CPUE standardization for southern bluefin tuna caught by Taiwanese longline fishery for 2002-2018

Ching-Ping Lu[1], Sheng-Ping Wang[1], Shu-Ting Chang[2], Ming-Hui Hish[3]

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

ABSTRACT

The CPUE standardization analyses were conducted using the data of Taiwanese longline fleets operated in the waters of the south of 20°S of the Indian Ocean for the period from 2002 to 2018. The cluster analysis was aimed to explore the targeting of fishing operations and also to produce the data filter for selecting the data for the CPUE standardizations. And the targeting of fishing operation could be identified by the cluster analyses with the weekly-aggregated data instead of set-by-set data. For CPUE standardizations, a simple delta-lognormal model without interactions were adopted to avoid the confounding from interactions.

1. INTRODUCTION

In the past, Southern bluefin tuna (*Thunnus maccoyii*; SBT) was the by-catch species of Taiwanese tuna longline fishery while targeting albacore. However, since the 1990s, some fishing vessels equipped with deep-frozen freezers started targeting SBT seasonally in the Indian Ocean. Because Taiwanese SBT statistics system was reformed in 2002, therefore, the reporting rate of SBT catch has substantially improved since then (Anon, 2014). Here, the major purpose of this study are to explore the temporal and spatial patterns based on the catch and effort data of Taiwanese longline fishery operated in the waters of the south of 20°S of the Indian Ocean. And we also aimed to perform the CPUE standardization for SBT caught by Taiwanese longline fishery for the period from 2002 to 2018.

2. MATERIALS AND METHODS

2.1. Catch and Effort data

The operational catch and effort data of Taiwanese longline fisheries from 2002 to 2018 provided by the Overseas Fisheries Development Council (OFDC) of Taiwan was used in this study. The resolution of the data, which were compiled from Taiwanese longline vessels by 5×5 degree fishing location grids.

As the findings of the previous studies (Wang et al., 2015;2017;2018) suggested, the SBT fishing ground could be divided into the central-eastern area (Area E) and western area (Area W) separated by the boundary at the 60°E (Fig. 1). Here, all of the analyses in this study were conducted based on this area stratification.

2.2. Cluster analysis

Based on the approach of the previous study (Wang et al. 2015) and the suggestions by the experts of CCSBT ESC meetings in 2015 and 2016, we conducted the cluster analysis (He et al., 1997) to explore the targeting of fishing operations and to produce the data filter for selecting the data for CPUE standardization. Cluster analysis was performed based on species composition of the catches of 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) (Fig. 2 and Fig. 3). According to the consideration of 2016 CCSBT ESC, the clustering operational set-by-set data might include 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. Additionally, ESC suggested that the cluster analysis could be conducted using the aggregated data rather than the operational data sets. Therefore, we performed 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. While using the monthly-aggregated data for running the cluster analysis, the proportion of SBT catches decreased substantially and there were more difficulties for the identification of the cluster contained SBT fishing operations (Wang et al., 2017). Therefore, we conducted the cluster analyses with weekly-aggregated data in this study.

The hierarchical cluster analysis with Ward minimum variance method was applied to the squared Euclidean distances calculated from the aggregated data sets. The analyses were performed 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 a large amount of zero SBT catch occurred in the fishing sets, we applied the delta-lognormal models for the CPUE standardization of SBT caught by Taiwanese longline fishery. As the suggestions in the previous ESC, there were four main effects of year, month, 5x5 grid and number of hooks between floats (NHBF) included in both of lognormal and delta models. To avoid the confounding resulted from interactions, the interactions between main effects were not considered in the models. The effects of latitude and longitude were replaced by the effect of 5x5 grid. Additionally, the effects of cluster and NHBF were included because various catch compositions can be observed in a cluster (Wang et al., 2017). The models were conducted as below:

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

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, 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:

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

where $CPUE$ 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

Here, we conducted the cluster analyses for the area E and area W separately. First, for the Area E, there are four clusters were selected (Fig. 4). Cluster 1 was mainly consisted of ALB and BET operations, also the rest of operations with less proportion including YFT, SBT, SWO and OTH were parts of components in the Cluster 1. The operations grouping in Cluster 2 mainly belonged to the ALB operations, also contained the operations for BET, SBT and OTH. The major operation in Cluster 3 was also the ALB operation. Cluster 4 was mainly contributed by the SBT operation (Figs. 5 and 6). Although the highest SBT catch proportion was occurred in Cluster 4, most of the SBT catches were contained in Cluster 2 (Fig. 7). For SBT Cluster (Cluster 4), the data mainly consisted of the data in the early 2000s; fishing mainly operated during June and September; NHBF concentrated at around 10 hooks; and the operations also concentrated in the waters between 30°S and 35°S (Fig. 8). We illustrated SBT catch proportion by spatial distribution, the SBT catch proportion of Cluster 4 was obviously higher than the rest of others clusters (Fig. 9).

Second, there were three clusters selected in the Area W (Fig. 10). Cluster 1 was contributed by the ALB operations. The ALB operations was the majority in Cluster 2 and also contained the other operations for BET, YFT, SWO and OTH. The OTH operations was belonged to Cluster 3 where mainly for oilfish) (Figs. 11 and 12). Most of SBT catches were found in Cluster 2 and Cluster 3. There were very few SBT catches in Cluster 1 (Fig. 13). For the factor of year in Clusters 2 and 3, Cluster 2 mainly consisted of the data before 2010, while the data of Cluster 3 were mainly after 2010. NHBF of Cluster 3 was more than that of Cluster 2 and Cluster 1. Fishing areas by longitude and latitude were different between Clusters 2 and 3 (Fig. 14). By illustrating the SBT catch proportion for the spatial distribution, the SBT catch proportion of Cluster 2 was higher than the other two Clusters (Fig. 15).

3.2 CPUE standardization

In the process of CPUE standardization, we excluded the data of Cluster 1 of Area W. Because there were too few SBT catches contained in the Cluster 1 to include into the CPUE standardization. For both of Areas E and W, the models with the lowest value of AIC were selected as the final models. The ANOVA tables for the lognormal models are shown in Table 1. All of the effects were statistically significant for both areas. About 19% and 38% 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 36% and 24% of CPUE variances were explained by the models for Area E and Area W, respectively.

The area-specific standardized CPUE trends were shown in Fig. 17. Standardized CPUE series generally revealed quite different trends for Area E and Area W. First, for Area E, the standardized CPUEs gradually increased before 2007, after that revealed decreasing trend from 2007 to 2011, substantially increased in 2012 and then gradually decreased until 2015, and increased again in recent three years. 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 now.

3.3 Retrospect analysis

In order to understand the influence of including the updated data on the CPUE standardization, we applied the retrospect analysis for this purpose. The analysis was conducted by removing the data from 2018 to 2012. The results indicated that the influence of including the updated data on the CPUE standardization was negligible for Area E, while including updated data changed the standardized CPUE series slightly for Area W, however, the pattern of the CPUE trends remained similar (Fig. 18).

REFERENCES

Butterworth, D.S., 1996. A possible alternative approach for generalized linear model analysis of tuna CPUE data. ICCAT Col. Vol. Sci. Pap., 45: 123-124.

He, X., Bigelow, K.A., Boggs, C.H., 1997. Cluster analysis of longline sets and fishing strategies within the Hawaii□based fishery. Fish. Res. 31: 147□158.

Maunder, N.M., Punt, A.E., 2004. Standardizing catch and effort data: a review of recent approaches. Fish. Res., 70: 141-159.

R Core Team (2019). R: A language and environment for statistical computing. R Foundation for Statistical Computing, Vienna, Austria. URL http://www.R-project.org/

Wang, S.P., Chang, S.T., Huang, A.C., Lin, S.L., 2017. CPUE standardization for southern bluefin tuna caught by Taiwanese longline fishery for 2002-2016. CCSBT-ESC/1708/33.

Wang, S.P., Chang, S.T., Lai, I.L. Lin, S.L., 2015. CPUE analysis for southern bluefin tuna caught by Taiwanese longline fleet. CCSBT-ESC/1509/23.

Wang, S.P., Lu, C.P., Chang, S.T., Huang, A.C., 2018. CPUE standardization for southern bluefin tuna caught by Taiwanese longline fishery for 2002-2017. CCSBT-ESC/1809/39.

Wang, S.P., Nishida, T., 2011. CPUE standardization of swordfish (*Xiphias gladius*) caught by Taiwanese longline fishery in the Indian Ocean. IOTC-2011-WPB09-12.

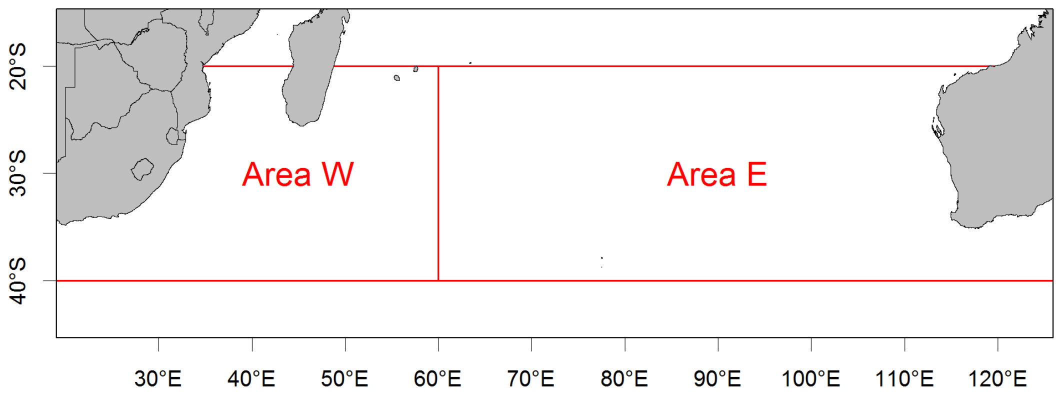


Fig. 1. Area stratification for southern bluefin tuna of Taiwanese large scale longline fishery in the Indian Ocean.

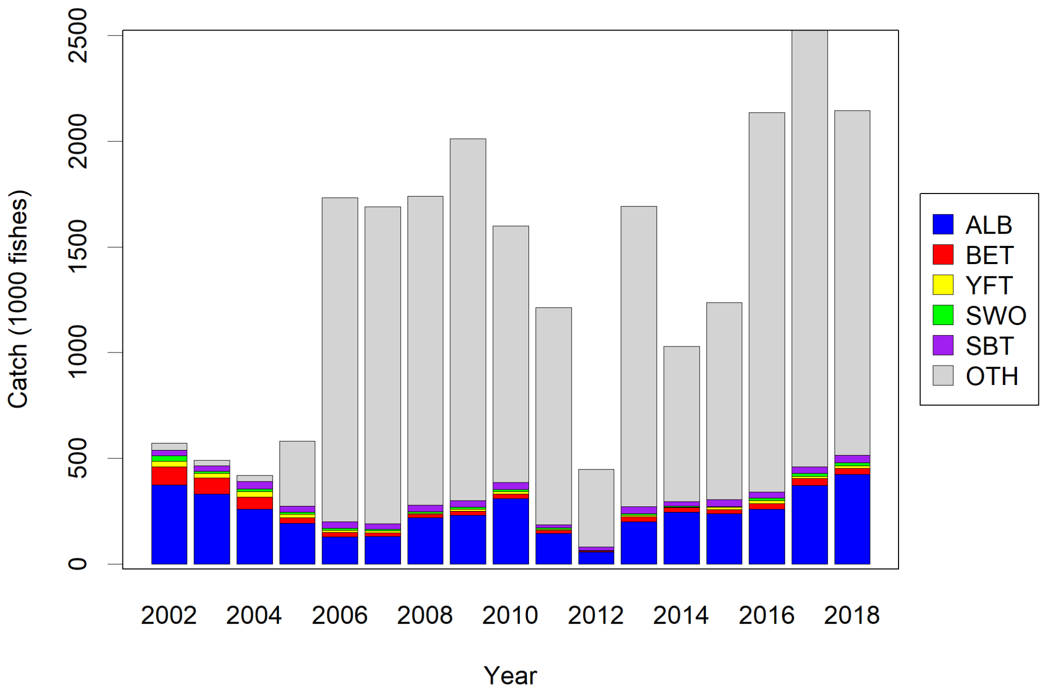


Fig. 2. Annual catch composition of Taiwanese longline fleets operated in the waters of south of 20°S.

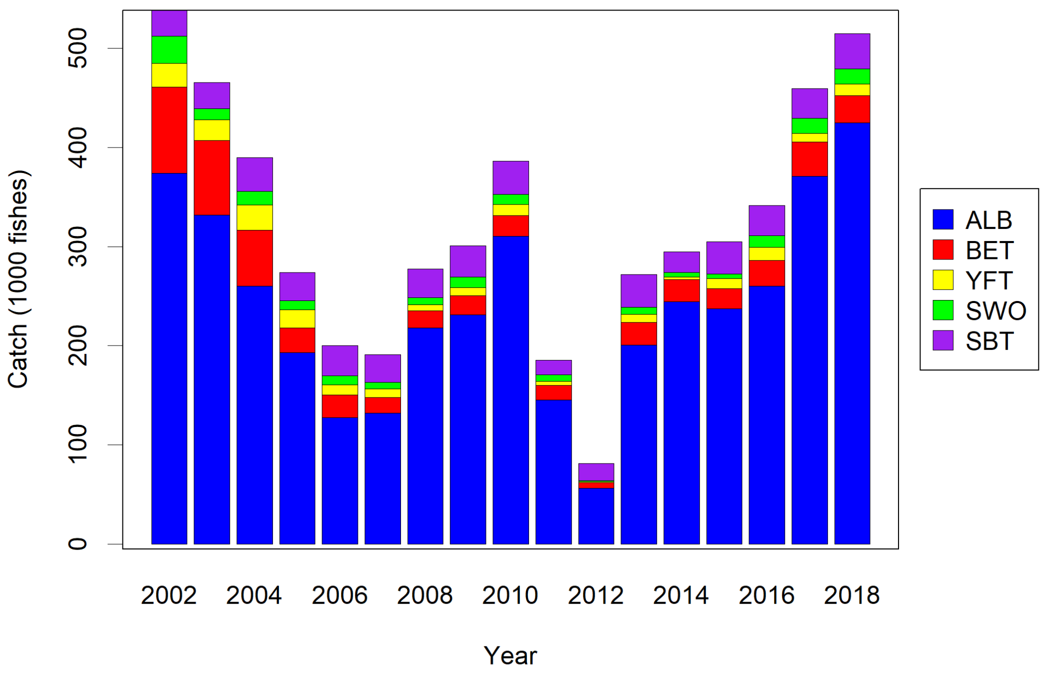


Fig. 3. Annual catch composition of Taiwanese longline fleets operated in the waters of south of 20°S. The catches of OTH are excluded.

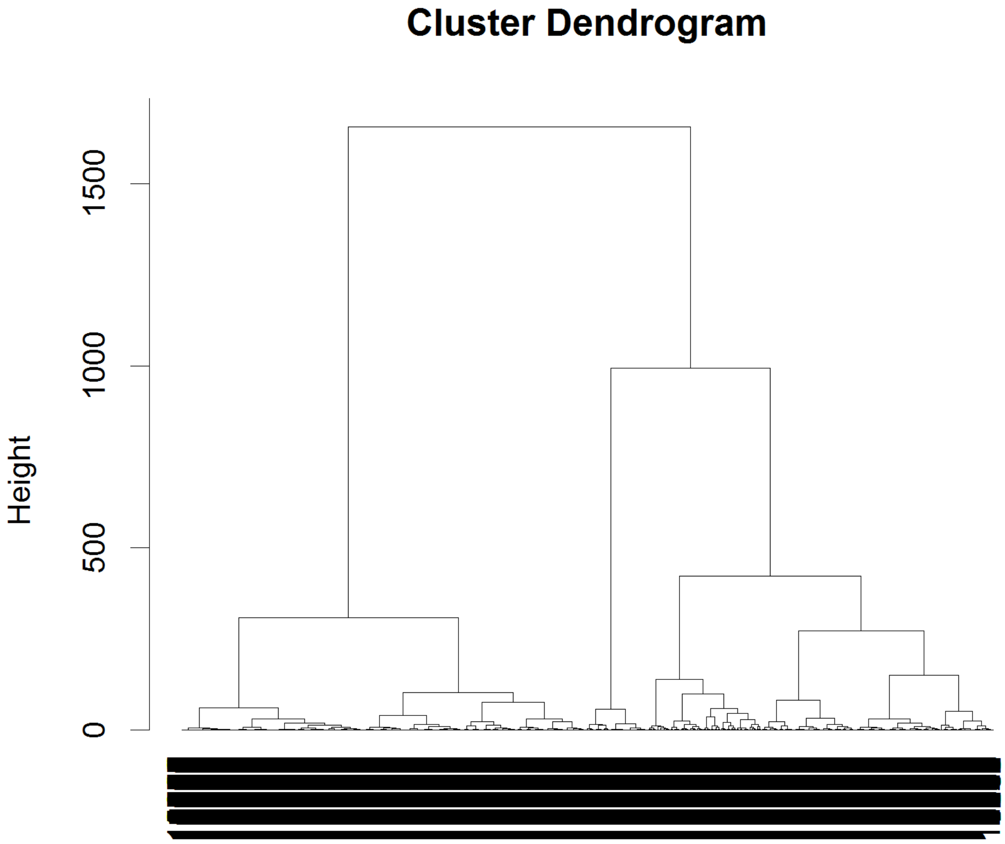


Fig. 4. The tree of cluster analysis using the data of Taiwanese large scale longline fishery in Southern Bluefin Tuna (SBT) Area E of the Indian Ocean.

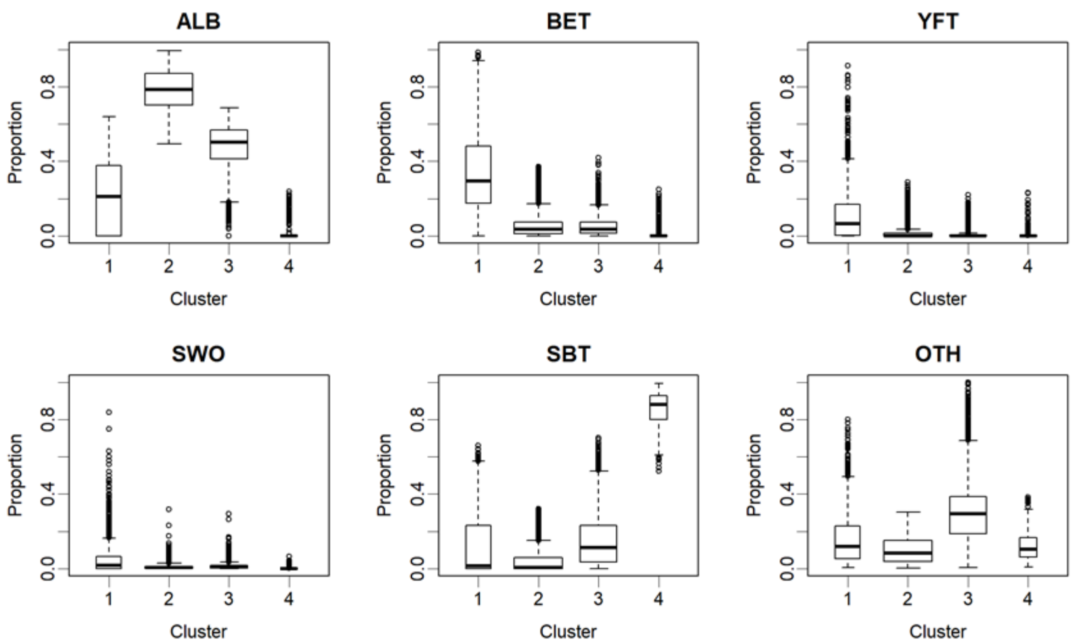


Fig. 5. Catch proportion by species for each cluster of Taiwanese large scale longline fishery in SBT Area E of the Indian Ocean.

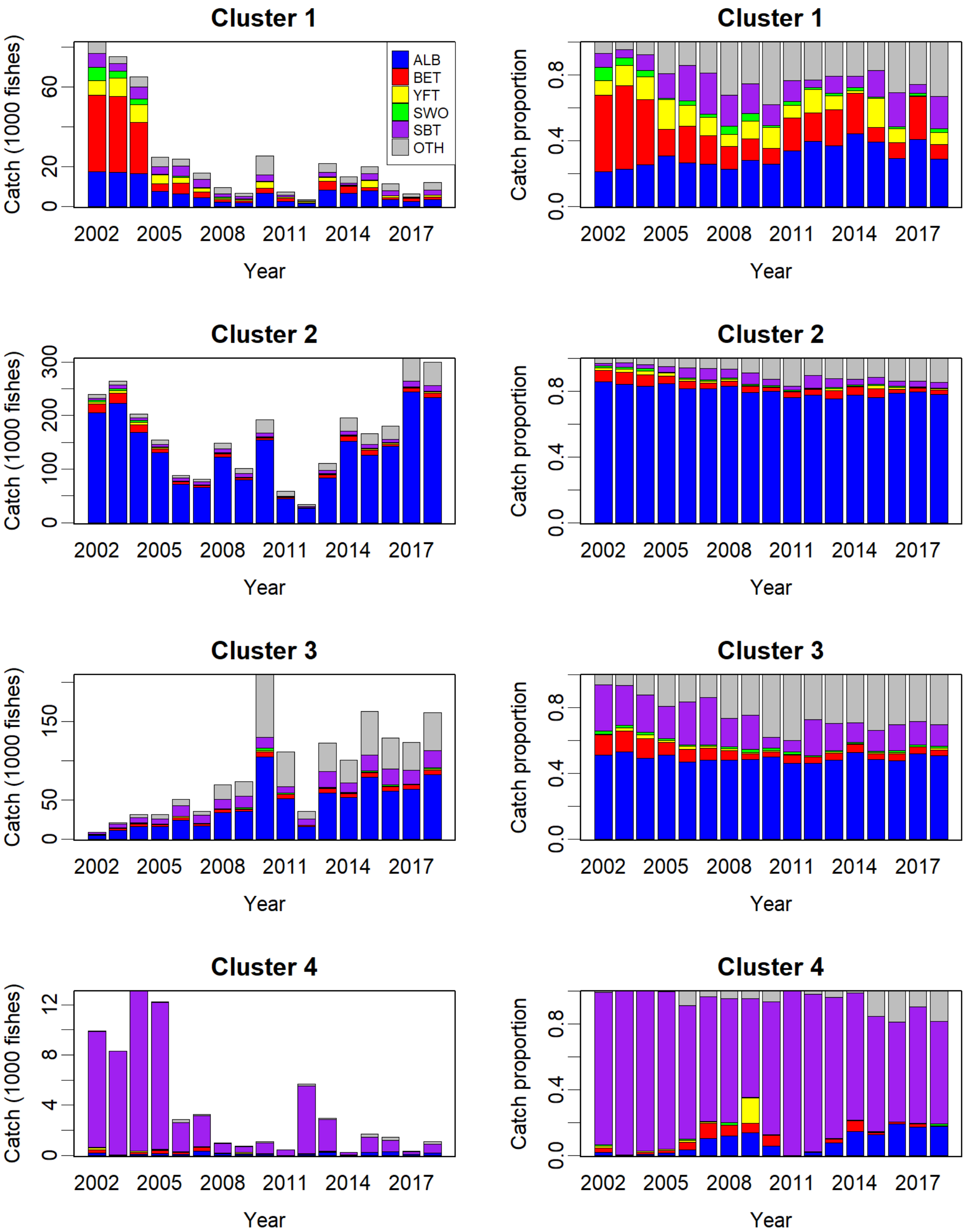
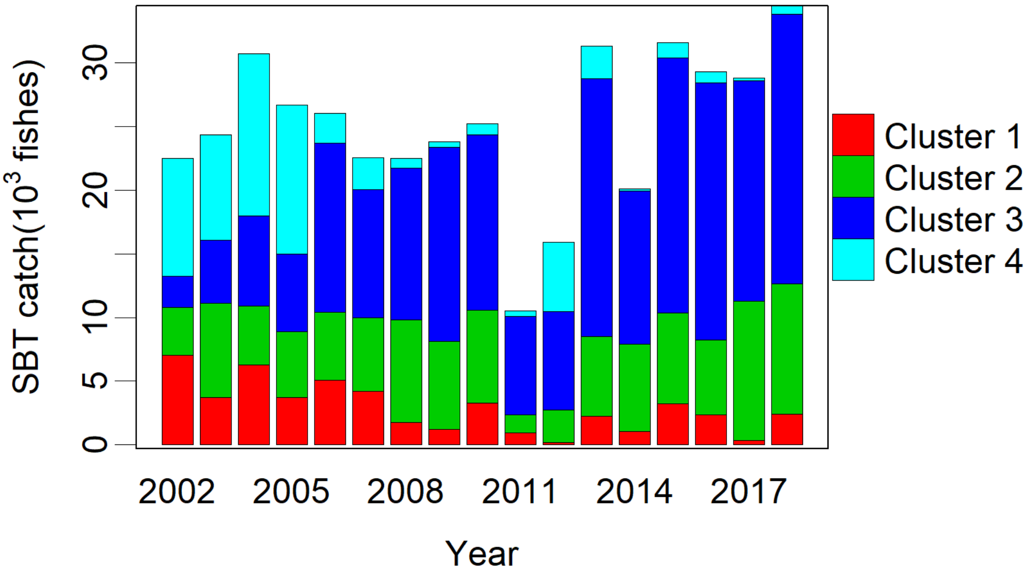


Fig. 6. Annual catch and catch proportion by species for each cluster of Taiwanese large scale longline fishery in SBT Area E of the Indian Ocean.



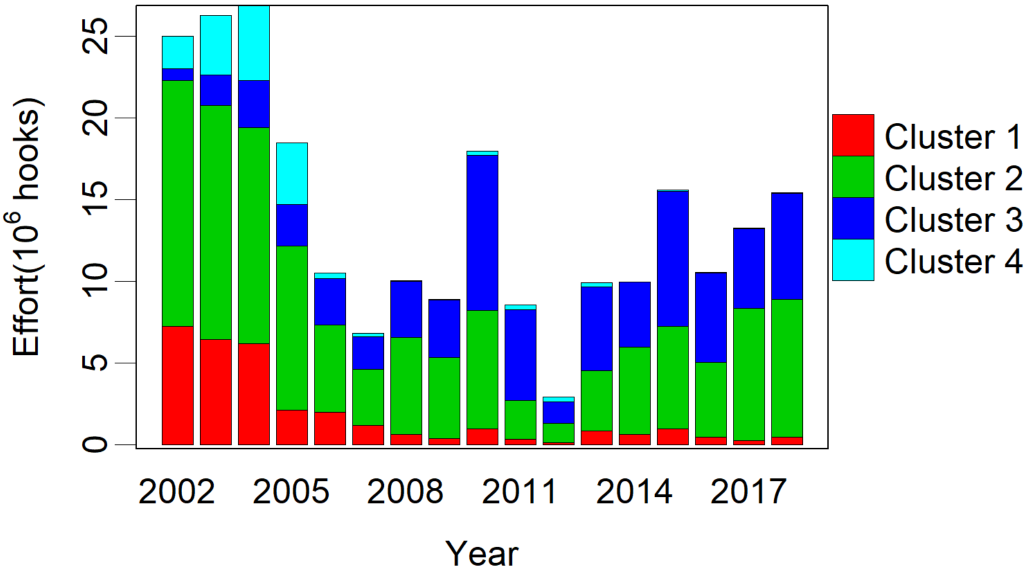


Fig. 7. Annual Southern Bluefin Tuna catches and efforts for each cluster of Taiwanese large scale longline fishery in Area E of the Indian Ocean.

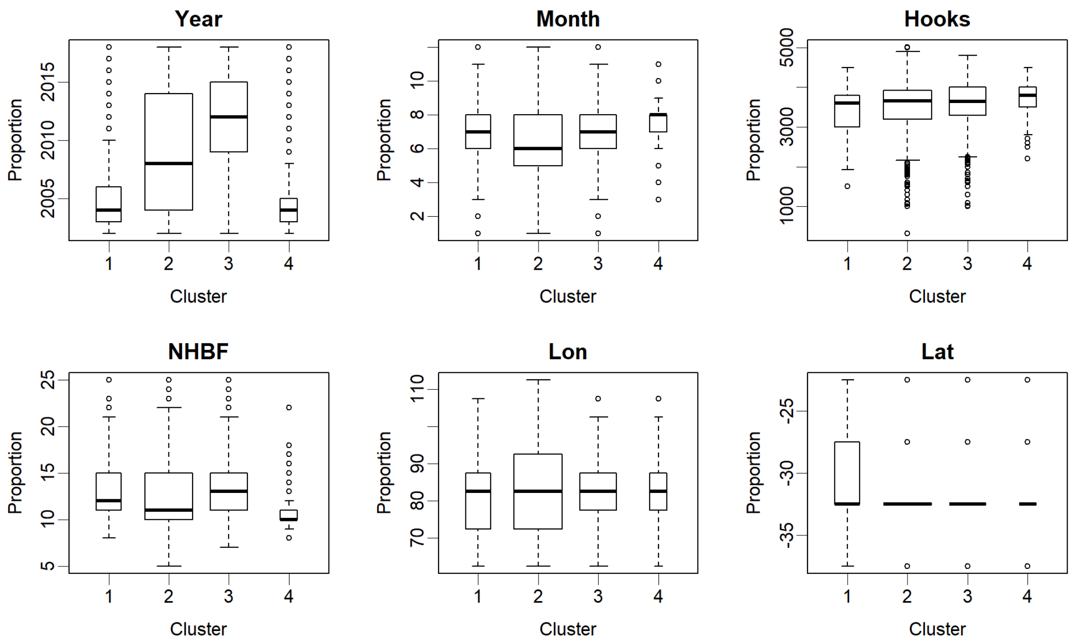


Fig. 8. Data composition by multiple factors for each cluster of Taiwanese large scale longline fishery in SBT Area E of the Indian Ocean.

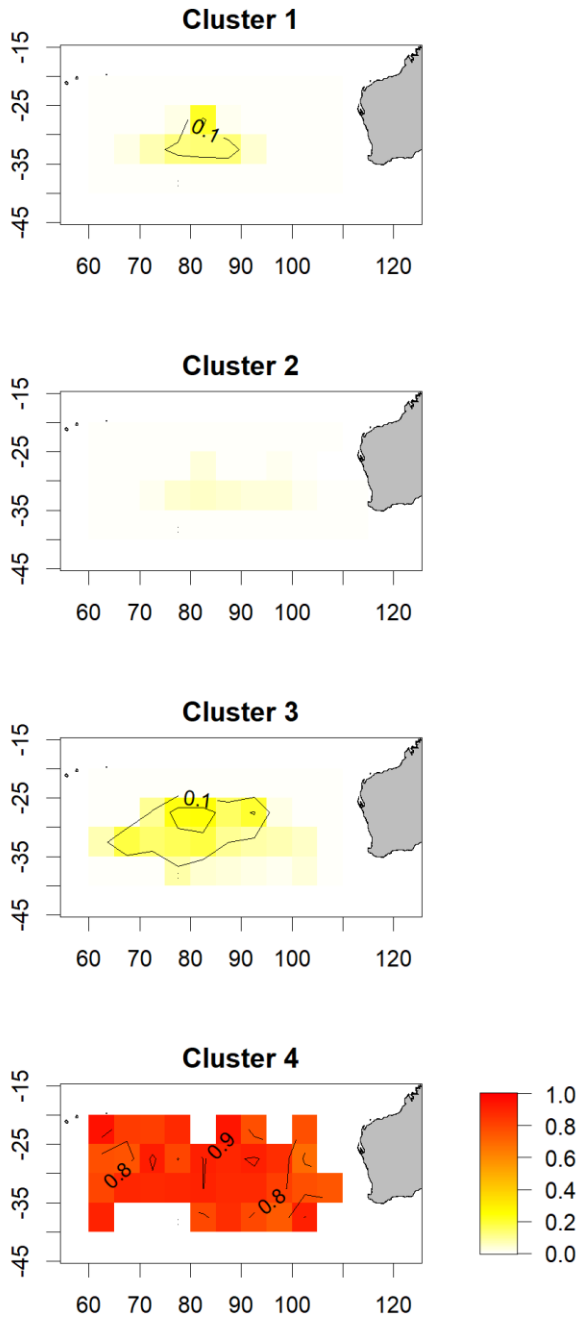


Fig. 9. Southern Bluefin Tuna catch distribution for each cluster of Taiwanese large scale longline fishery in Area E of the Indian Ocean. Red color represents high catch proportion and yellow color presents low catch proportion.

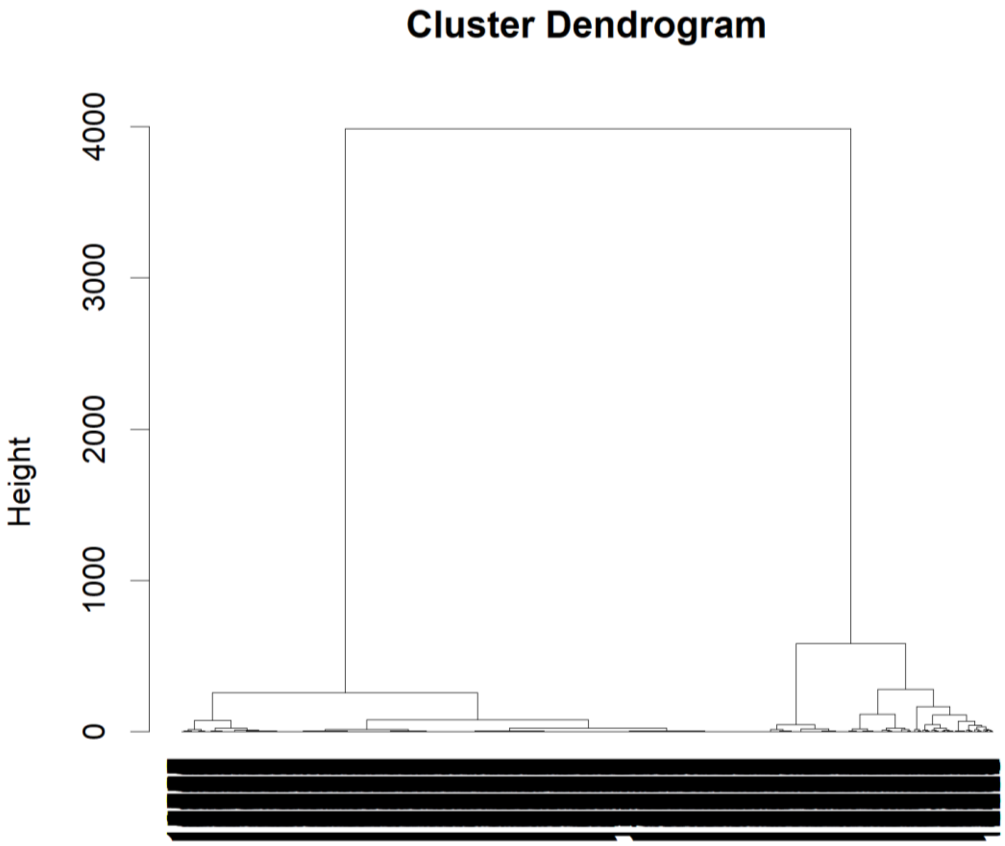


Fig. 10. The tree of cluster analysis using the data of Taiwanese large scale longline fishery in SBT Area W of the Indian Ocean.

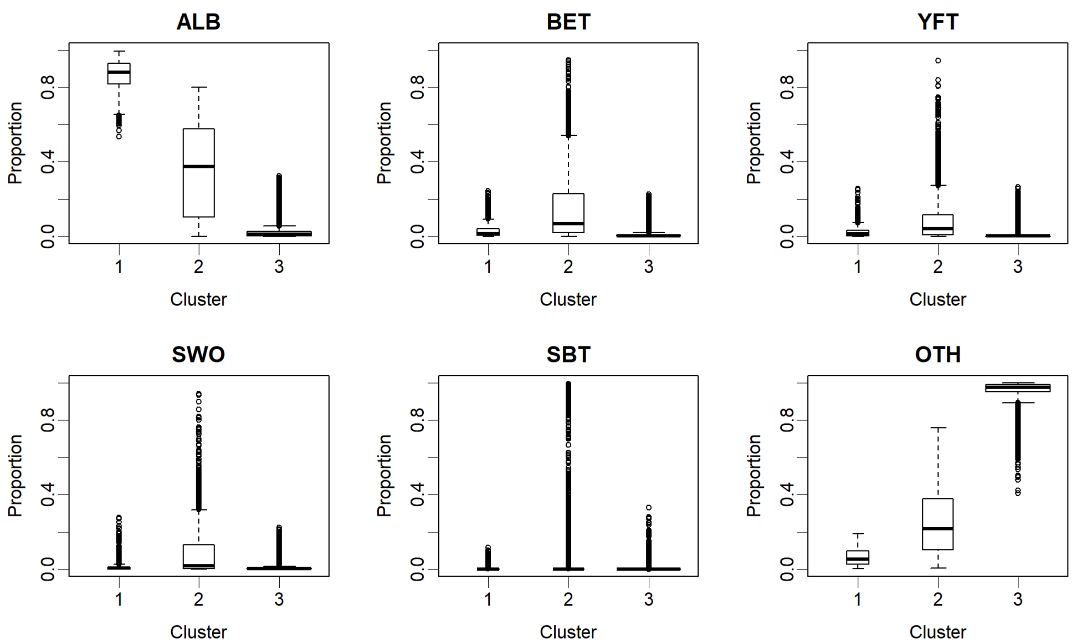


Fig. 11. Catch proportion by species for each cluster of Taiwanese large scale longline fishery in SBT Area W of the Indian Ocean.

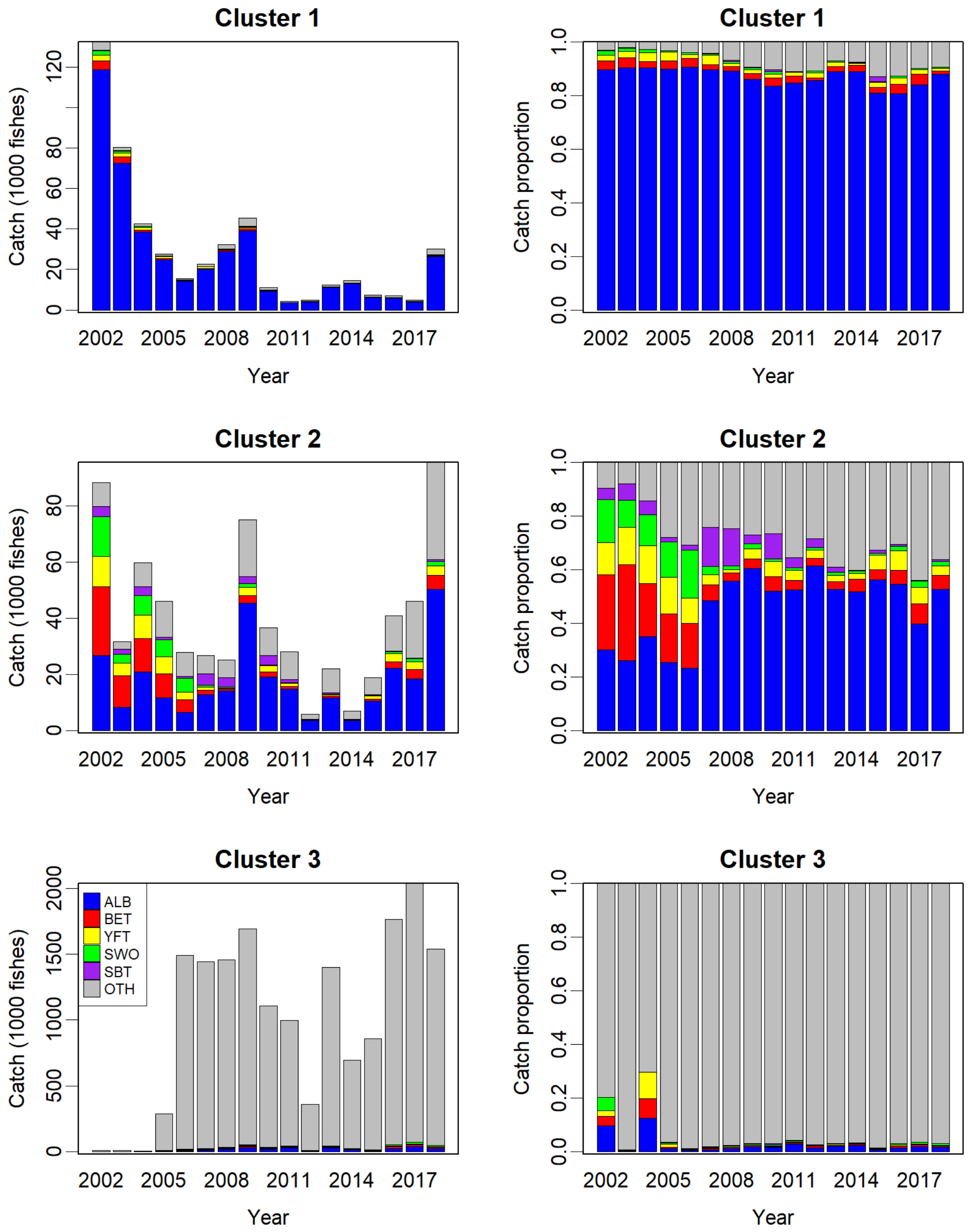
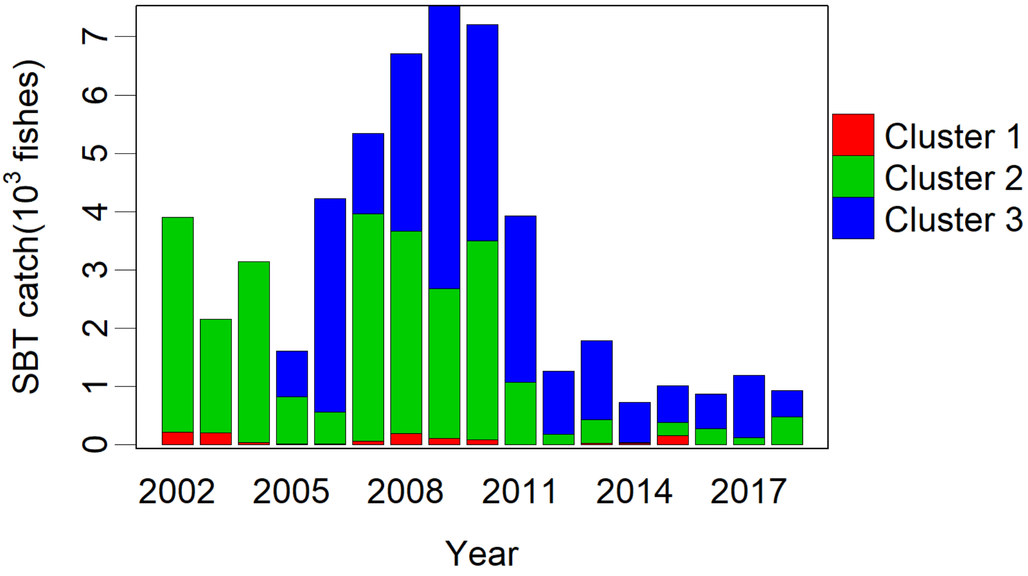


Fig. 12. Annual catch and catch proportion by species for each cluster of Taiwanese large scale longline fishery in SBT Area W of the Indian Ocean.



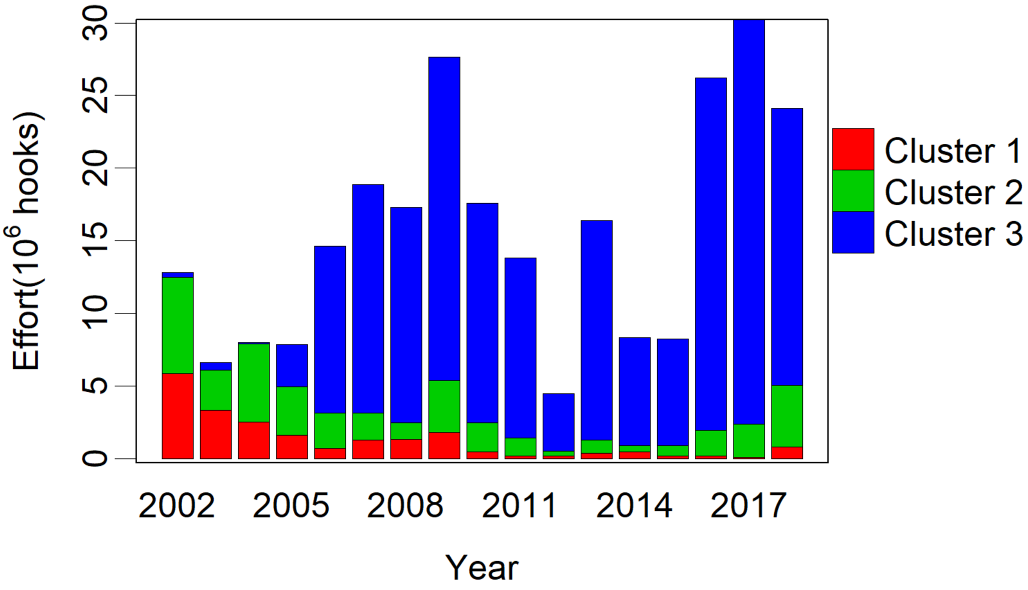


Fig. 13. Annual Southern Bluefin Tuna catches and efforts for each cluster of Taiwanese large scale longline fishery in Area W of the Indian Ocean.

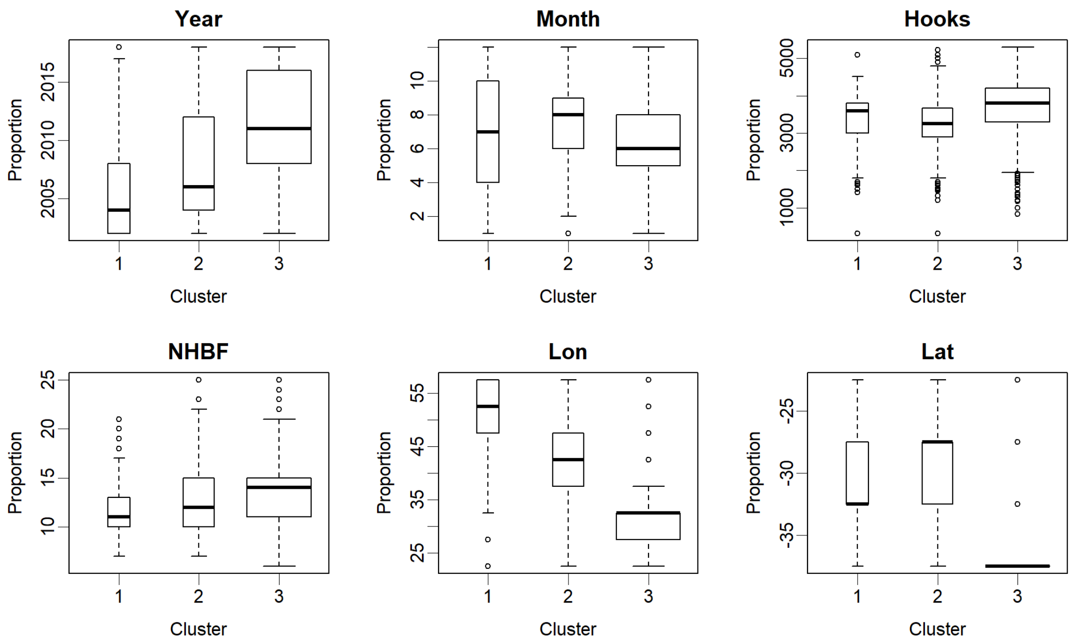


Fig. 14. Data composition by multiple factors for each cluster of Taiwanese large scale longline fishery in Southern Bluefin Tuna Area W of the Indian Ocean.

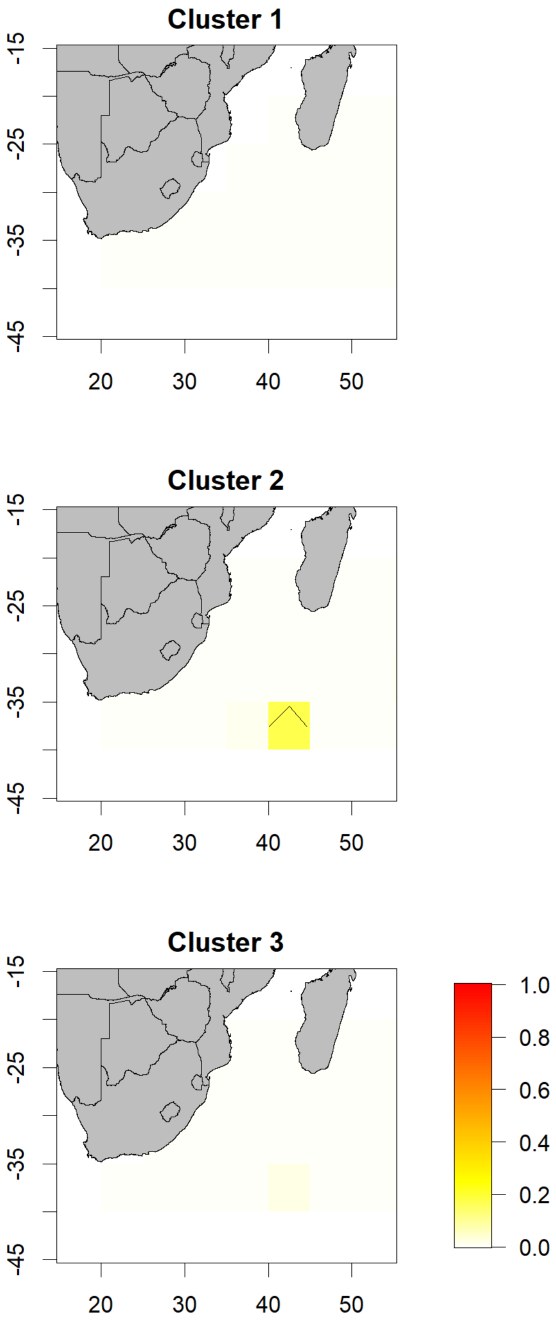
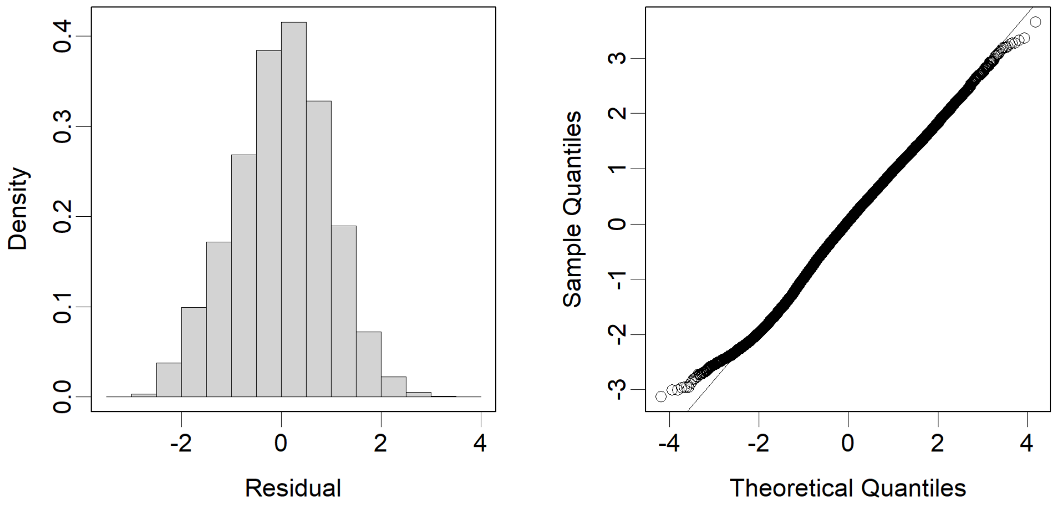


Fig. 15. Southern Bluefin Tuna catch distribution for each cluster of Taiwanese large scale longline fishery in Area W of the Indian Ocean. Red color represents high catch proportion and yellow color presents low catch proportion.

Area E



Area W

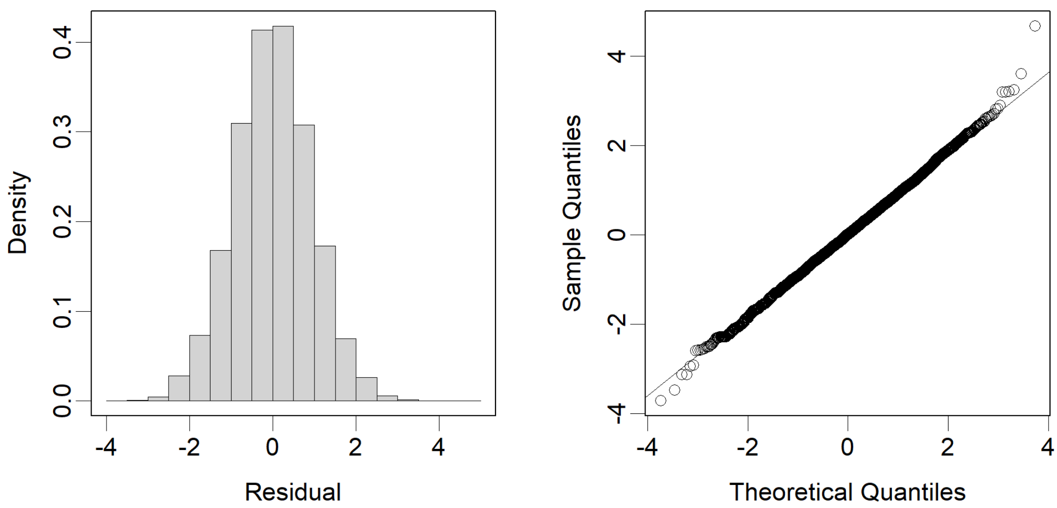
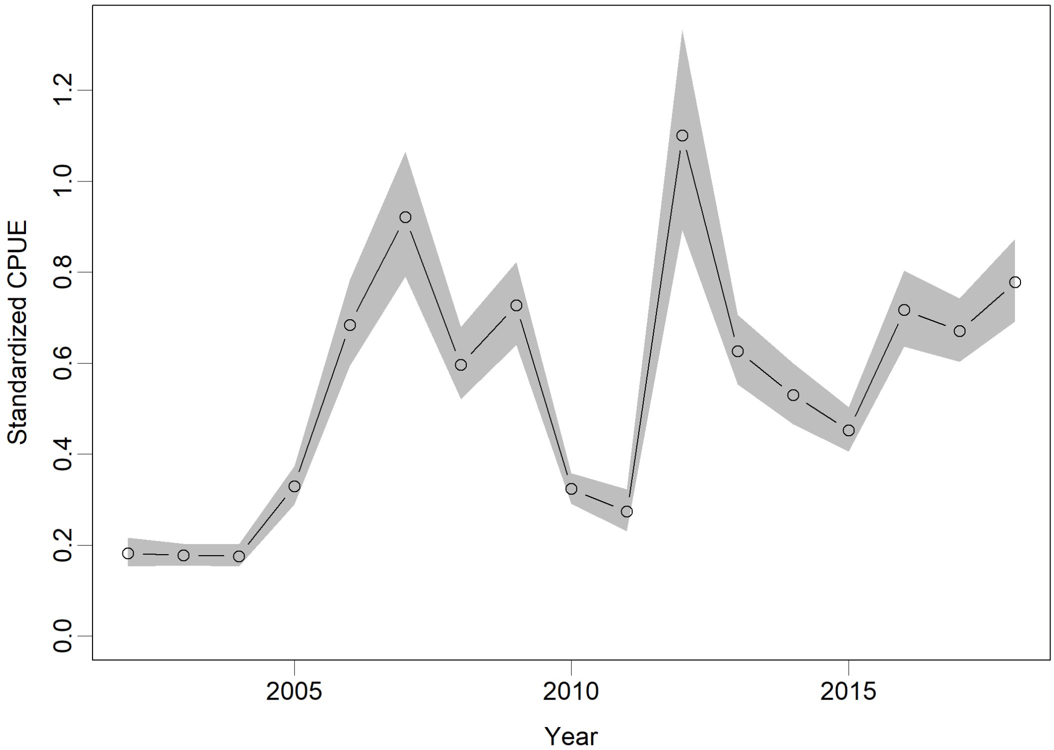


Fig. 16. The frequency distributions and Quantile-Quantile Plots for standardized residuals obtained from lognormal models for Area E and Area W.

Area E



Area W

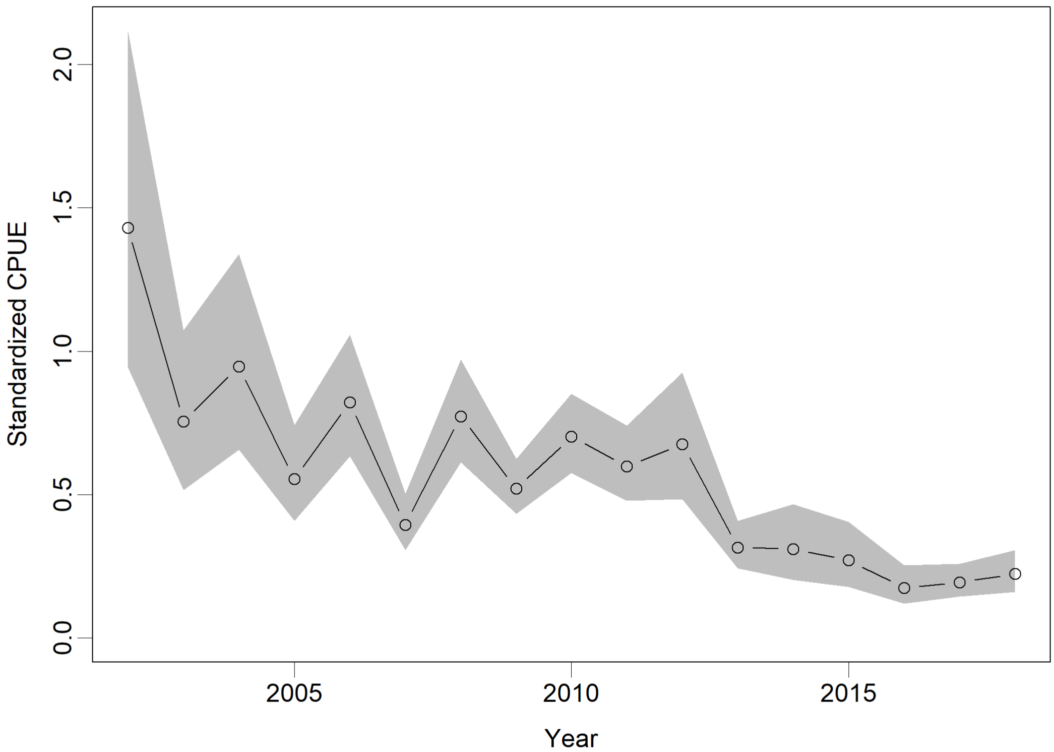
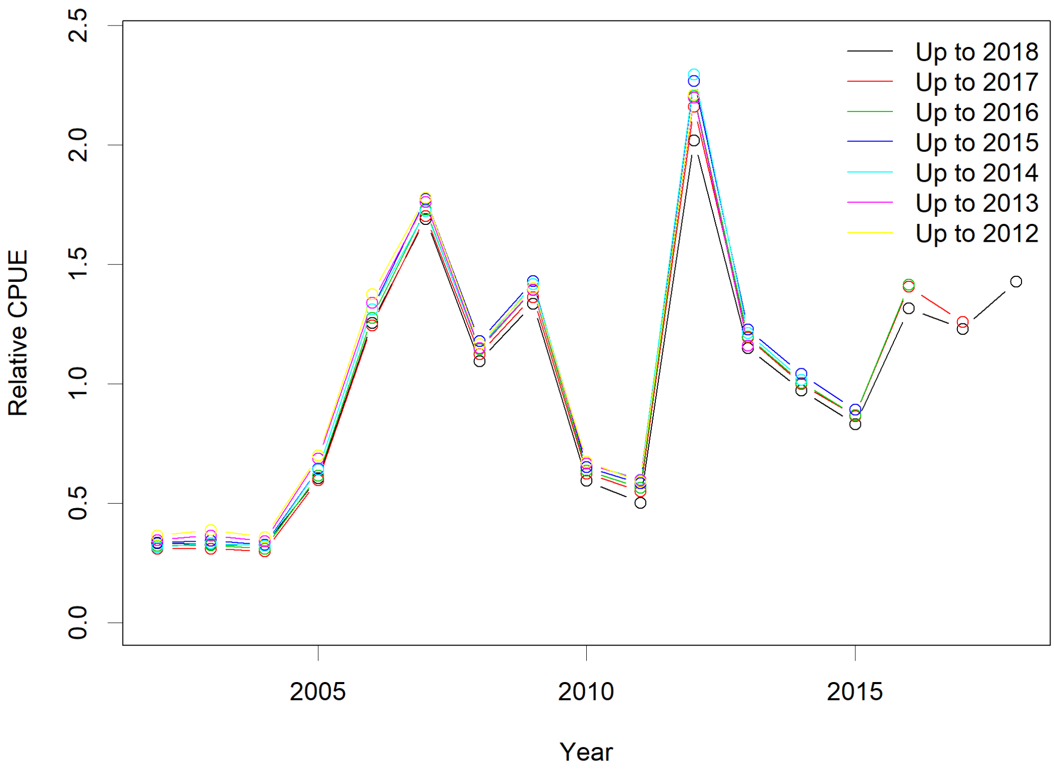


Fig. 17. Area-specific standardized CPUE of SBT caught by Taiwanese longline fishery. Shaded areas show the 95% confidence intervals.

Area E



Area W

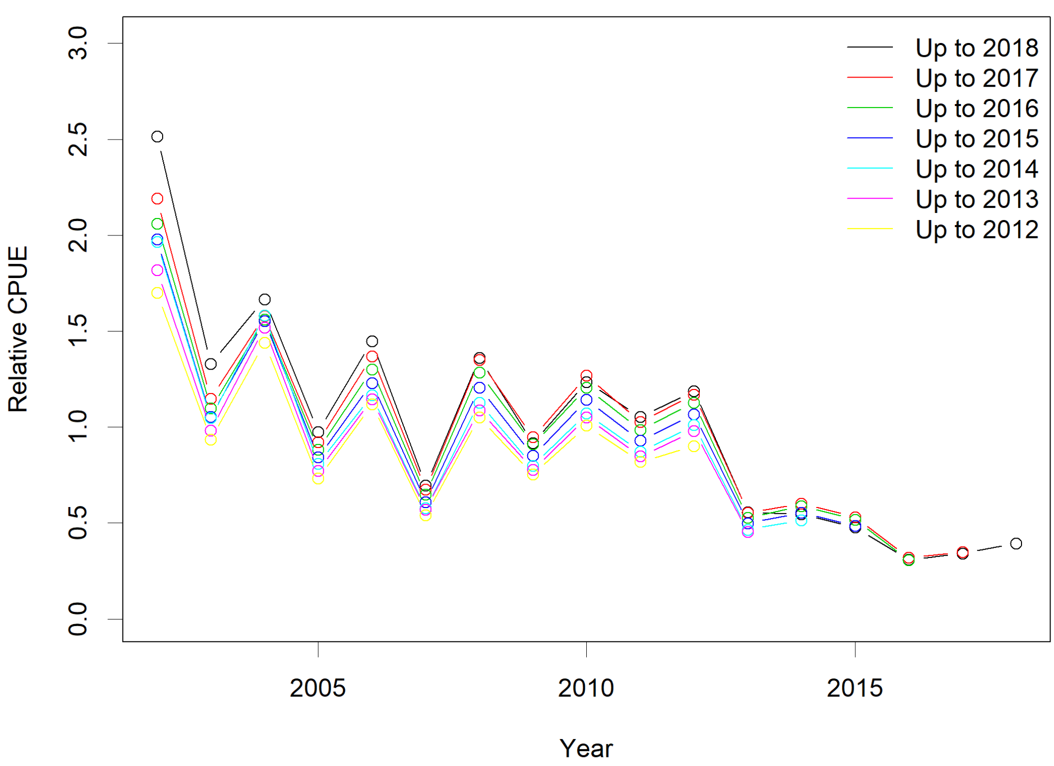


Fig. 18. The results of CPUE standardization based on including the updated data from different years.

Table 1. ANOVA tables for the lognormal models for Area E and Area W.

Area E

Source of variance	SS	Df	F	Pr(>F)
Y	2131	16	146.007	< 2.2e-16 ***
M	583	9	70.940	< 2.2e-16 ***
CT	276	3	100.987	< 2.2e-16 ***
G	822	37	24.335	< 2.2e-16 ***
C	985	3	359.885	< 2.2e-16 ***
NHBF	33	2	17.874	1.74E-08 ***
Residuals	33313	36511		

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

Area W

Source of variance	SS	Df	F	Pr(>F)
Y	575.5	16	41.564	< 2.2e-16 ***
M	344.3	10	39.784	< 2.2e-16 ***
CT	75.6	2	43.711	< 2.2e-16 ***
G	78.8	22	4.140	2.84E-10 ***
C	28.7	1	33.121	9.15E-09 ***
NHBF	40.5	2	23.376	7.81E-11 ***
Residuals	4598.3	5314		

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

Table 2. ANOVA tables for the delta models for Area E and Area W.

Area E

Source of variance	LR Chisq	Df	Pr(>Chisq)
Y	4100.7	16	< 2.2e-16 ***
M	4688.3	11	< 2.2e-16 ***
CT	141.1	3	< 2.2e-16 ***
G	4523.2	41	< 2.2e-16 ***
C	6283.7	3	< 2.2e-16 ***
NHBF	76.3	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	578.6	16	< 2.2e-16 ***
M	2974.3	11	< 2.2e-16 ***
CT	8.7	2	0.01317 *
G	3422.1	27	< 2.2e-16 ***
C	187.3	1	< 2.2e-16 ***
NHBF	20.9	2	2.95E-05 ***

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