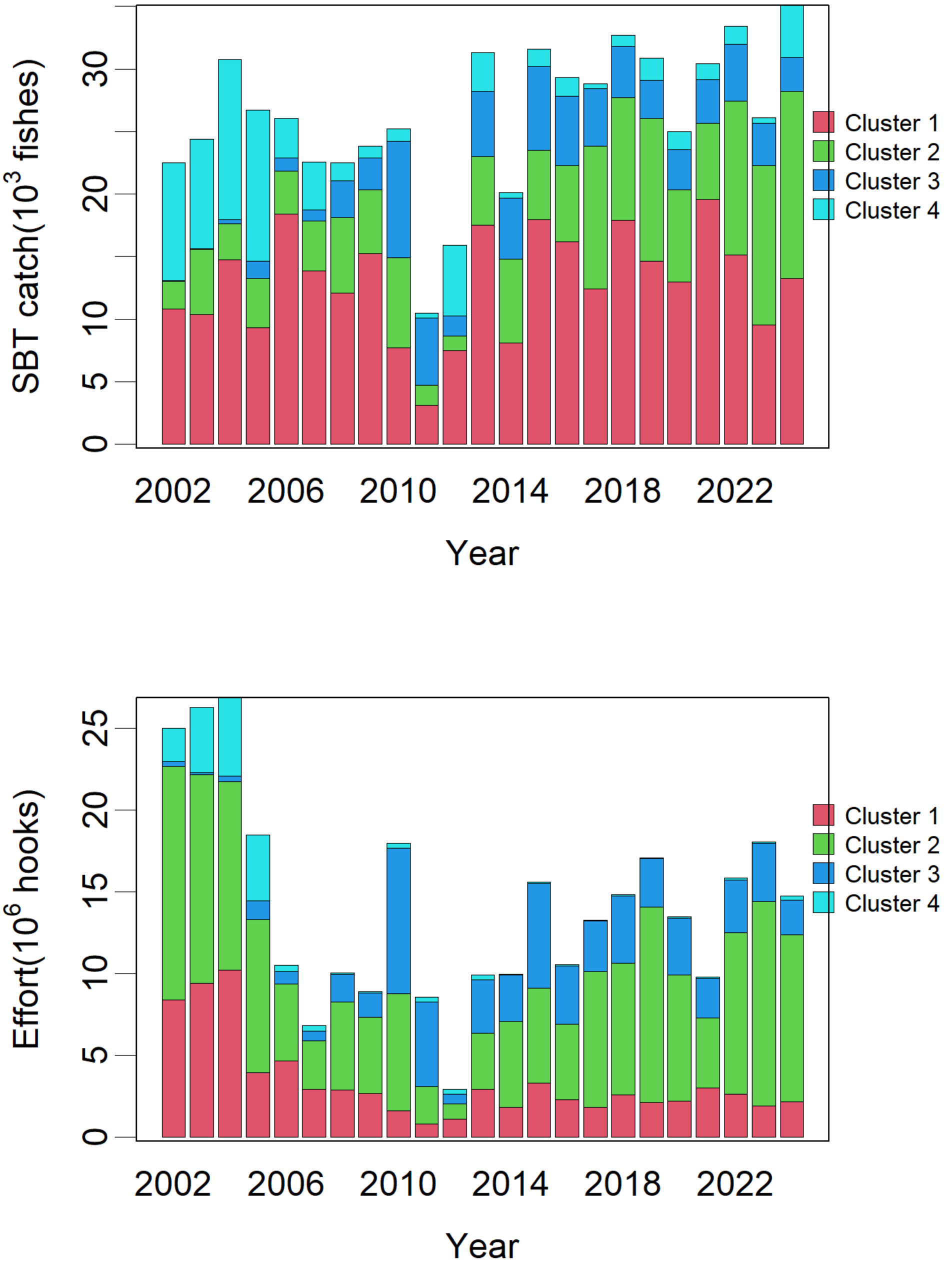


Fig. 7. Annual Southern Bluefin Tuna catches and efforts for each cluster of Taiwanese large scale longline fishery in Area E of the Indian Ocean.

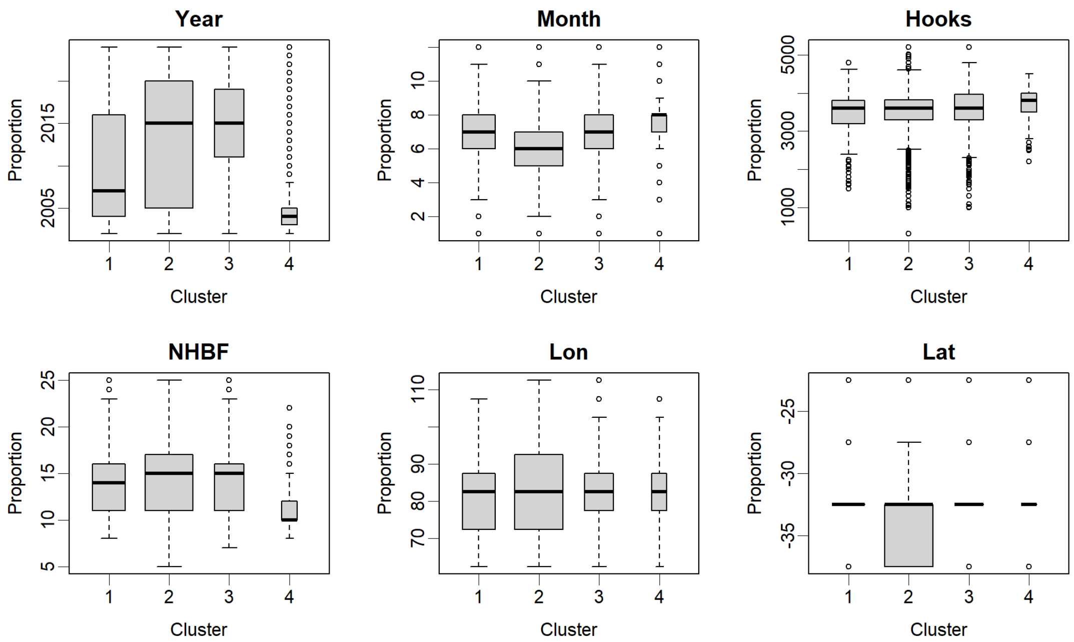


Fig. 8. Data composition by multiple factors for each cluster of Taiwanese large scale longline fishery in SBT Area E of the Indian Ocean.

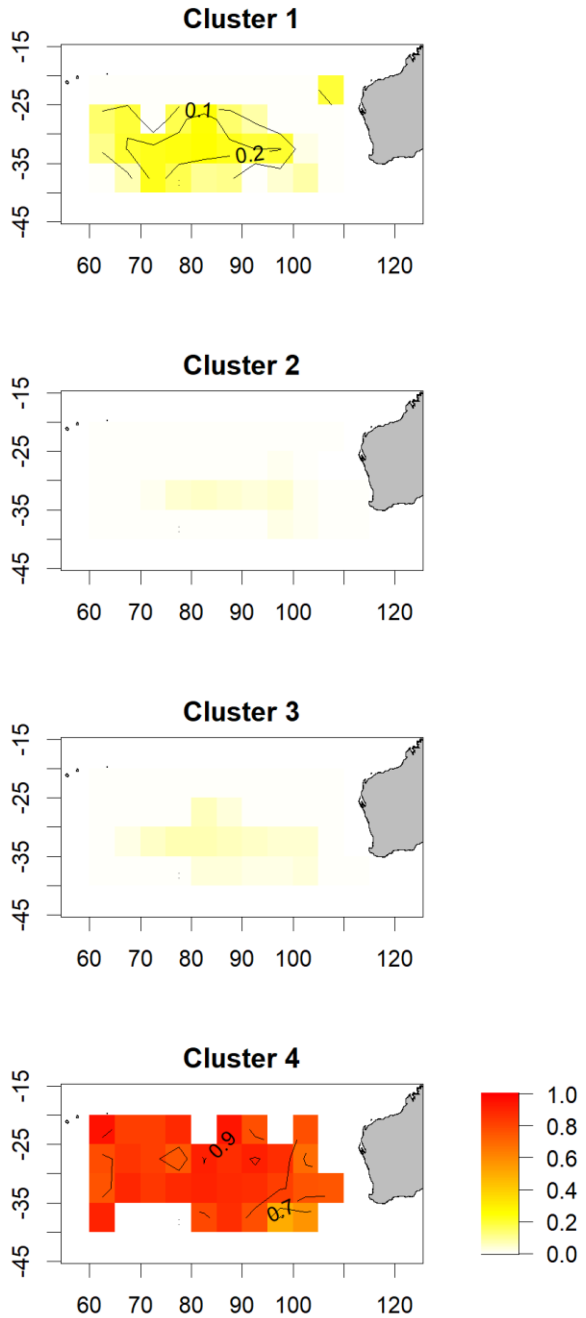


Fig. 9. Southern Bluefin Tuna catch distribution for each cluster of Taiwanese large scale longline fishery in Area E of the Indian Ocean. Red color represents high catch proportion and yellow color presents low catch proportion.

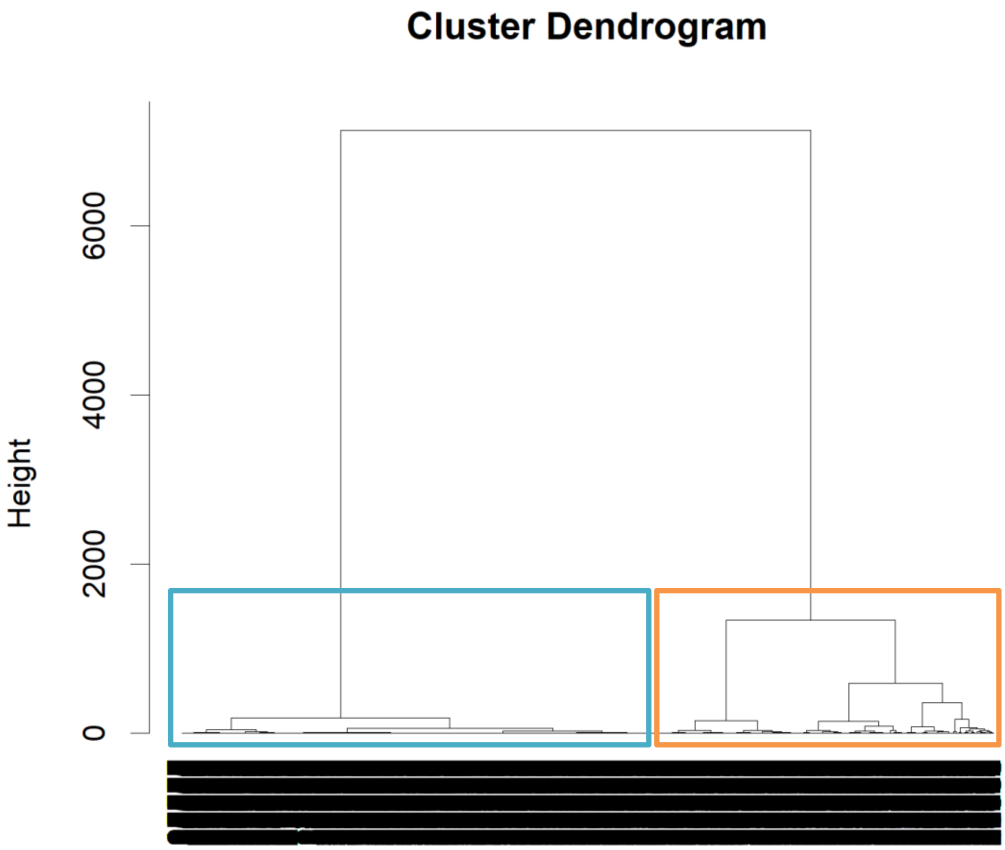


Fig. 10. The tree of cluster analysis using the data of Taiwanese large scale longline fishery in SBT Area W of the Indian Ocean.

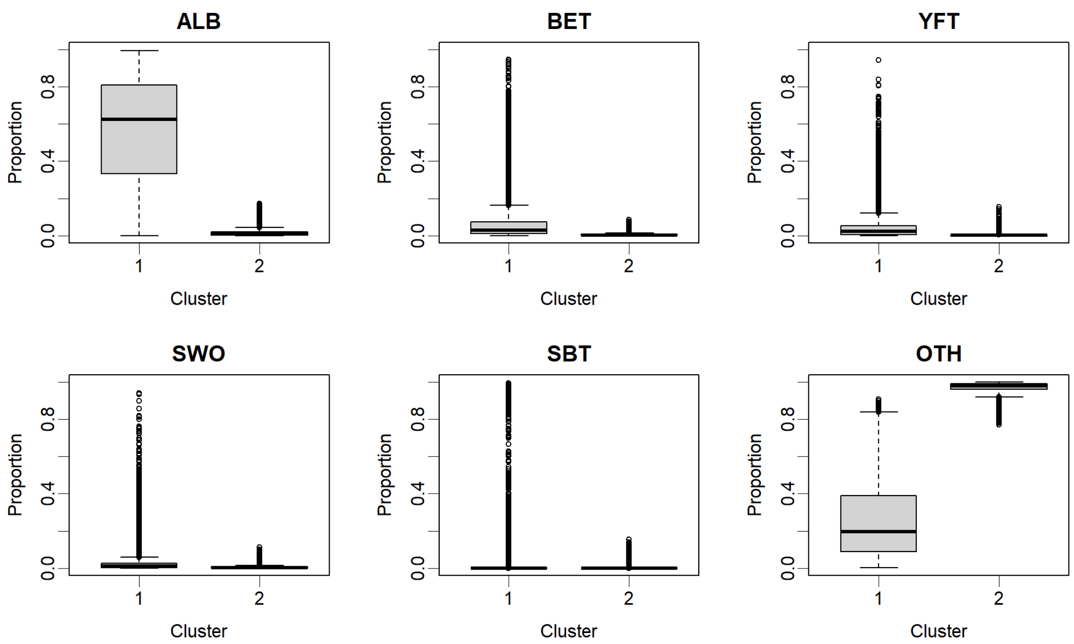


Fig. 11. Catch proportion by species for each cluster of Taiwanese large scale longline fishery in SBT Area W of the Indian Ocean.

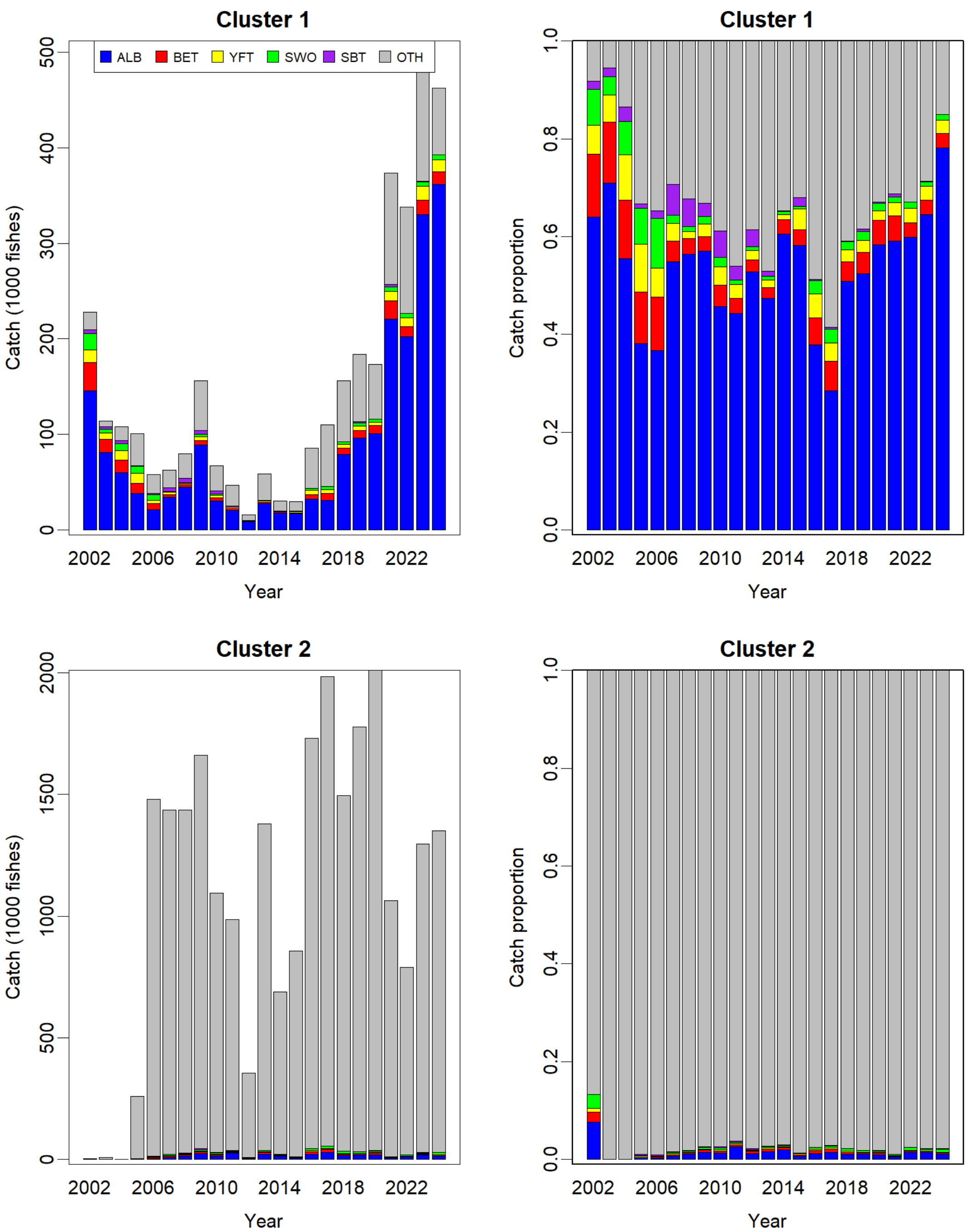


Fig. 12. Annual catch and catch proportion by species for each cluster of Taiwanese large scale longline fishery in SBT Area W of the Indian Ocean.

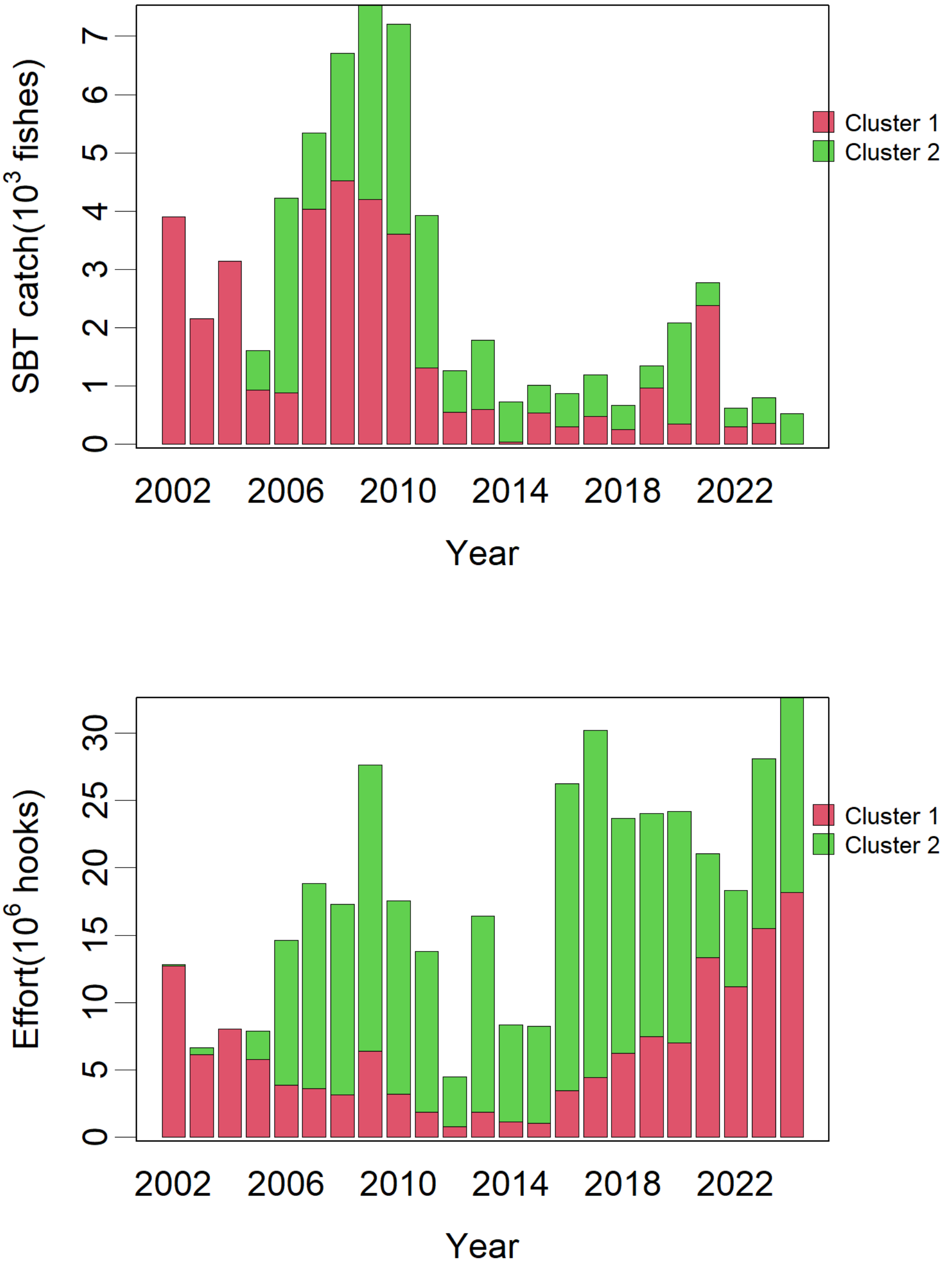


Fig. 13. Annual Southern Bluefin Tuna catches and efforts for each cluster of Taiwanese large scale longline fishery in Area W of the Indian Ocean.

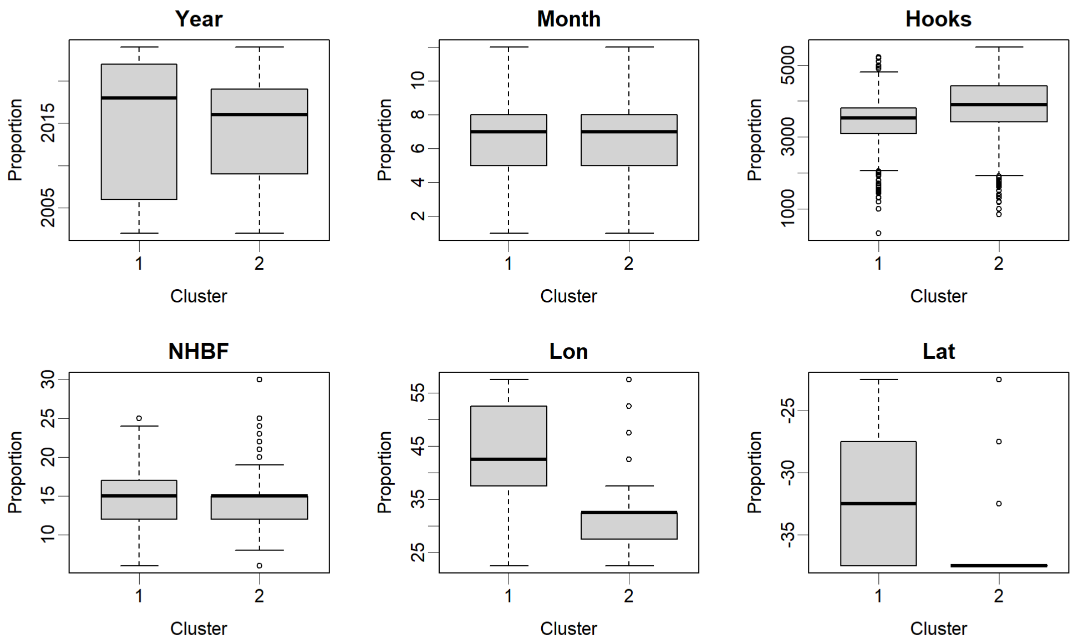


Fig. 14. Data composition by multiple factors for each cluster of Taiwanese large scale longline fishery in Southern Bluefin Tuna Area W of the Indian Ocean.

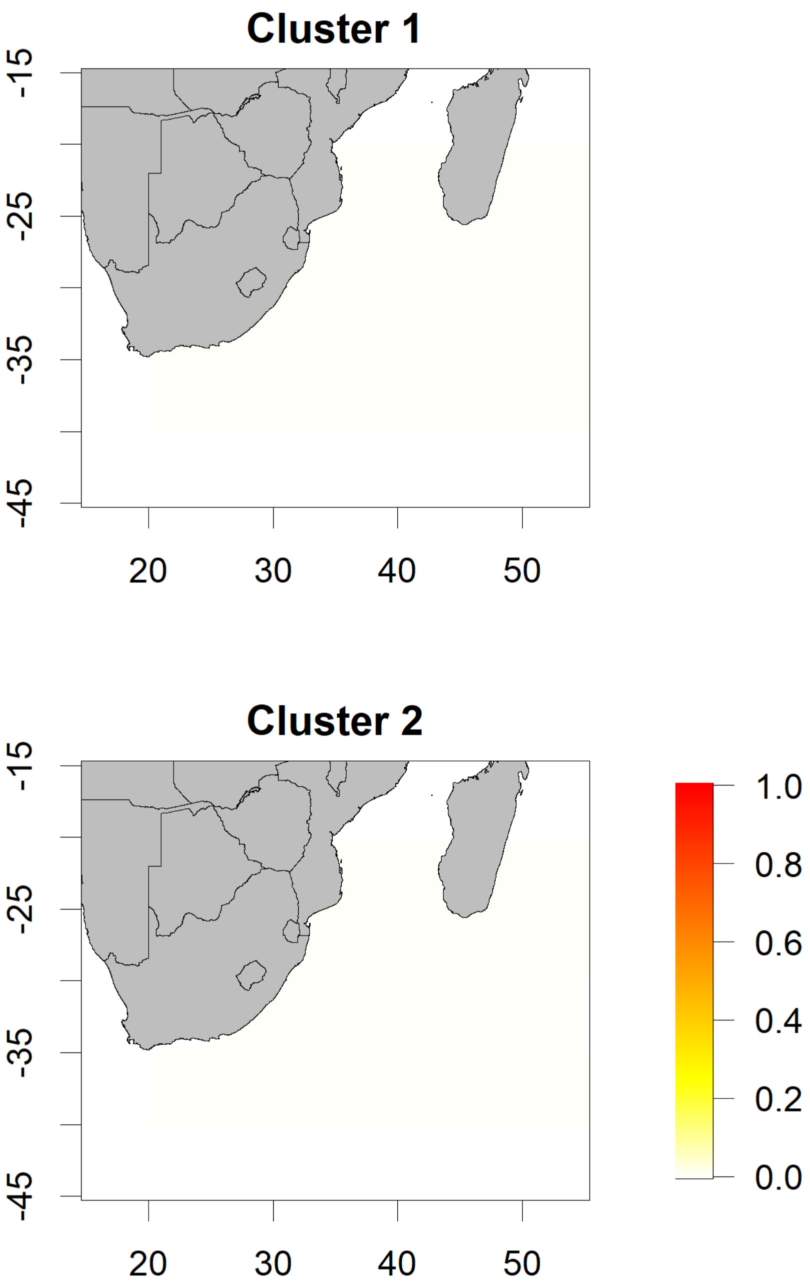
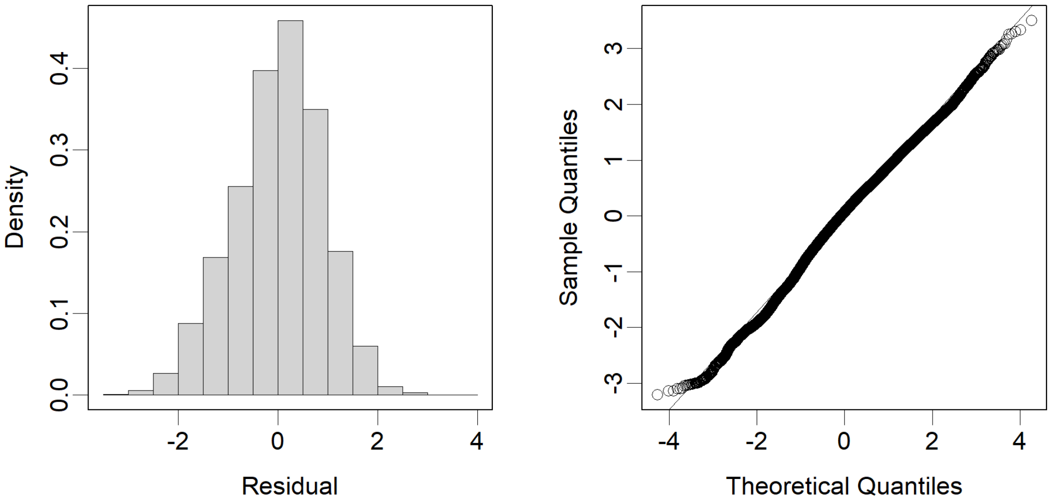


Fig. 15. Southern Bluefin Tuna catch distribution for each cluster of Taiwanese large scale longline fishery in Area W of the Indian Ocean. Red color represents high catch proportion and yellow color presents low catch proportion.

Area E



Area W

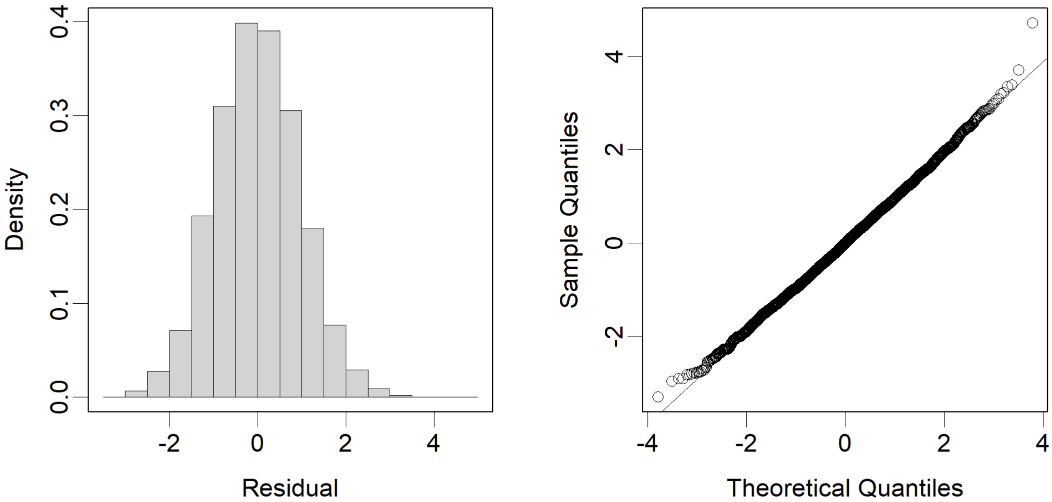
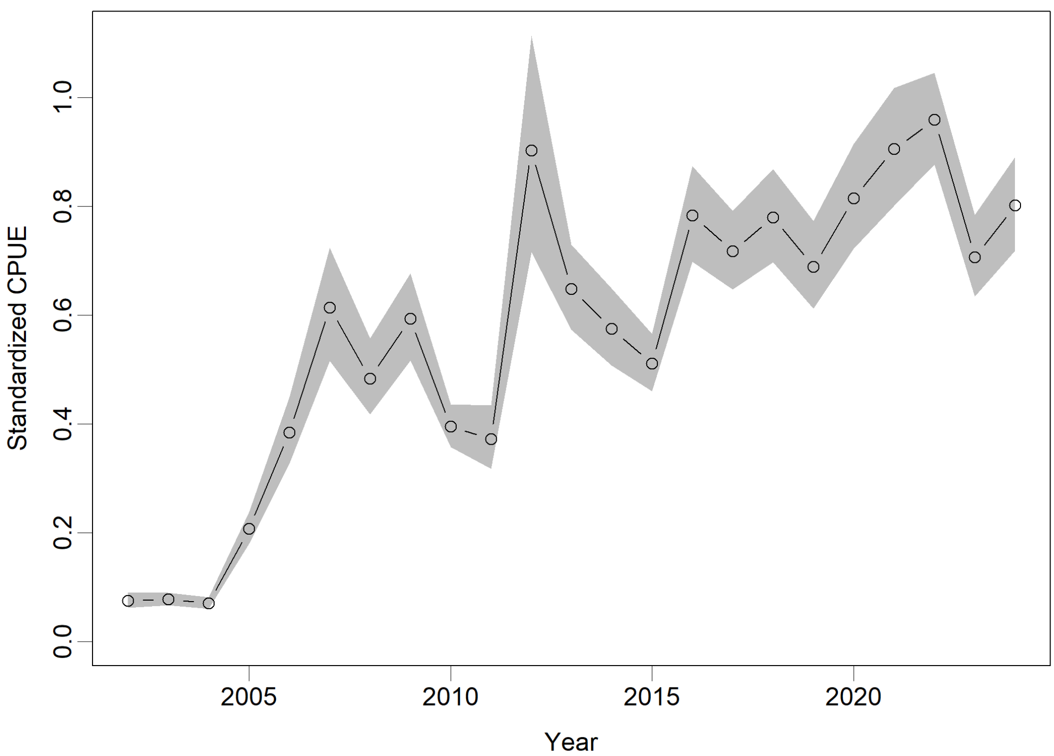


Fig. 16. The frequency distributions and Quantile-Quantile Plots for standardized residuals obtained from lognormal models for Area E and Area W.

Area E



Area W

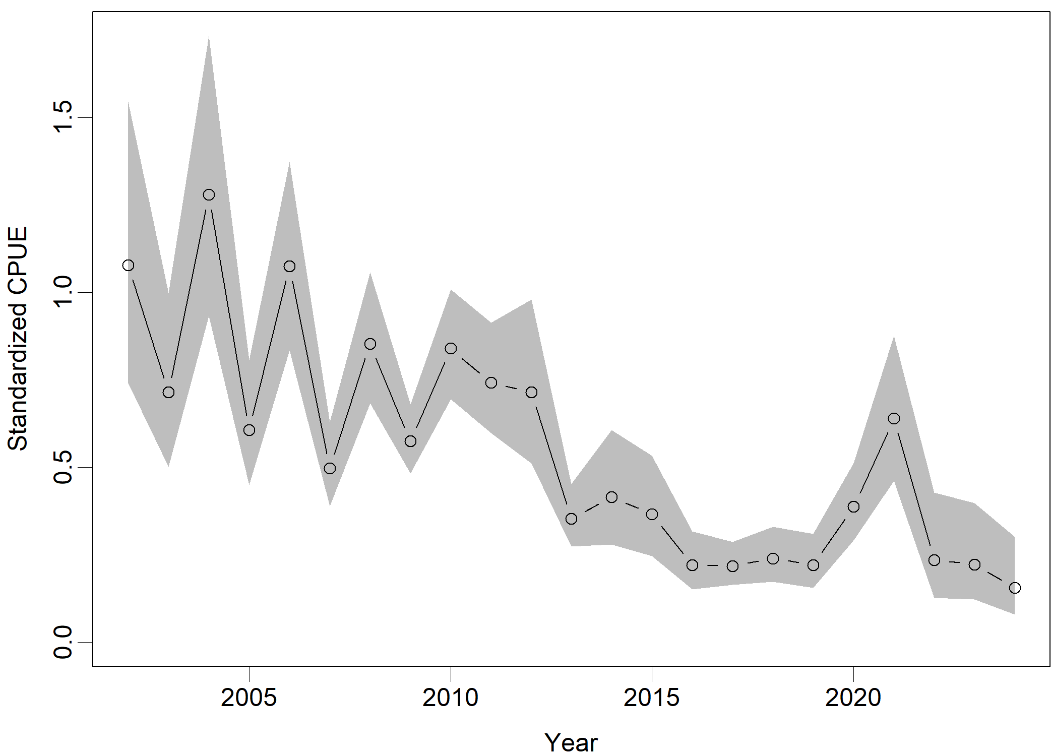
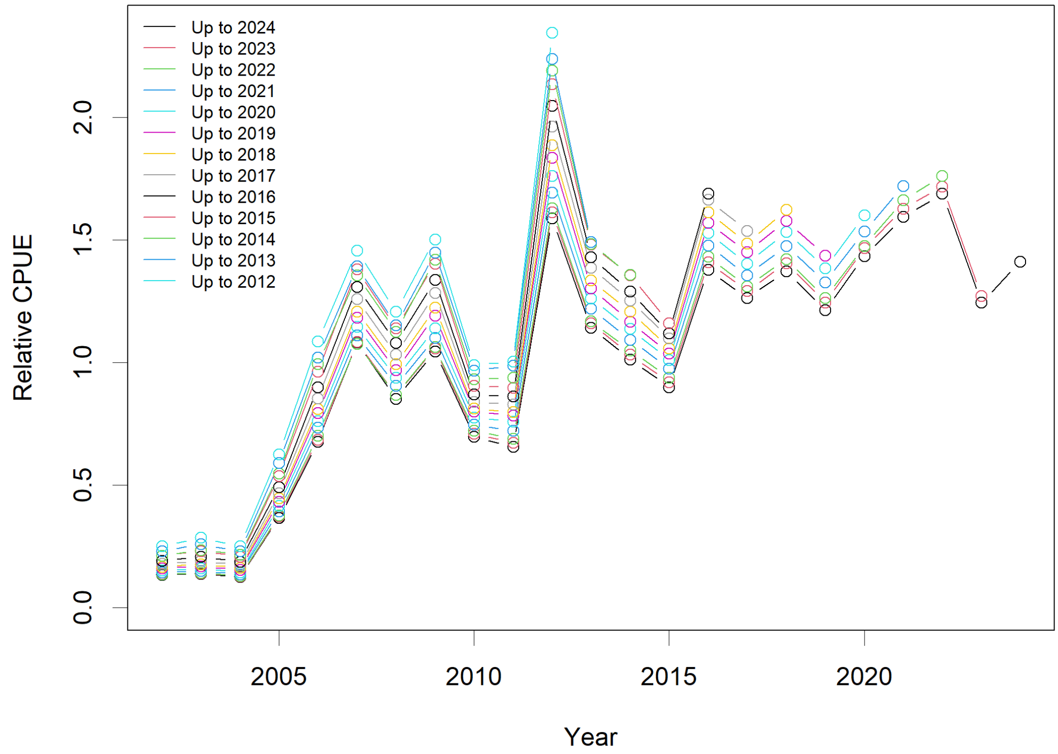


Fig. 17. Area-specific standardized CPUE of SBT caught by Taiwanese longline fishery. Shaded areas illustrate the 95% confidence intervals.

Area E



Area W

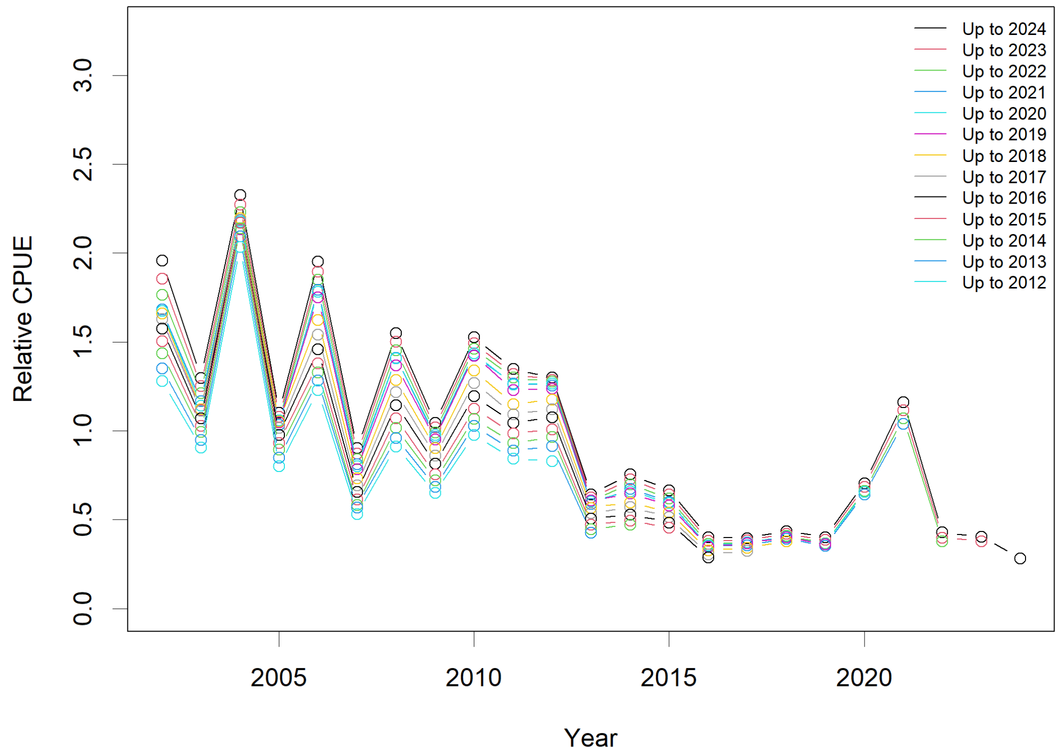


Fig. 18. The retrospect results of CPUE standardization based on including the updated data from different years.

Table 1. The results of ANOVA for the lognormal models for Area E and Area W.

Area E

Source of variance	SS	Df	F	Pr(>F)
Y	2501	22	140.677	< 2.2e-16 ***
M	646	11	72.720	< 2.2e-16 ***
G	630	37	21.072	< 2.2e-16 ***
C	6657	3	2746.520	< 2.2e-16 ***
NHBF	19	2	11.480	1.036e-05 ***
Residuals	40473	50093		

Significant level: 0 '***' 0.001 '**' 0.01 '*' 0.05 '.' 0.1 ' ' 1

Area W

Source of variance	SS	Df	F	Pr(>F)
Y	716.3	22	35.1170	< 2.2e-16 ***
M	428.5	11	42.0127	< 2.2e-16 ***
G	147.4	22	7.2273	< 2.2e-16 ***
C	101.1	1	109.0818	< 2.2e-16 ***
NHBF	42.1	2	22.6961	1.505e-10 ***
Residuals	6029.2	6503		

Significant level: 0 '***' 0.001 '**' 0.01 '*' 0.05 '.' 0.1 ' ' 1

Table 2. The results of ANOVA for the delta models for Area E and Area W.

Area E

Source of variance	LR Chisq	Df	Pr(>Chisq)
Y	7850.9	22	< 2.2e-16 ***
M	5150.8	11	< 2.2e-16 ***
G	10216.1	41	< 2.2e-16 ***
C	8631.8	3	< 2.2e-16 ***
NHBF	156.7	2	< 2.2e-16 ***

Significant level: 0 ‘***’ 0.001 ‘**’ 0.01 ‘*’ 0.05 ‘.’ 0.1 ‘ ’ 1

Area W

Source of variance	LR Chisq	Df	Pr(>Chisq)
Y	1785.4	22	< 2.2e-16 ***
M	3922.0	11	< 2.2e-16 ***
G	4339.0	27	< 2.2e-16 ***
C	297.9	1	< 2.2e-16 ***
NHBF	21.4	2	2.273e-05 ***

Significant level: 0 ‘***’ 0.001 ‘**’ 0.01 ‘*’ 0.05 ‘.’ 0.1 ‘ ’ 1