Data analysis and CPUE standardization of albacore caught by Taiwanese longline fishery in the Indian Ocean

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ABSTRACT

This paper described the historical trends of fishing operations and albacore catches of Taiwanese large scale longline fishery in the Indian Ocean. The cluster analysis was adopted to explore the targeting of fishing operations. In addition, the CPUE standardizations were conducted using generalized linear model and generalized linear mixed model for examining the influence of treating the vessel ID as fixed and random effects on the CPUE standardizations.

1. 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, 2016). This report briefly describes temporal and spatial patterns of fishing operations and albacore catches caught by Taiwanese longliners in the Indian Ocean. The cluster analysis (He et al., 1997; Hoyle et al., 2014) was adopted to explore the targeting of fishing operations and to produce the data filter for selecting the data for CPUE standardization.

2. MATERIALS AND METHODS

2.1. Catch and Effort data

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

2.2. Cluster analysis

Cluster analysis was performed based on species composition of the catches of albacore (ALB), bigeye tuna (BET), yellowfin tuna (YFT), swordfish (SWO), blue marlin (BUM), striped marlin (MLS), black marlin (BLM) and other species (OTH). However, clustering operational set-by-set data might include large amount noise because most of billfishes were caught by Taiwanese vessels as bycatches. Therefore, the cluster analysis was performed based weekly-aggregated data and then merged the clusters with set-by-set operational data to identify the targeting fishing operations.

He et al. (1997) suggested a cluster analysis with two steps to classify the data sets because the large number of data sets precluded direct hierarchical cluster analysis. First, a non-hierarchical cluster analysis (K-means method) was used to group the species composition from all data sets into 64 clusters for taking the mixture of fishing operations into account (P_2^6 which means 2 species can be chosen with priority from 8 species). Second, a hierarchical cluster analysis with Ward minimum variance method was applied to the squared Euclidean distances calculated based on the species composition from 64 non-hierarchical clusters. Non-hierarchical and hierarchical cluster analyses were conducted using R functions kmeans and hclust (The R Foundation for Statistical Computing Platform, 2018).

The choice for the number of clusters to produce was largely subjective. At least two clusters were expected. In this study, the number of clusters was selected based on the basic concept of cluster analysis approach that is to produce clusters with high similarity within a cluster and low similarity between clusters. In this study, the number of clusters was selected when the difference in the relative variance between groups and the relative variance within the group was more than 50~60%. In addition, cluster analyses were performed by four fishing areas separately (Fig. 1).

2.3. CPUE Standardization

The vessel ID was incorporated into the CPUE standardizations as an effect in generalized linear model (GLM). However, the vessels operated in the Indian Ocean varied over time and space and they did not operate all the time and space. In addition, vessels may have specialties that mean they may tend to catch a particular species and some vessels may tend to catch another species, such that within a vessel, species composition may be more homogeneous than they are between vessels. Therefore, this study attempted to conduct the CPUE standardization using a generalized linear mixed model (GLMM) and the vessel ID was treated as a random effect. In addition, the CPUE standardizations were conducted by incorporating the year-quarter and year+quarter effect to produce annual and year-quarter trends of standardized CPUE series.

Year-quarter model:

GLM : $\log(CPUE + c) = \mu + YQ + G + T + V + \varepsilon$

$GLMM$: $\log(CPUE + c) = \mu + YQ + G + T + random(V) + \varepsilon$

Annual model:

GLM : $\log(CPUE + c) = \mu + Y + Q + G + T + V + \varepsilon$

$GLMM$: $\log(CPUE + c) = \mu + Y + Q + G + T + random(V) + \varepsilon$

where $CPUE$ is the nominal CPUE (catch in number/1,000 hooks),
c is the constant value (10% of all of nominal CPUE),
μ is the intercept,
YQ is the effect of year-quarter,
Y is the effect of yea,
Q is the effect of quarter,
G is the effect of 5x5 longitude-latitude grid,
T is the effect of targeting (cluster),
G is the effect of 5x5 longitude-latitude grid,
V is the effect of vessel ID
ε is the error term, ε~ normal distribution.

The GLMM was conducted using R function of glmer. The standardized CPUE series were calculated based on the least squared means of year-quarter and year effects using R function of lsmeans.

3. RESULTS AND DISCUSSION

3.1. Historical fishing trends

Figs. 2 to 4 show the distributions of species composition, catch and CPUE of albacore caught by Taiwanese longliners in the Indian Ocean. Before 1990s, 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. 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) (Fig. 5). In addition, vessels operated in the southern Indian Ocean also tended to use deep sets since early 2000s (Figs. 6 and 7).

3.2. Cluster analysis

For Area 1 (NW), 4 clusters were selected (Fig. 8). Cluster 1 was the operations consisted of mixed species, cluster 2 was the operations for bigeye, cluster 3 was for yellowfin tuna and cluster 4 was for albacore (Fig. 9). The operations of cluster 4 mainly concentrated subtropical and temperate waters before 1990s and NHBF were about 10 hooks; operations of cluster 2, 3 and 4 concentrated in tropical waters after 1990s and NHBF increased to about 15 hooks (Fig. 10). The proportion of albacore catches of cluster 4 were obviously higher than those of other clusters (Fig. 11). The historical trends of catches by species are shown in Fig. 12 and the trends of albacore catch and fishing effort by clusters are also shown in Fig. 13. Except for cluster 4, the proportion of albacore catches of cluster 1 obviously increased in recent years.

For Area 2 (NE), 4 clusters were selected (Fig. 14). Cluster 4 was the operations for albacore, cluster 1, 2 and 3 consisted of more operations for bigeye tuna, but cluster 3, 1 and 2 were mainly for bigeye tuna, yellowfin tuna and other species, respectively (Fig. 15). The operations of cluster 4 mainly concentrated subtropical and temperate waters before 1990s and NHBF were about 10 hooks; operations of cluster 1 and 2 concentrated in tropical waters since early 2000s and NHBF were about 15 hooks; operations widely distributed with NHBF less than 10 hooks for cluster 3 (Fig. 16). The proportion of albacore catches of cluster 4 were obviously higher than those of other clusters (Fig. 17). The historical trends of catches by species are shown in Fig. 18 and the trends of albacore catch and fishing effort by clusters are also shown in Fig. 19. In this area, most of the catches of albacore were grouped into cluster 4 but the catches have substantially increased in recent years.

For Area 3 (SW), 3 clusters were selected (Fig. 20). The operations of cluster 2 were mainly for albacore, cluster 3 was the operations for other species, and cluster 1 contained the operations for albacore, bigeye tuna, yellowfin tuna and swordfish (Fig. 21). Cluster 1 mainly consisted of the operations before 1990s; operations of cluster 2 were mainly from 1990s to early 2000s; and most operations of cluster 3 concentrated in the southwest waters after the mid-2000s; and NHBF were mainly 10 hooks for clusters 1 and 2, and NHBF were about 10-15 hooks for cluster 3 (Fig. 22). The proportion of albacore catches of cluster 2 were obviously higher than those of other clusters (Fig. 23). The historical trends of catches by species are shown in Fig. 24 and the trends of albacore catch and fishing effort by clusters are also shown in Fig. 25. Most of the catches of albacore were made by the operations of cluster 2 but the albacore catches of cluster 3 slightly increased with the fishing effort in recent years.

For Area 4 (SE), 4 clusters were selected (Fig. 26). Clusters 1 and 2 contained the operations mainly for albacore, cluster 4 were the operations for the bigeye tuna but they also had some operations for yellowfin tuna and swordfish, cluster 3 were the operations for other species but clusters 1 and 4 also contained some operations for other species (Fig. 27). The operations of cluster 2 mainly occurred before the early 2000s; most of operations were made after the mid-2000s for other clusters; the operations of cluster 2 were mainly from the first half year; the differences in the characteristics of the operations were not significant for other factors (Fig. 28). The highest proportion of albacore catches was found in cluster 2 and cluster 1 also contained the operations with high proportion of albacore catches (Fig. 29). The historical trends of catches by species are shown in Fig. 30 and the trends of albacore catch and fishing effort by clusters are also shown in Fig. 31. The albacore catches were mainly made by the operations of cluster 2 before early 2000s and the albacore catches of cluster 1 obviously increased with the fishing effort after the early 2000s.

3.3. CPUE standardization

The clusters contained very few catches of albacore were excluded when doing the CPUE standardizations. Clusters 2 and 3 were excluded for Area 1 (NW) and Area 2 (NE), cluster 3 were excluded for Area 3 (SW), and clusters 3 and 4 were excluded for Area 4 (SE).

Tables 1-4 show the ANOVA tables for the CPUE standardizations using GLM and GLMM for year-quarter and annual models. All of the effects were statistically significant and remained in the models. The normal Quantile-Quantile plots are also shown in Figs. 32-35, and they indicated that the residuals approximated to be normal distributions although more negative values occurred. The statistics of model selection, including R^2, AIC and BIC, are shown in Table 5. However, the comparability of model selection statistics between GLM and GLMM should be considered because the CPUE standardizations were conducted using GLM, which incorporated only fixed effects, and GLMM, which incorporated fixed and random effects.

The year-quarterly and annual trends of standardized CPUE series obtained from GLM and GLMM are shown in Figs. 36 and 37. Generally, the trends of standardized CPUE series obtained from GLMM are very similar to those from GLM, but spikes in some years can be reduced when using GLMM. In addition, unreasonable high values of the standardized CPUE were observed in Area 2 (NE) based on the results obtained from both of annual GLM and GLMM. Since 2012, very few albacore catches were caught in Area (NE) and fishing efforts also substantially decreased (Figs. 18 and 19). Therefore, biased estimates of standardized CPUE might be resulted from sparse fishing information for albacore in Area (NE) in recent years.

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Hoyle1, S.D., Langley, A.D., Campbell, R.A. (2014). Recommended approaches for standardizing CPUE data from pelagic fisheries. WCPFC-SC10-2014/ SA-IP-10.

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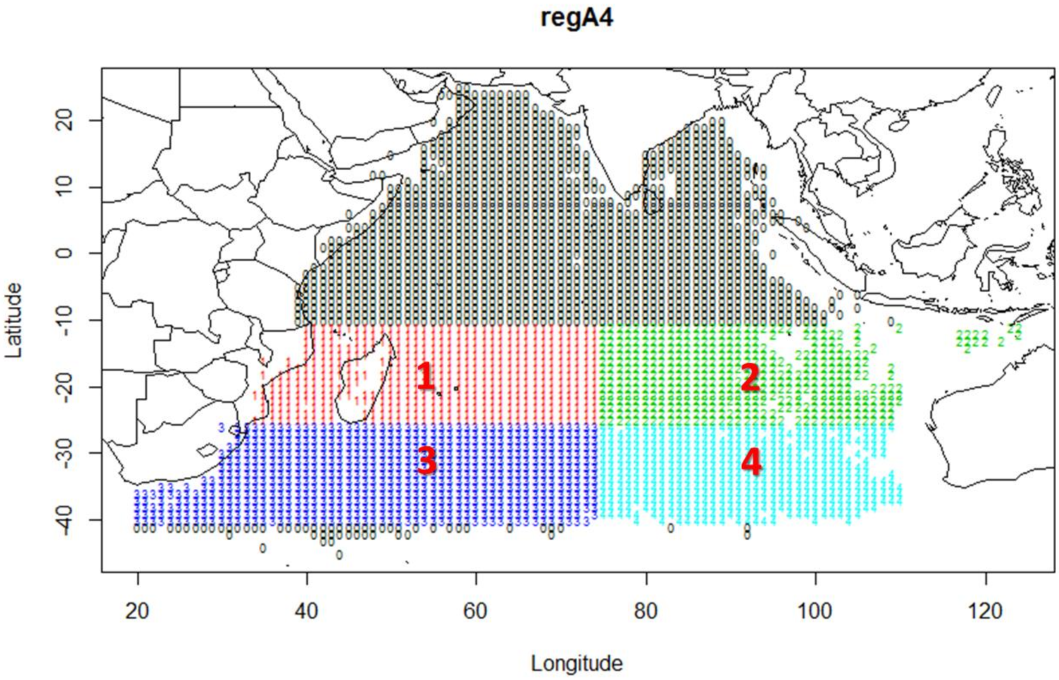


Fig. 1. Area stratification for albacore in the Indian Ocean.

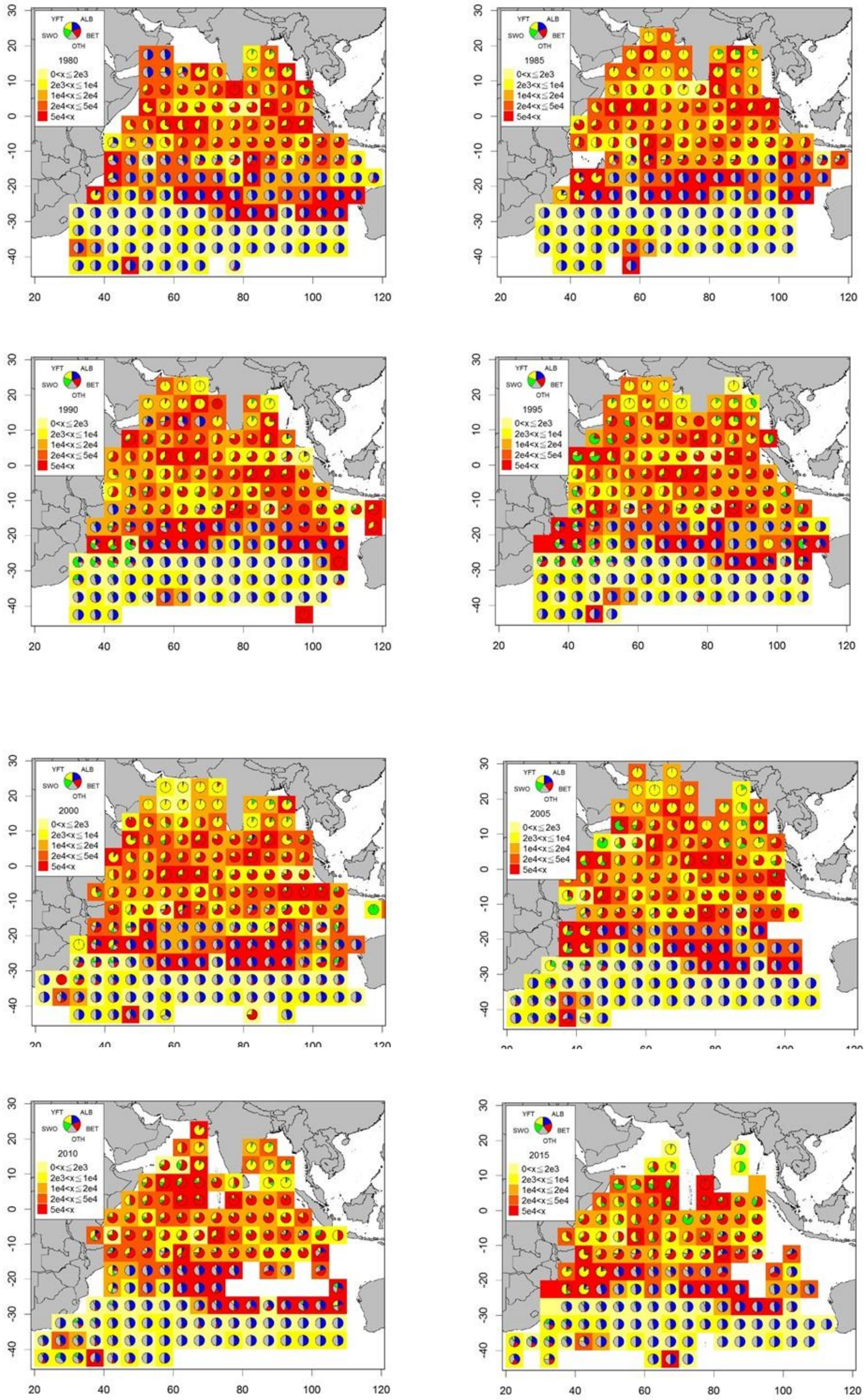


Fig. 2. Catch composition distribution of Taiwanese large scale longline fishery in the Indian Ocean.

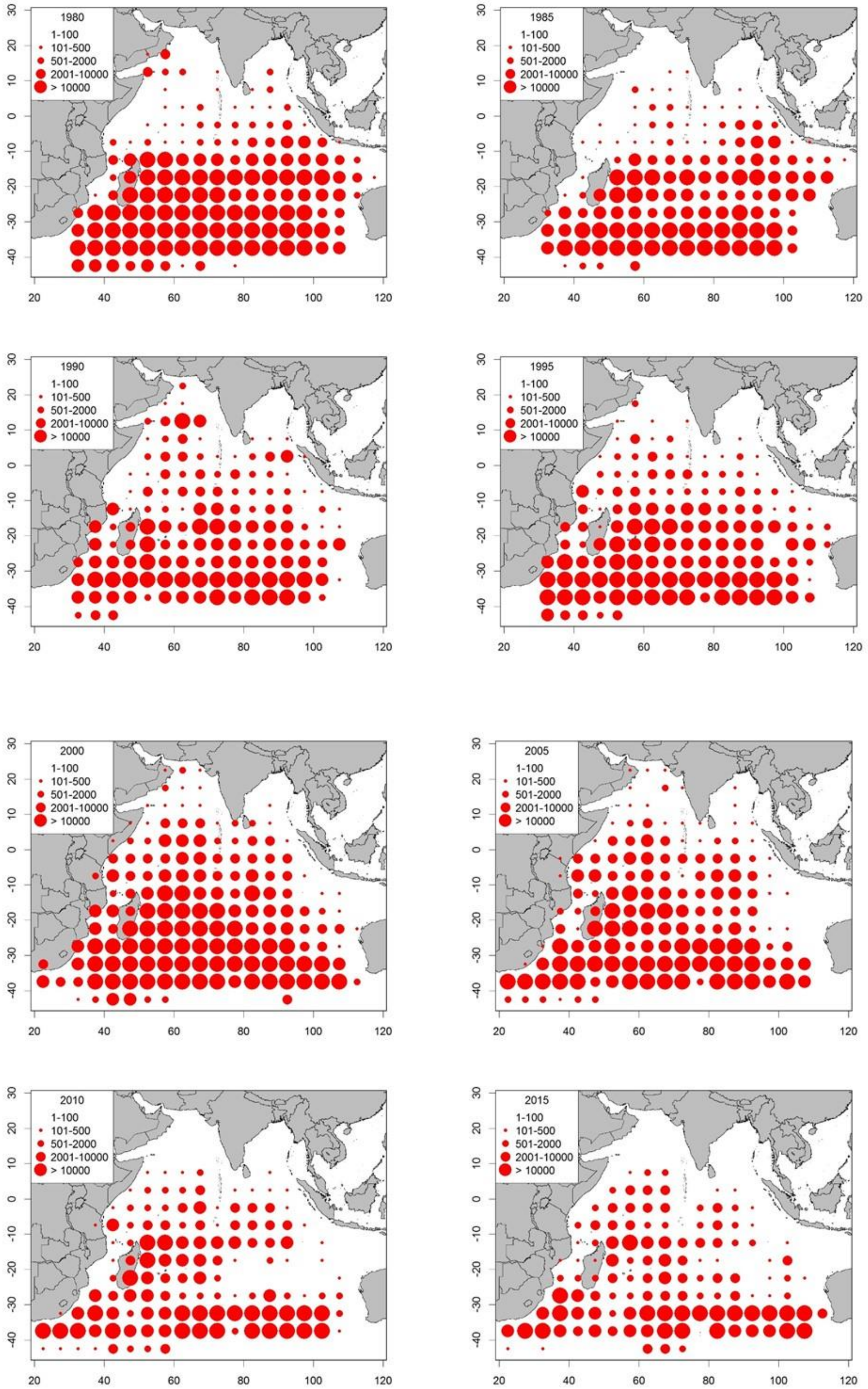


Fig. 3. Albacore catch distribution of Taiwanese large scale longline fishery in the Indian Ocean.

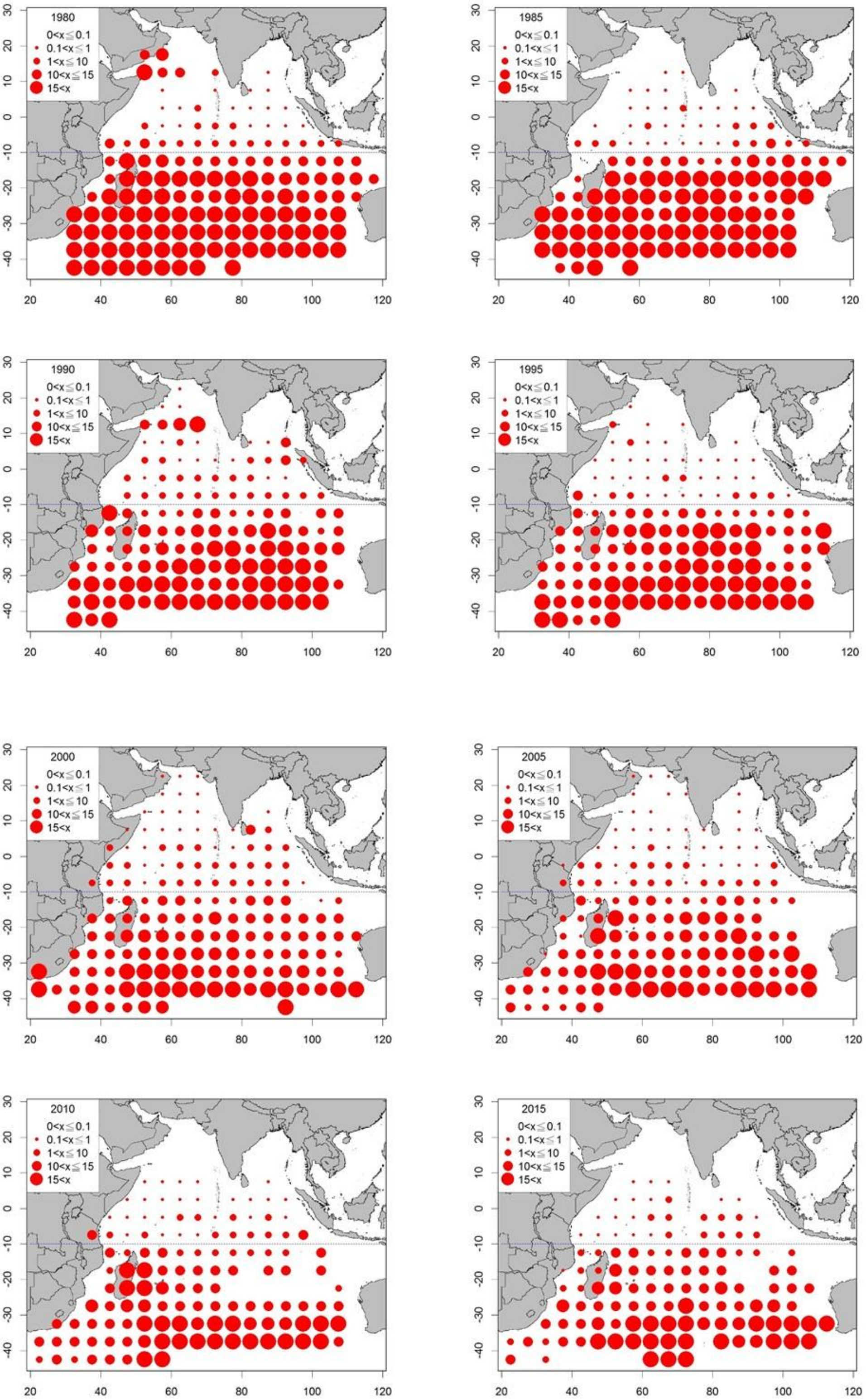


Fig. 4. Albacore CPUE distribution of Taiwanese large scale longline fishery in the Indian Ocean.

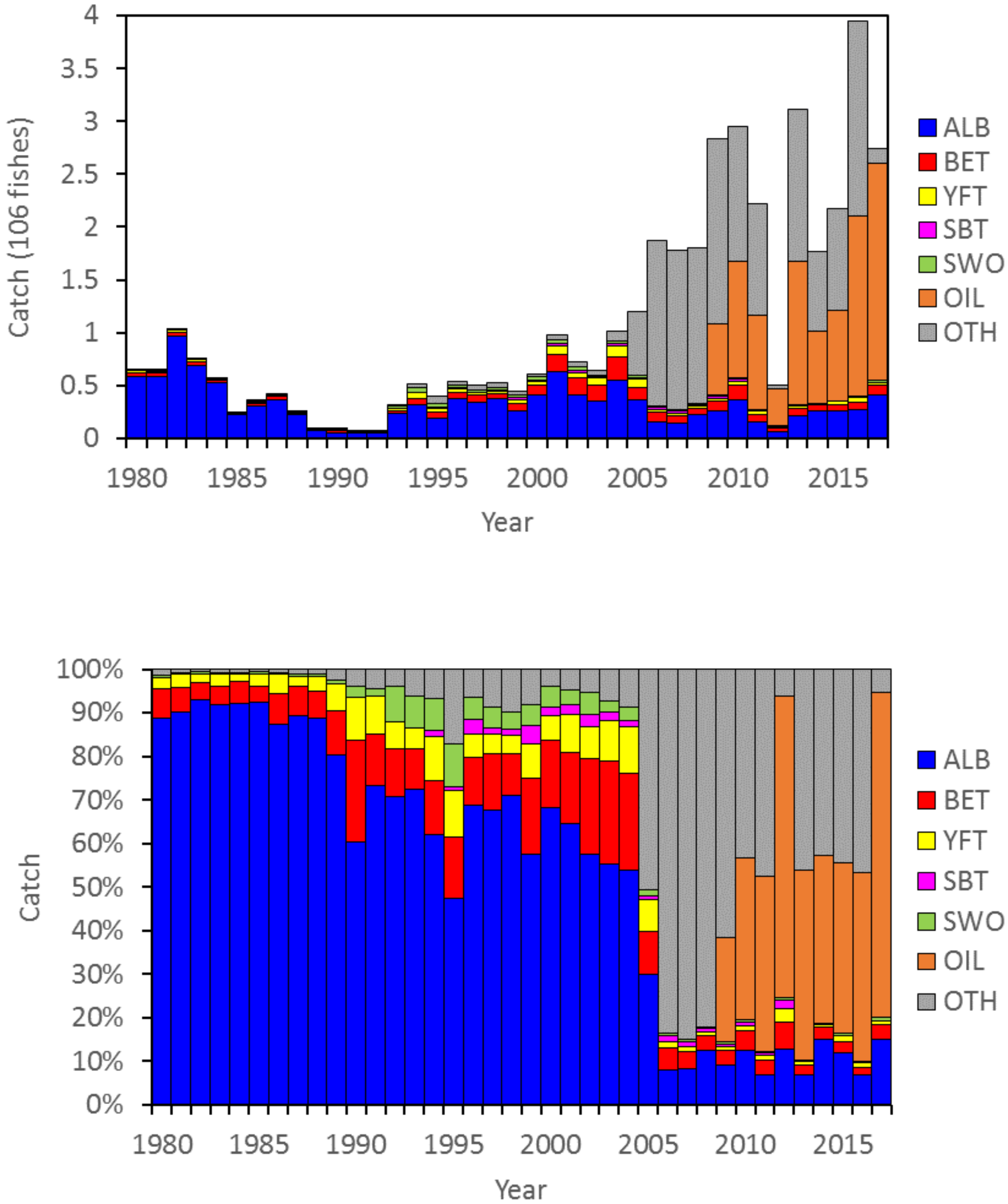


Fig. 5. Annual catch composition of Taiwanese large scale longline fishery in the south of 10S of the Indian Ocean.

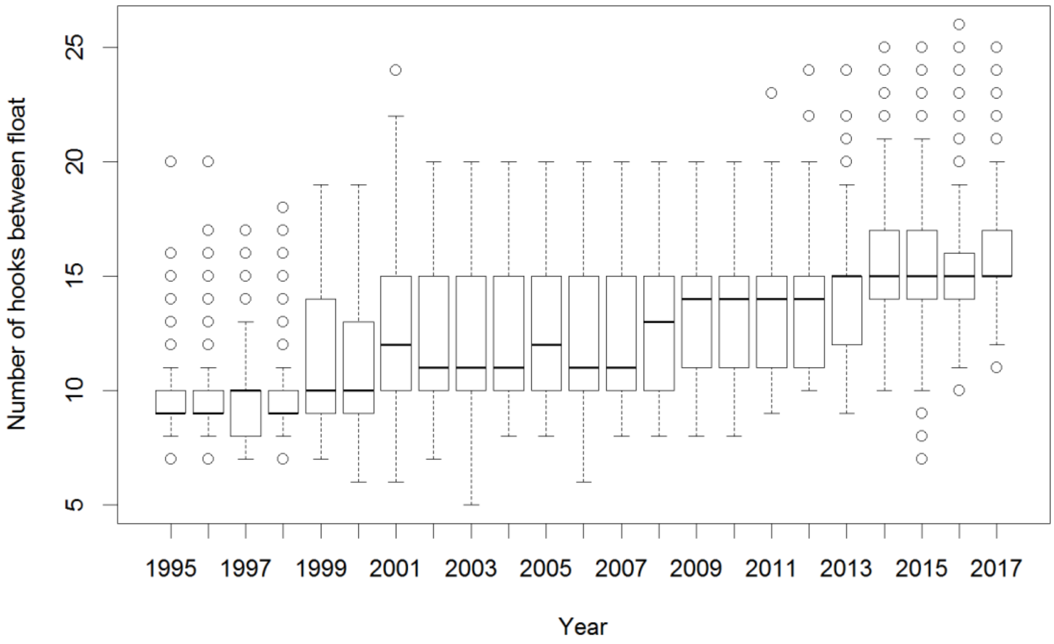


Fig. 6. Annual trend of the boxplot for the number of hooks between float of Taiwanese large scale longline fishery in the south of 10S of the Indian Ocean.

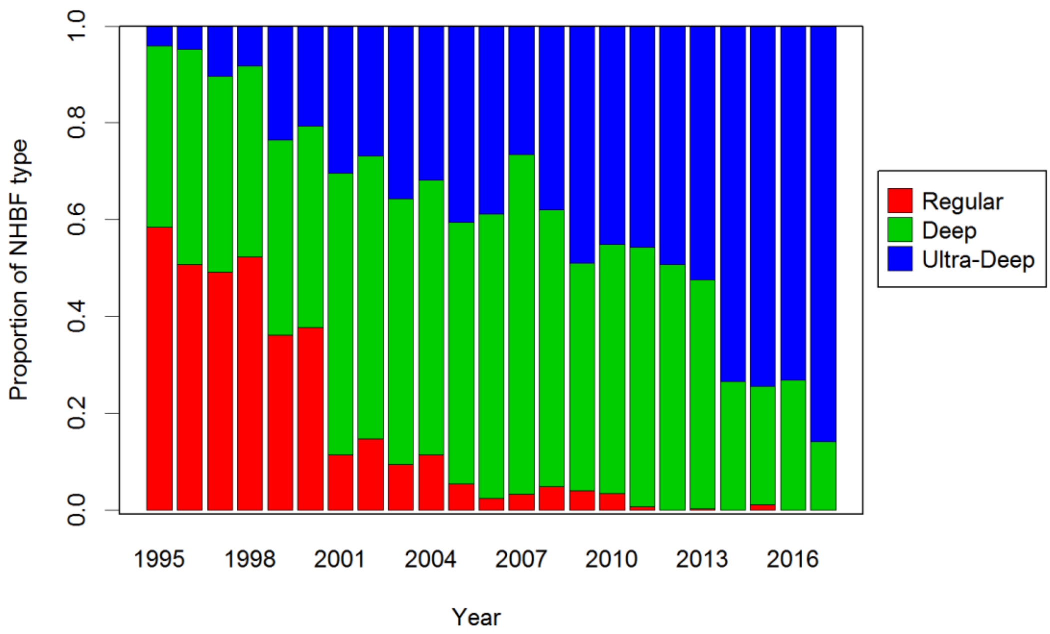
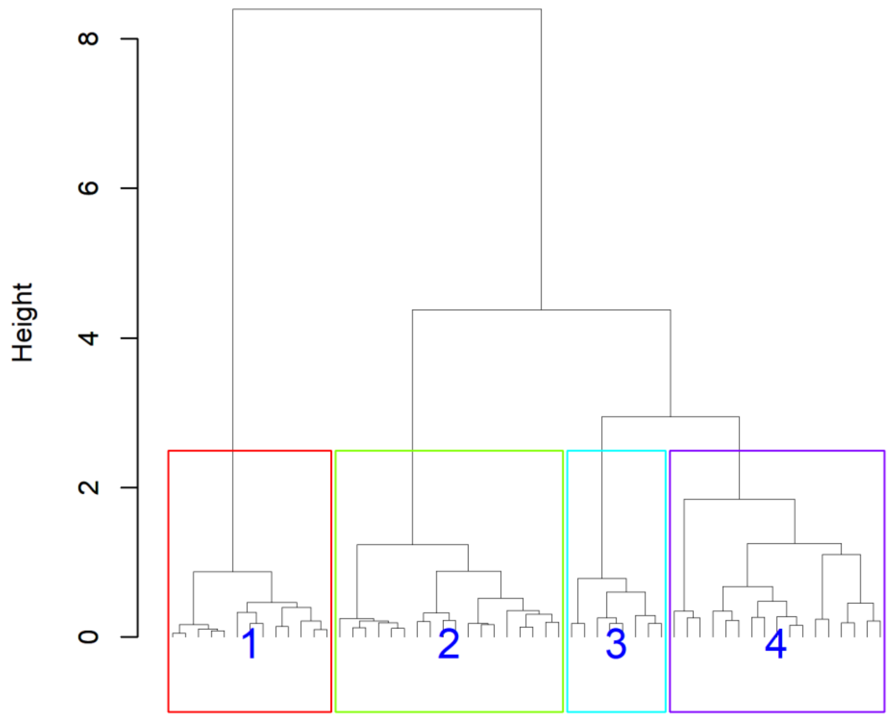


Fig. 7. Annual trend of the proportion of set type of Taiwanese large scale longline fishery in the south of 10S of the Indian Ocean. Regular set: number of hooks between float (NHBF) < 10 hooks; Deep set: 10 hooks ≤ NHBF < 15 hooks; Ultra-deep: NHBF ≥ 15 hooks.



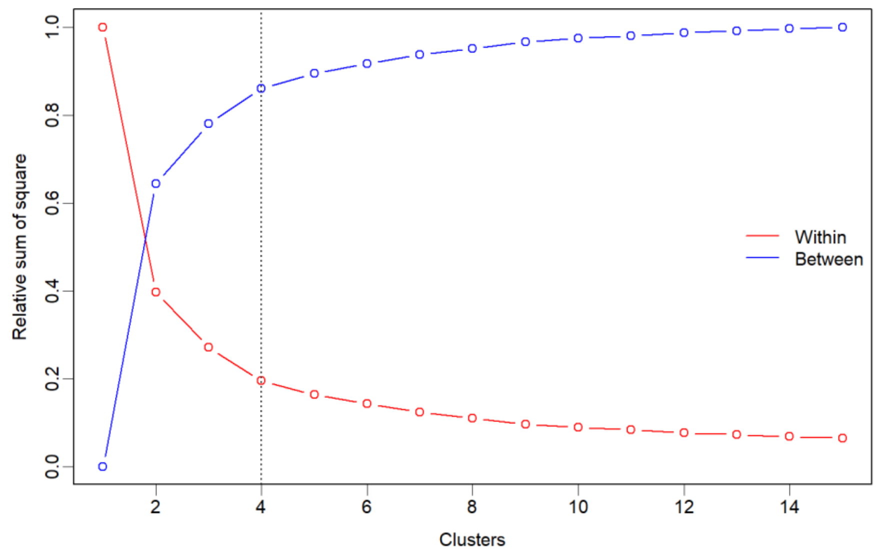


Fig. 8. Cluster tree and sum of squares within and between clusters for the data of Taiwanese large scale longline fishery in Albacore Area 1 of the Indian Ocean.

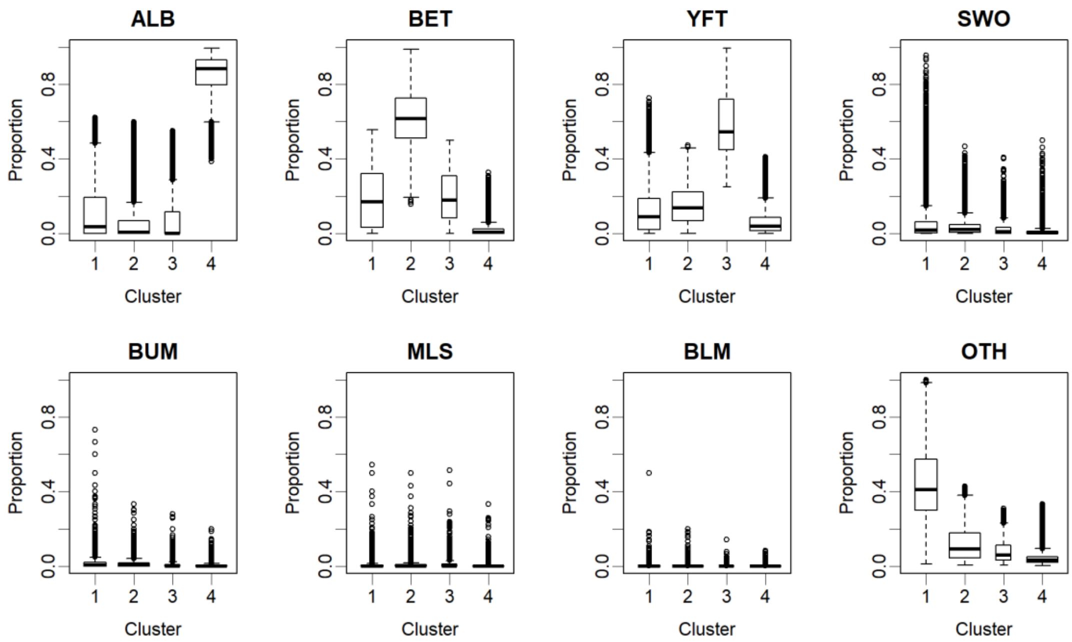


Fig. 9. Catch proportion by species for each cluster of Taiwanese large scale longline fishery in Albacore Area 1 of the Indian Ocean.

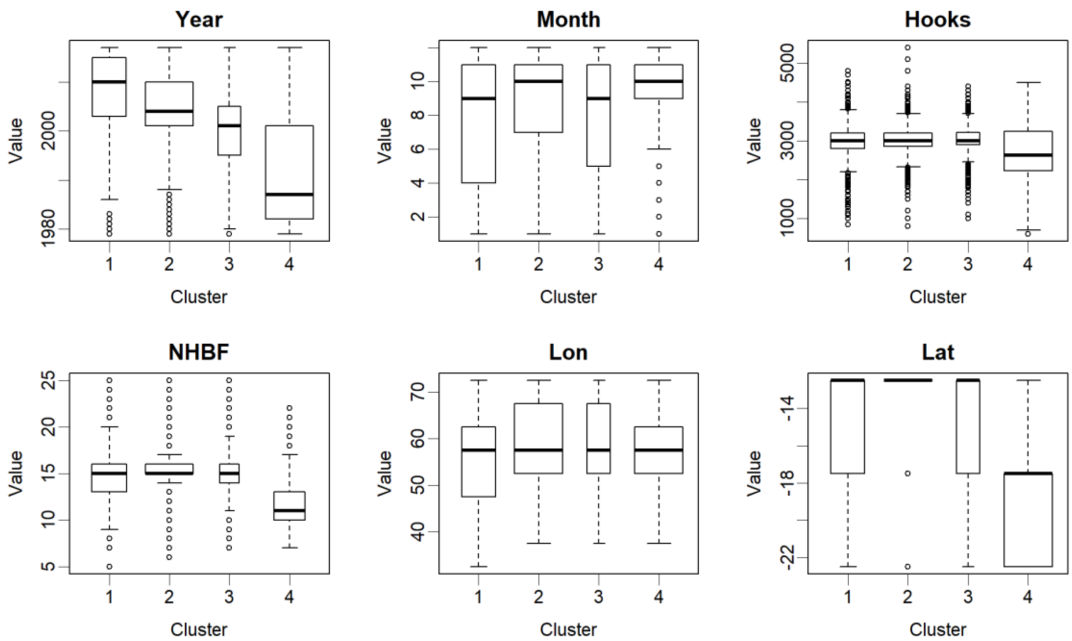


Fig. 10. Data composition by factors for each cluster of Taiwanese large scale longline fishery in Albacore Area 1 of the Indian Ocean.

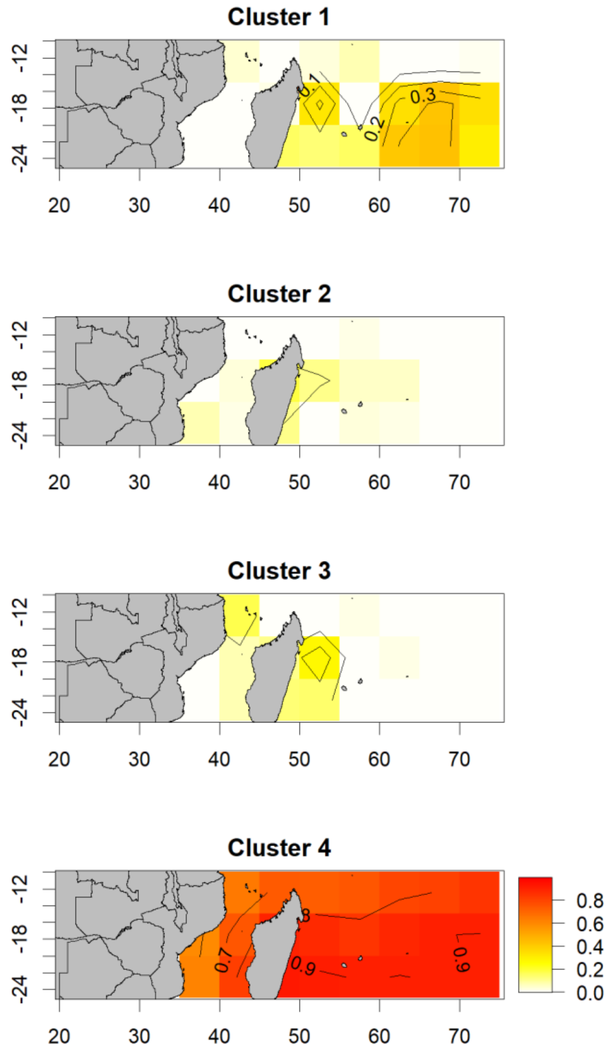


Fig. 11. Albacore catch distribution for each cluster of Taiwanese large scale longline fishery in Albacore Area 1 of the Indian Ocean. Yellow is high catch and red is low catch.

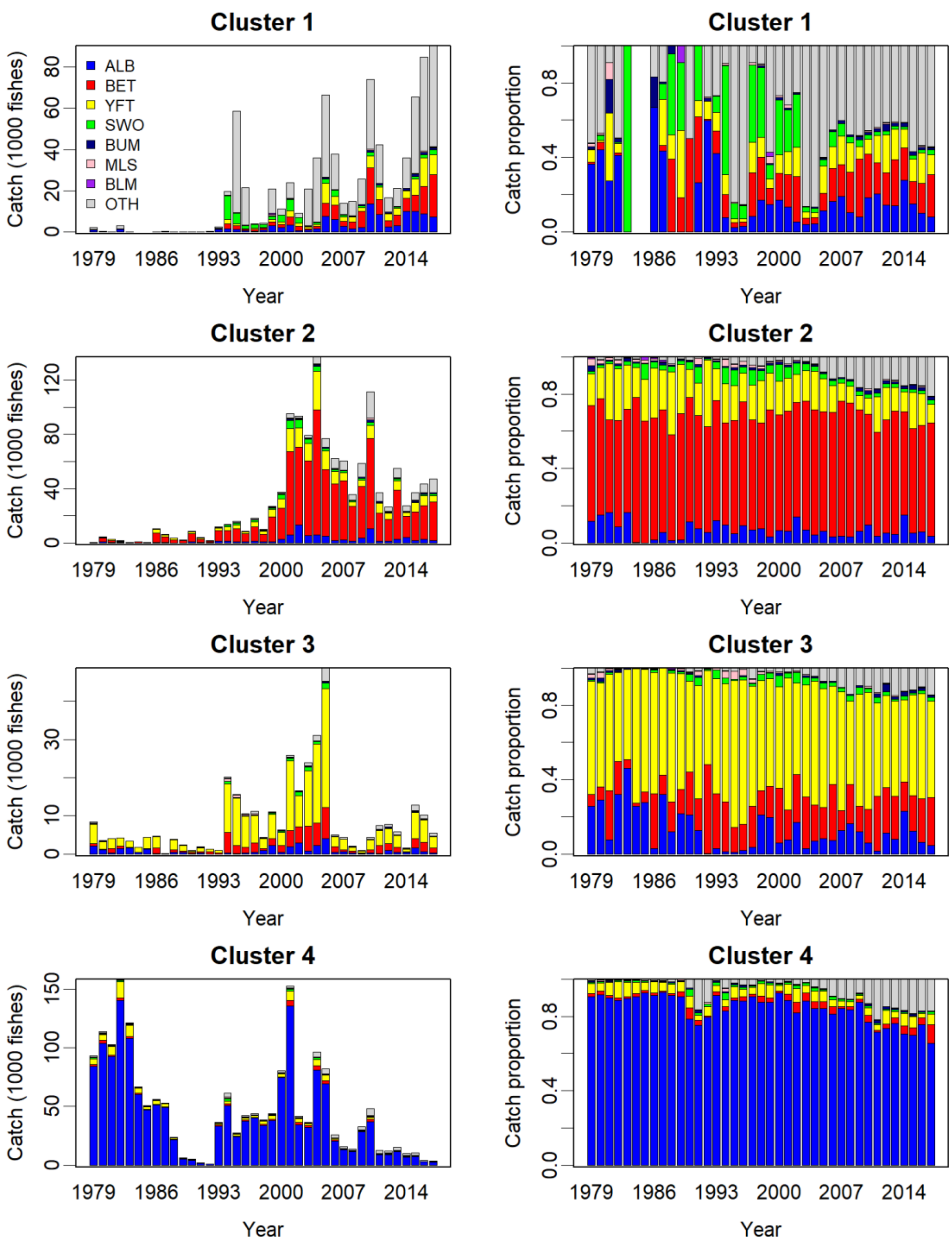


Fig. 12. Annual and catch proportion by species for each cluster of Taiwanese large scale longline fishery in Albacore Area 1 of the Indian Ocean.

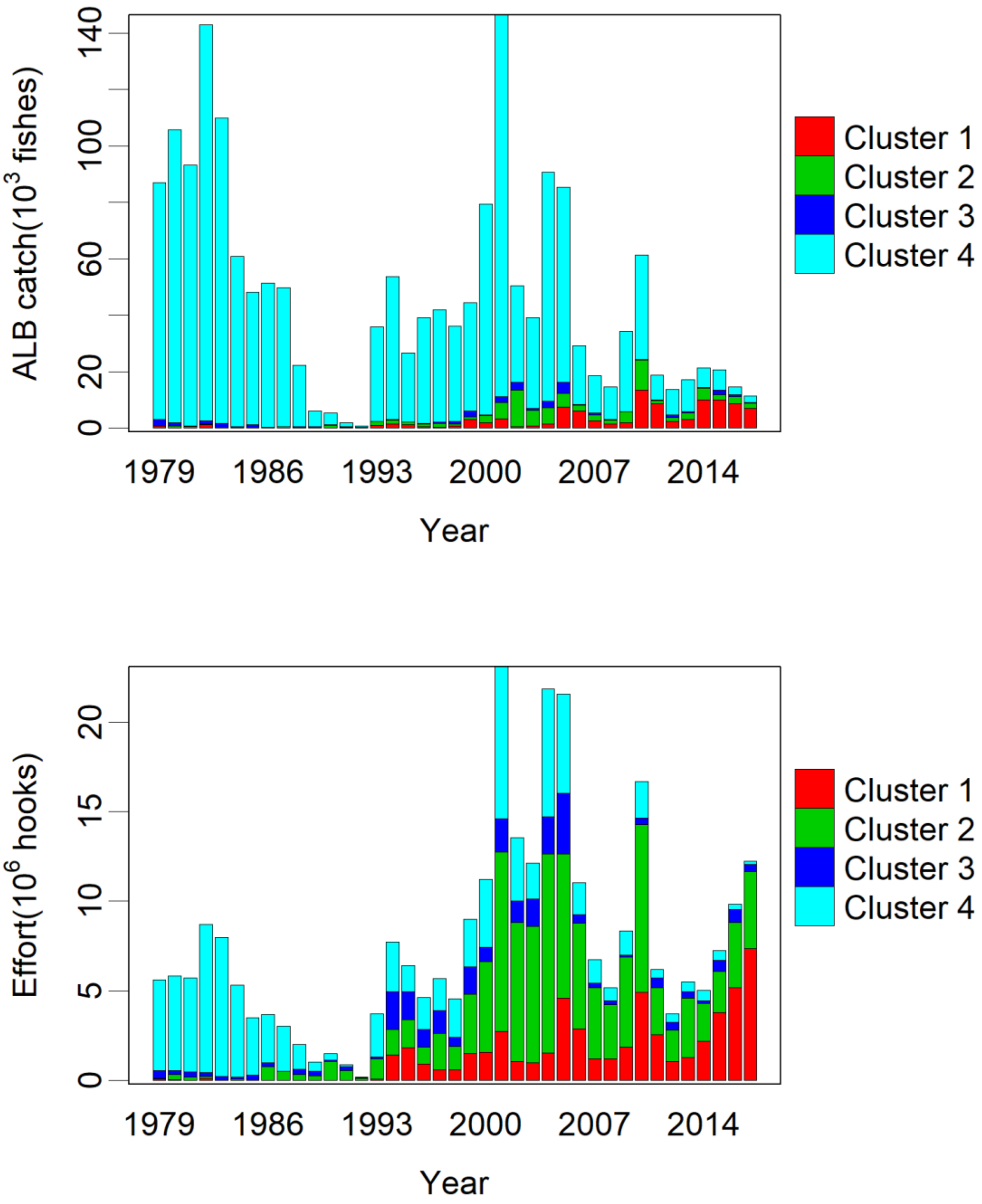
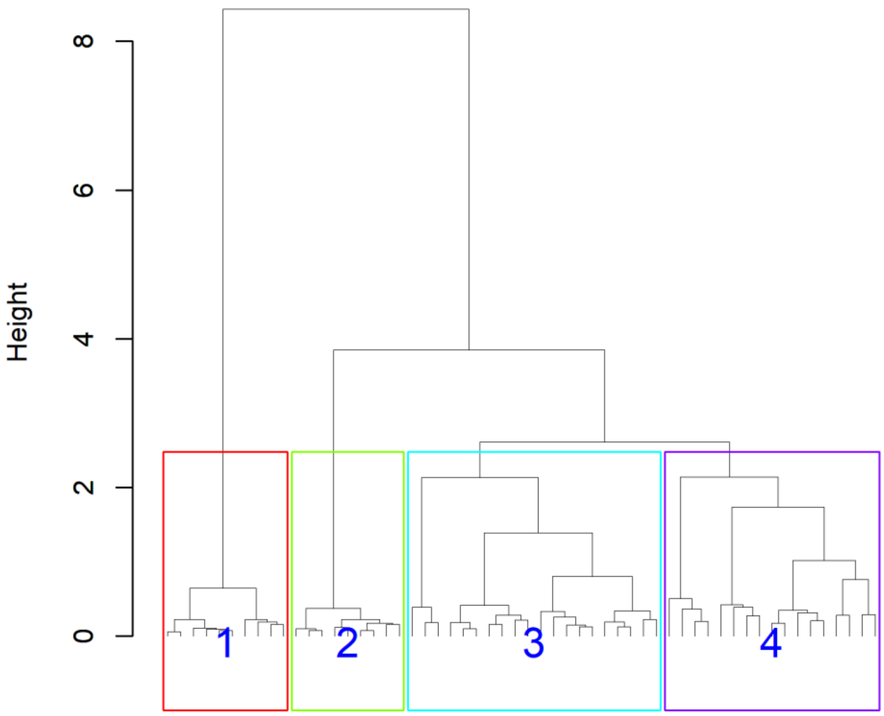


Fig. 13. Annual striped marlin catches for each cluster of Taiwanese large scale longline fishery in Albacore Area 1 of the Indian Ocean.



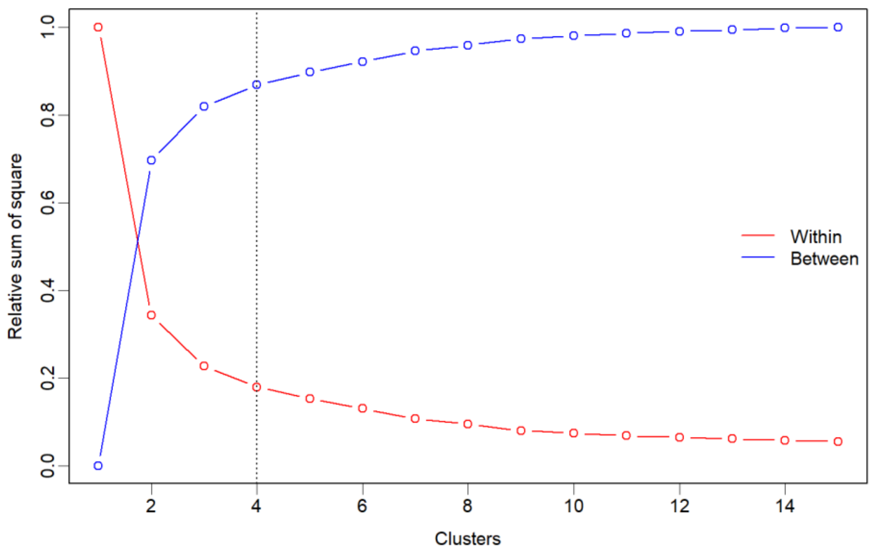


Fig. 14. Cluster tree and sum of squares within and between clusters for the data of Taiwanese large scale longline fishery in Albacore Area 2 of the Indian Ocean.

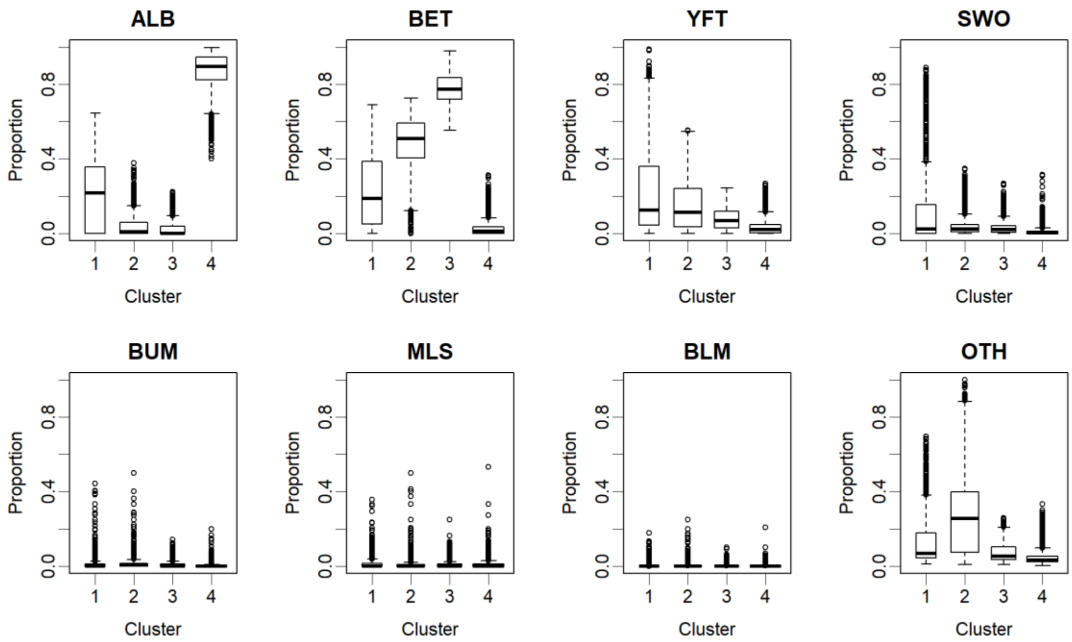


Fig. 15. Catch proportion by species for each cluster of Taiwanese large scale longline fishery in Albacore Area 2 of the Indian Ocean.

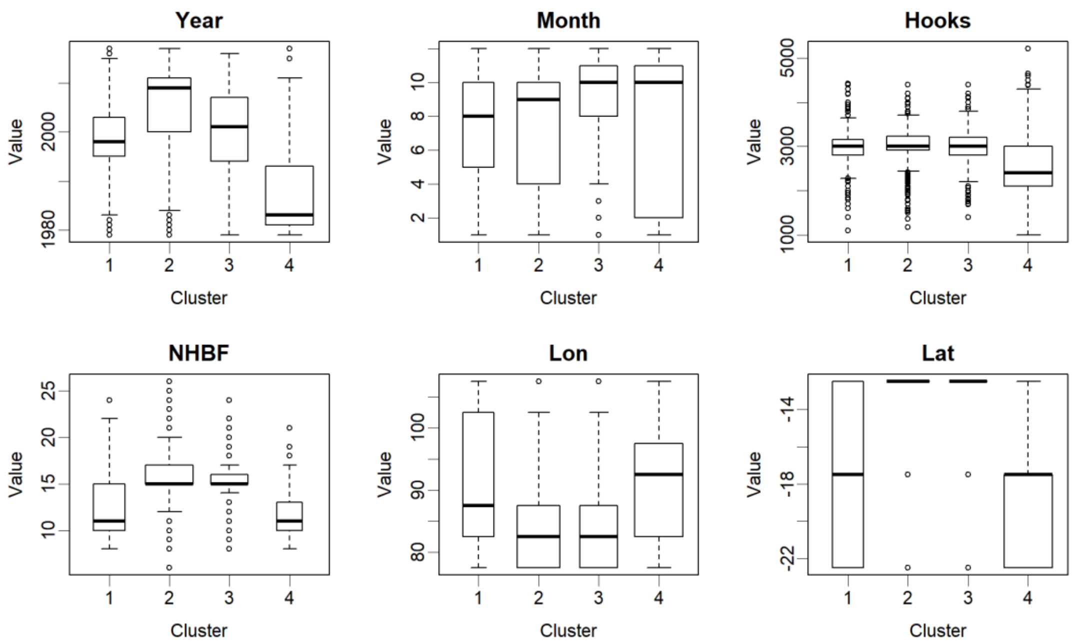


Fig. 16. Data composition by factors for each cluster of Taiwanese large scale longline fishery in Albacore Area 2 of the Indian Ocean.

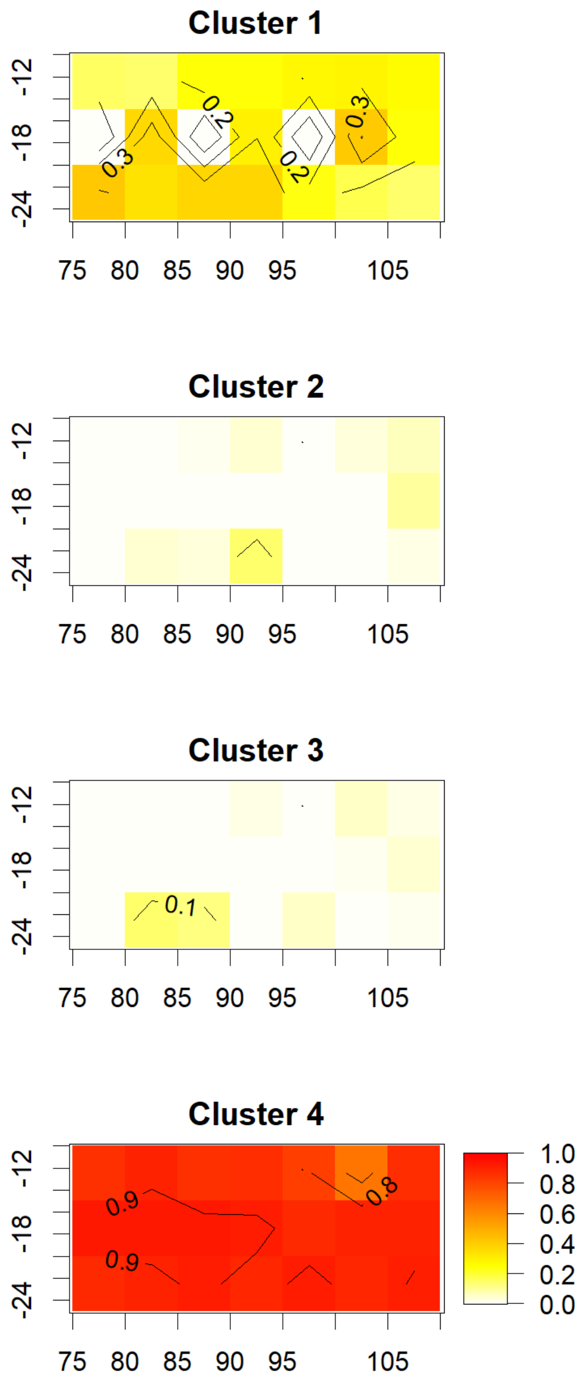


Fig. 17. Albacore catch distribution for each cluster of Taiwanese large scale longline fishery in Albacore Area 2 of the Indian Ocean. Yellow is high catch and red is low catch.

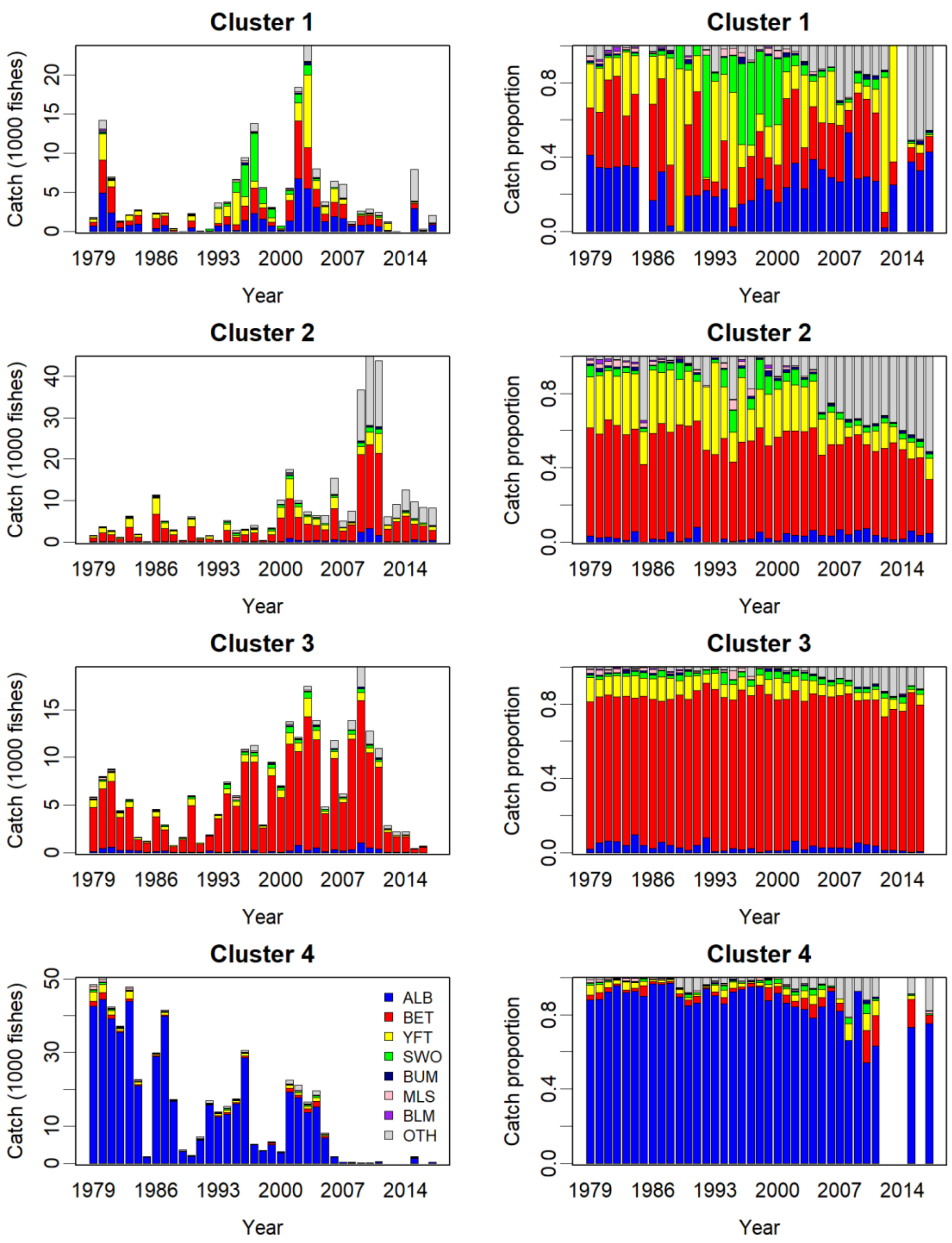


Fig. 18. Annual and catch proportion by species for each cluster of Taiwanese large scale longline fishery in Albacore Area 2 of the Indian Ocean.

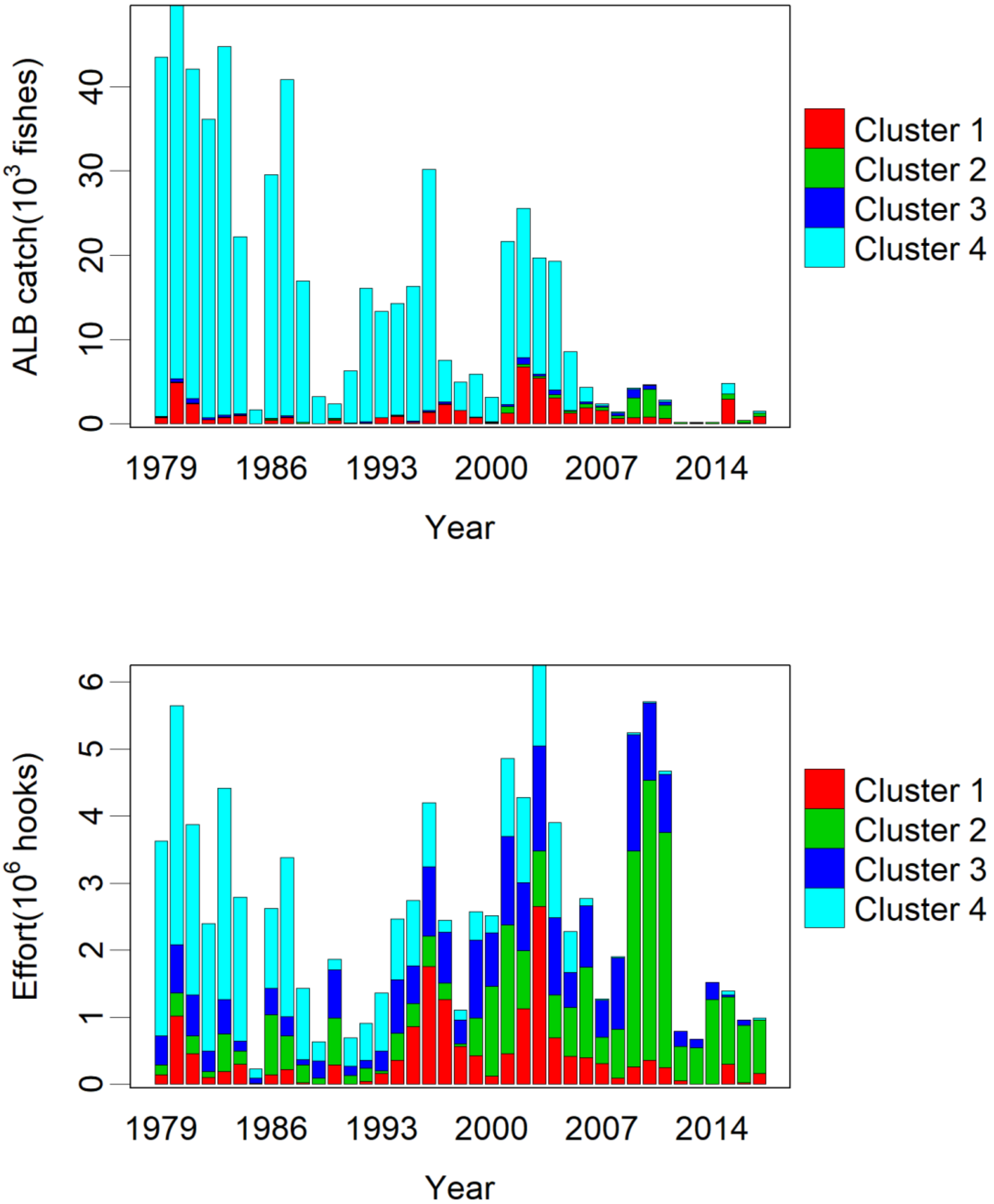
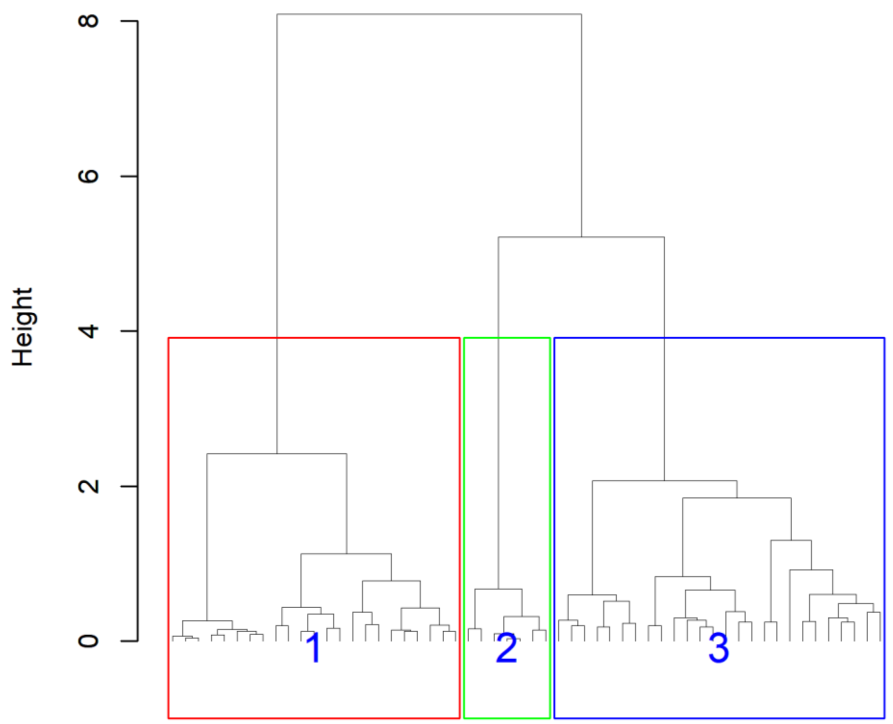


Fig. 19. Annual striped marlin catches for each cluster of Taiwanese large scale longline fishery in Albacore Area 2 of the Indian Ocean.



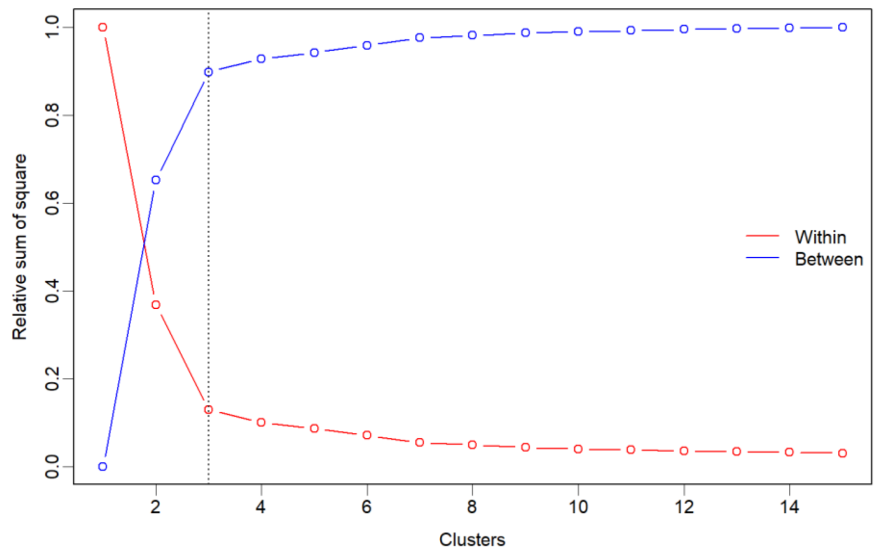


Fig. 20. Cluster tree and sum of squares within and between clusters for the data of Taiwanese large scale longline fishery in Albacore Area 3 of the Indian Ocean.

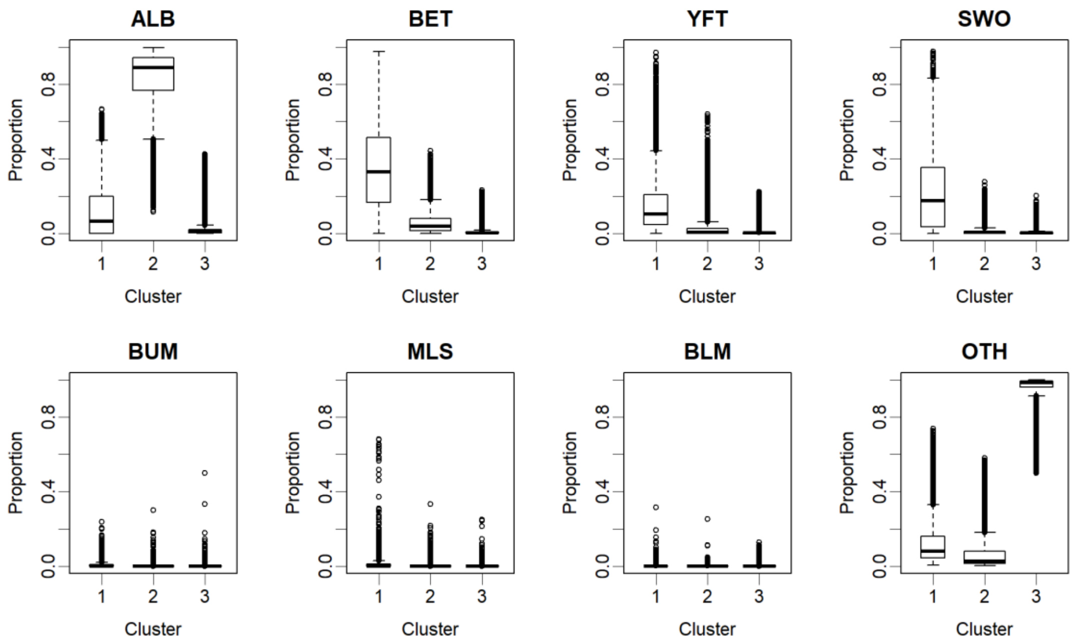


Fig. 21. Catch proportion by species for each cluster of Taiwanese large scale longline fishery in Albacore Area 3 of the Indian Ocean.

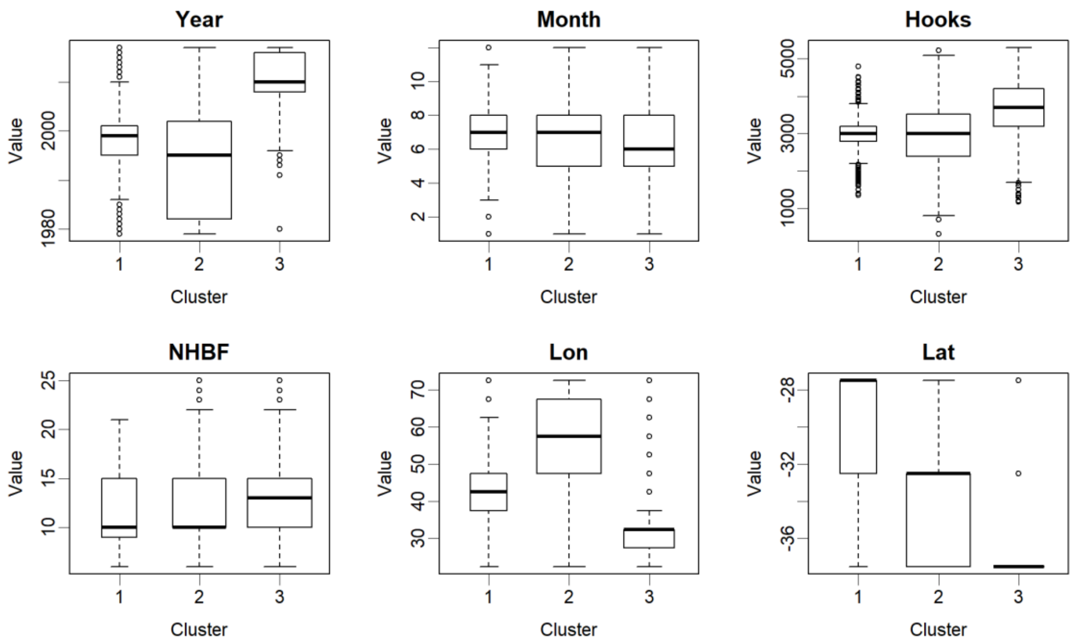


Fig. 22. Data composition by factors for each cluster of Taiwanese large scale longline fishery in Albacore Area 3 of the Indian Ocean.

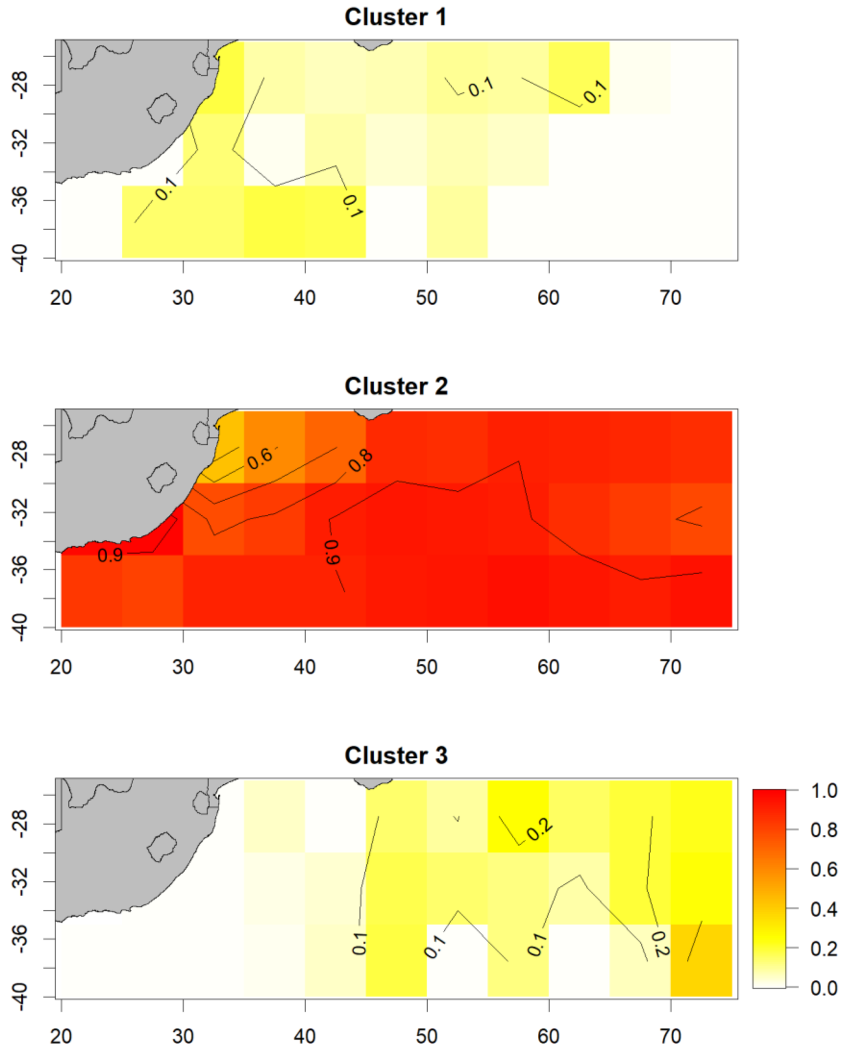


Fig. 23. Albacore catch distribution for each cluster of Taiwanese large scale longline fishery in Albacore Area 3 of the Indian Ocean. Yellow is high catch and red is low catch.

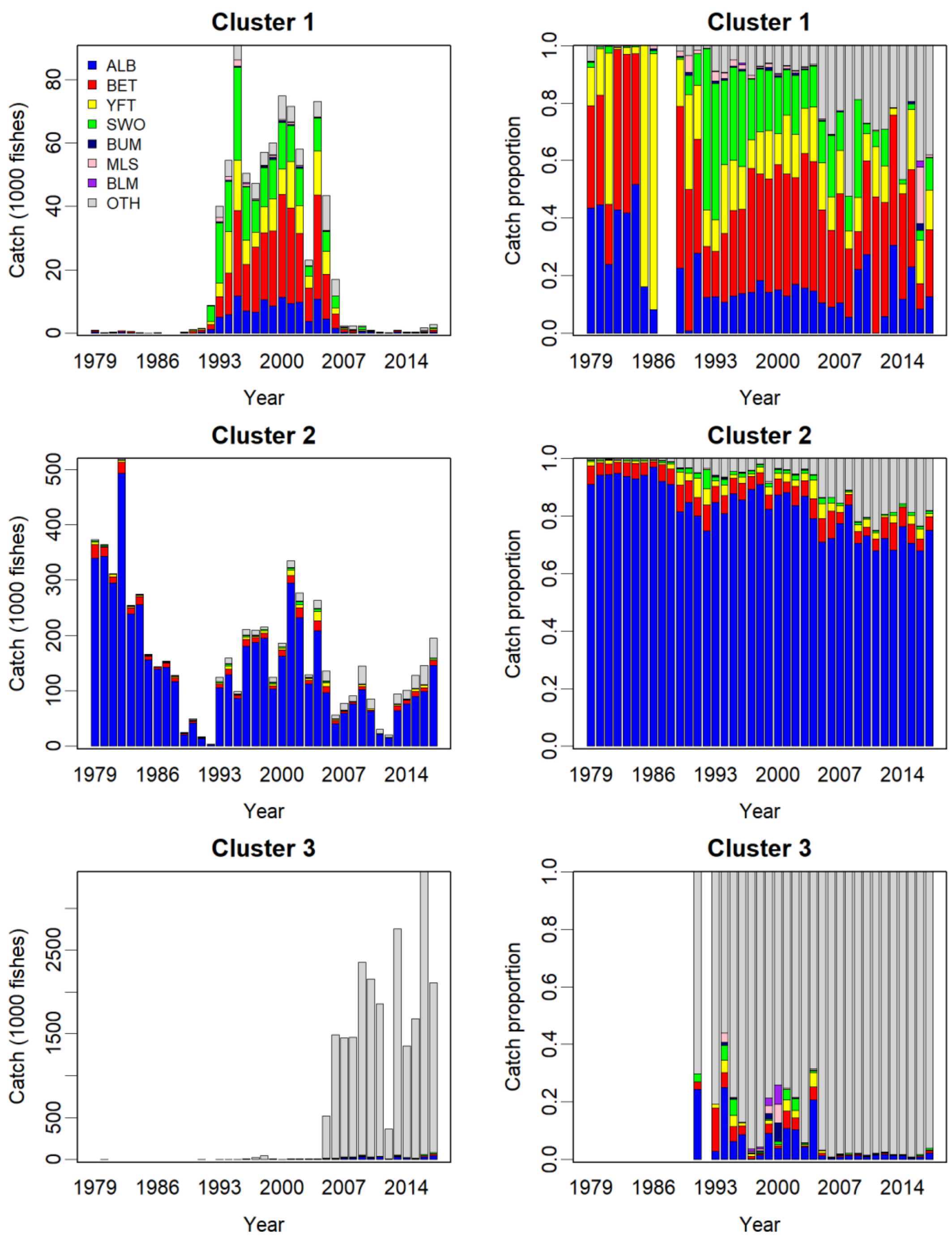


Fig. 24. Annual and catch proportion by species for each cluster of Taiwanese large scale longline fishery in Albacore Area 3 of the Indian Ocean.

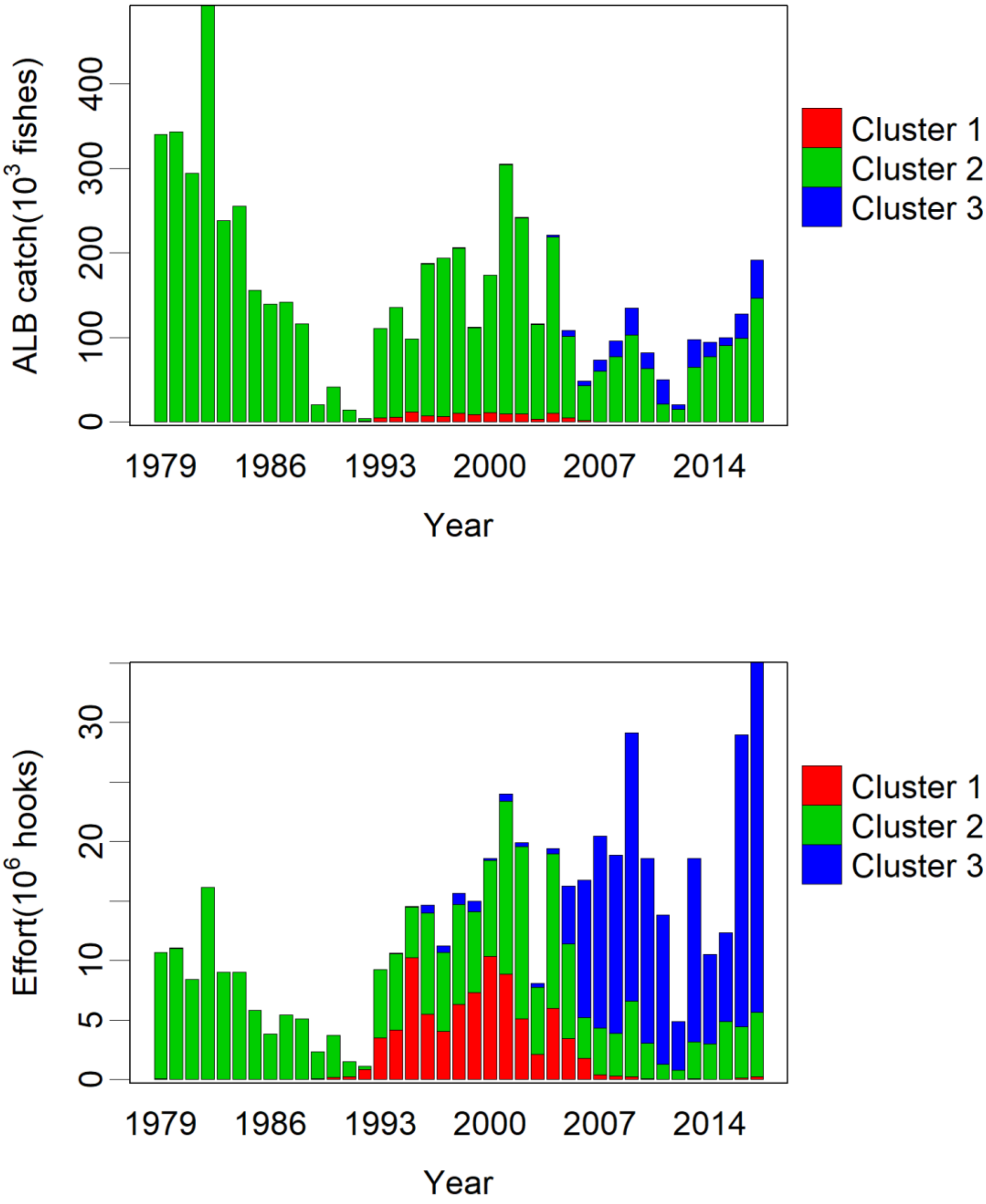
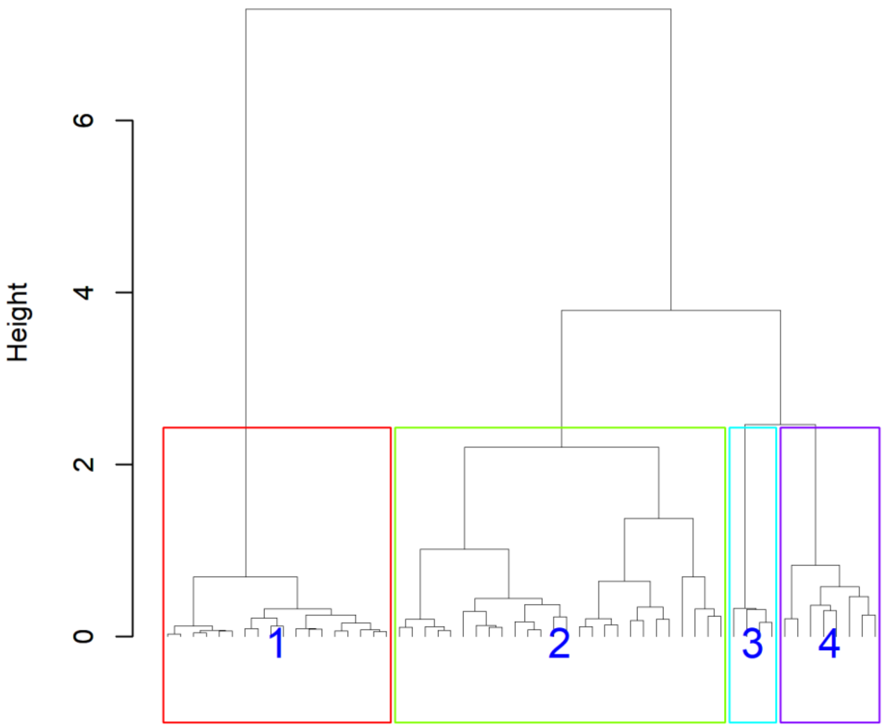


Fig. 25. Annual striped marlin catches for each cluster of Taiwanese large scale longline fishery in Albacore Area 3 of the Indian Ocean.



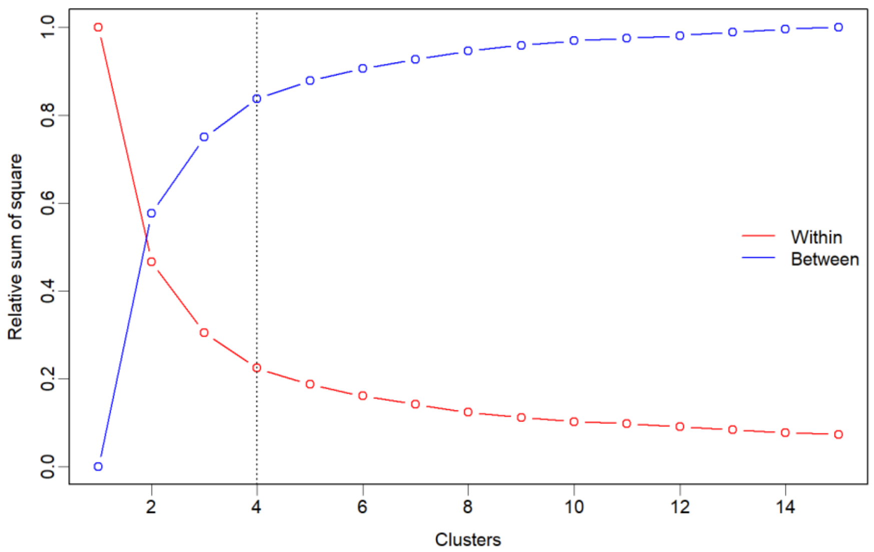


Fig. 26. Cluster tree and sum of squares within and between clusters for the data of Taiwanese large scale longline fishery in Albacore Area 4 of the Indian Ocean.

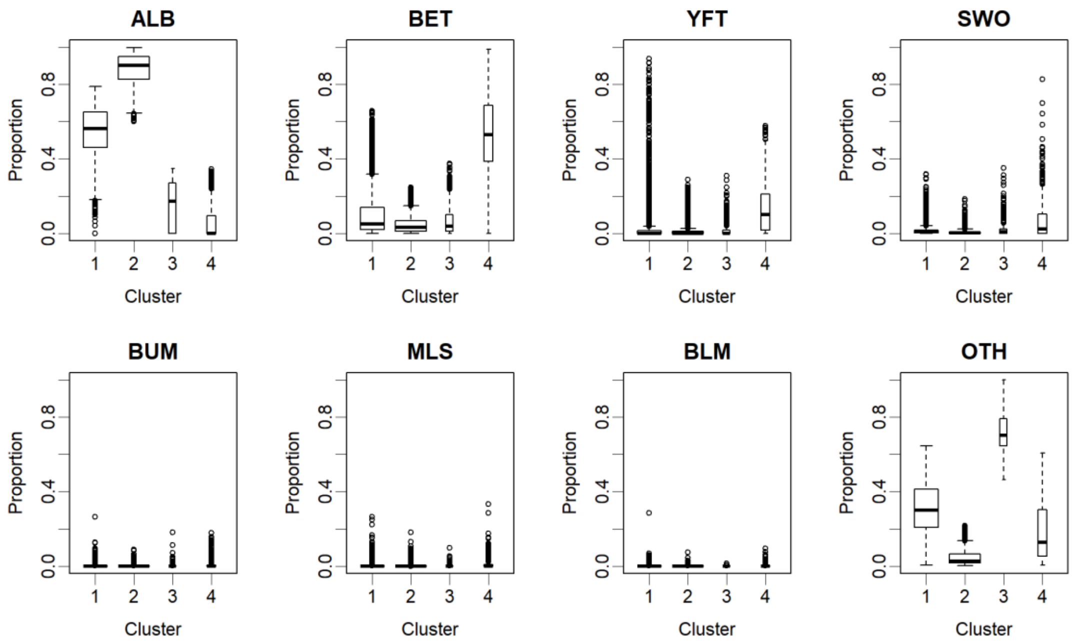


Fig. 27. Catch proportion by species for each cluster of Taiwanese large scale longline fishery in Albacore Area 4 of the Indian Ocean.

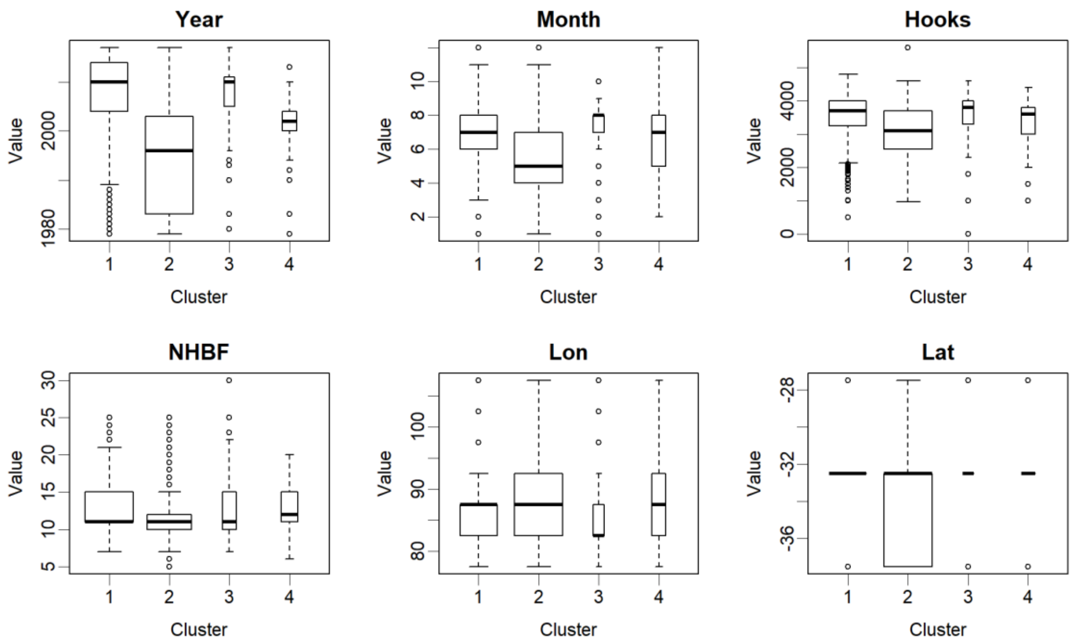


Fig. 28. Data composition by factors for each cluster of Taiwanese large scale longline fishery in Albacore Area 4 of the Indian Ocean.

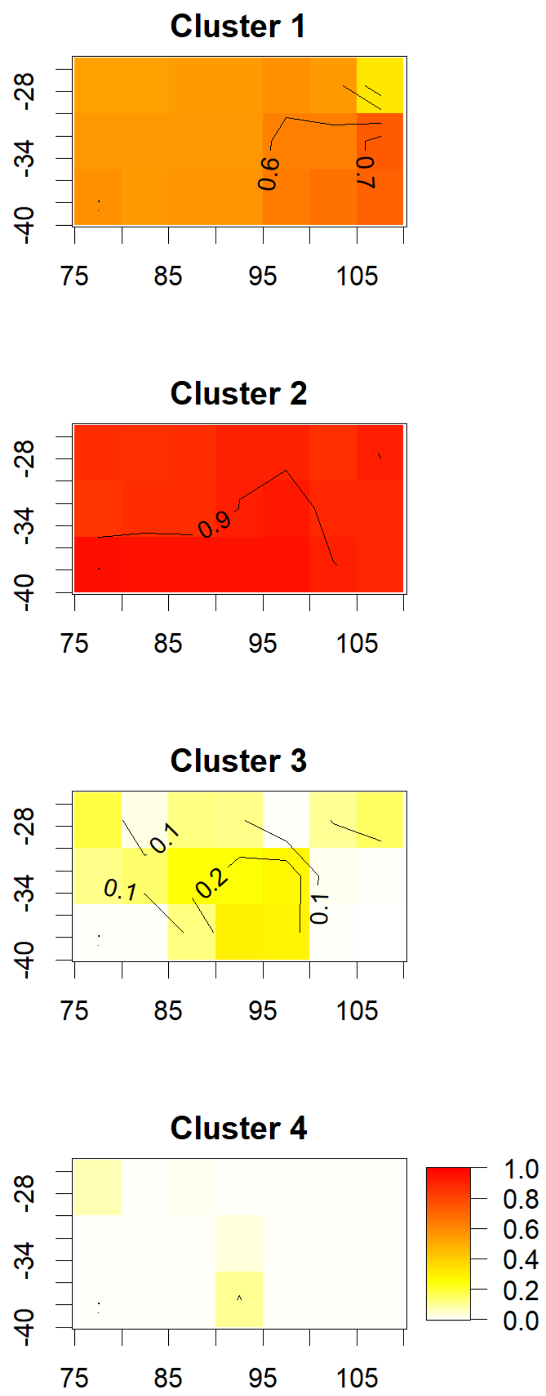


Fig. 29. Albacore catch distribution for each cluster of Taiwanese large scale longline fishery in Albacore Area 4 of the Indian Ocean. Yellow is high catch and red is low catch.

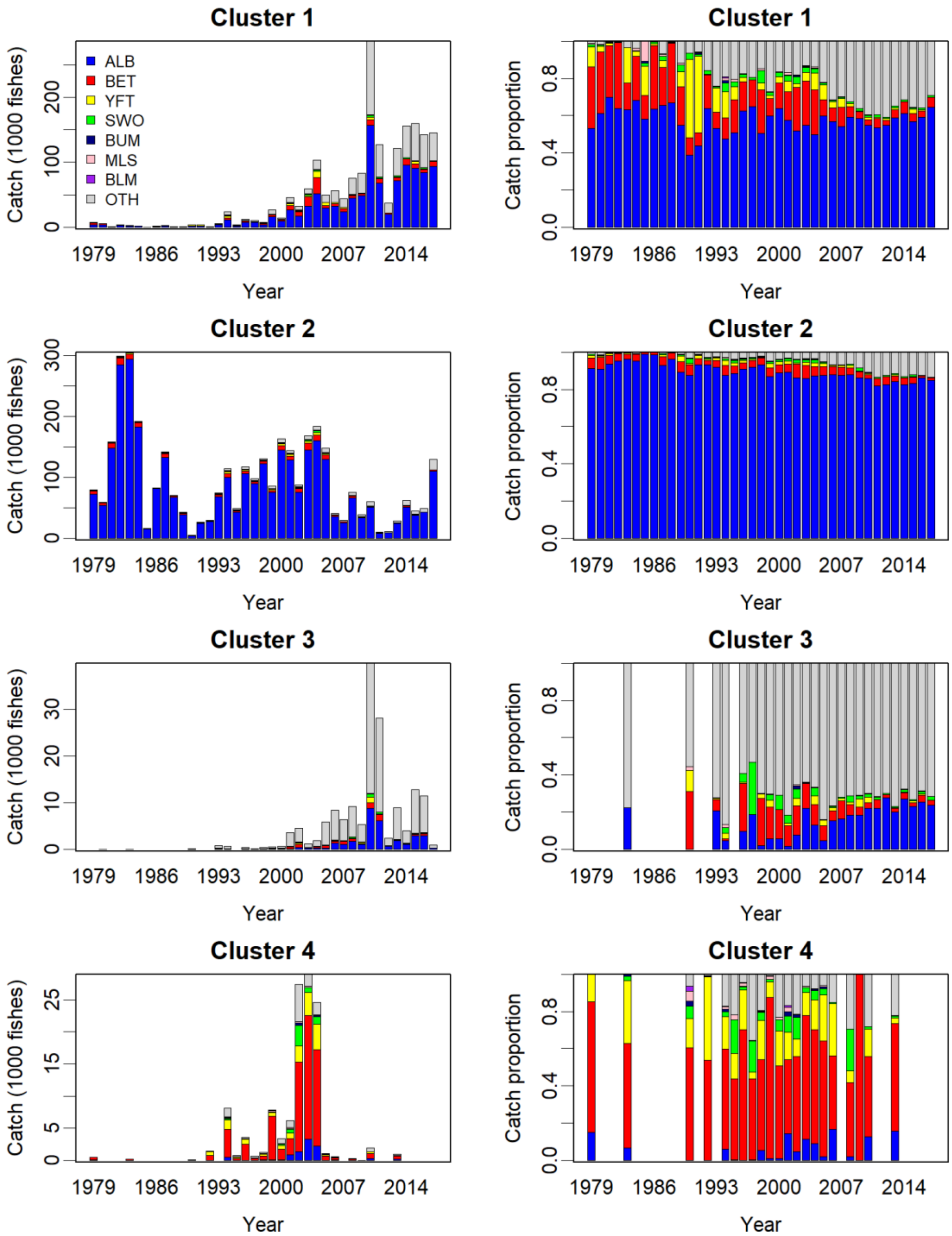
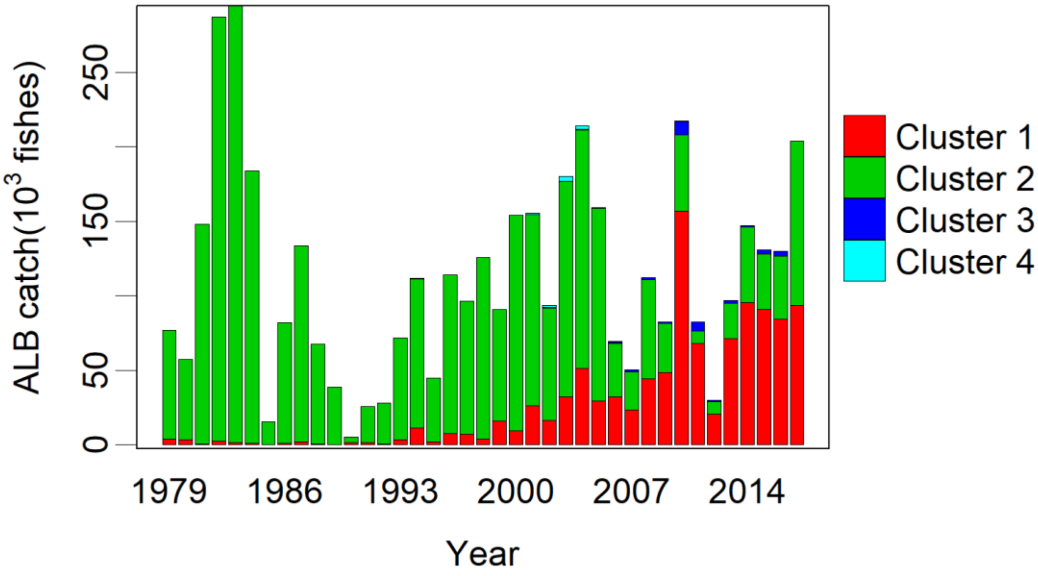


Fig. 30. Annual and catch proportion by species for each cluster of Taiwanese large scale longline fishery in Albacore Area 4 of the Indian Ocean.



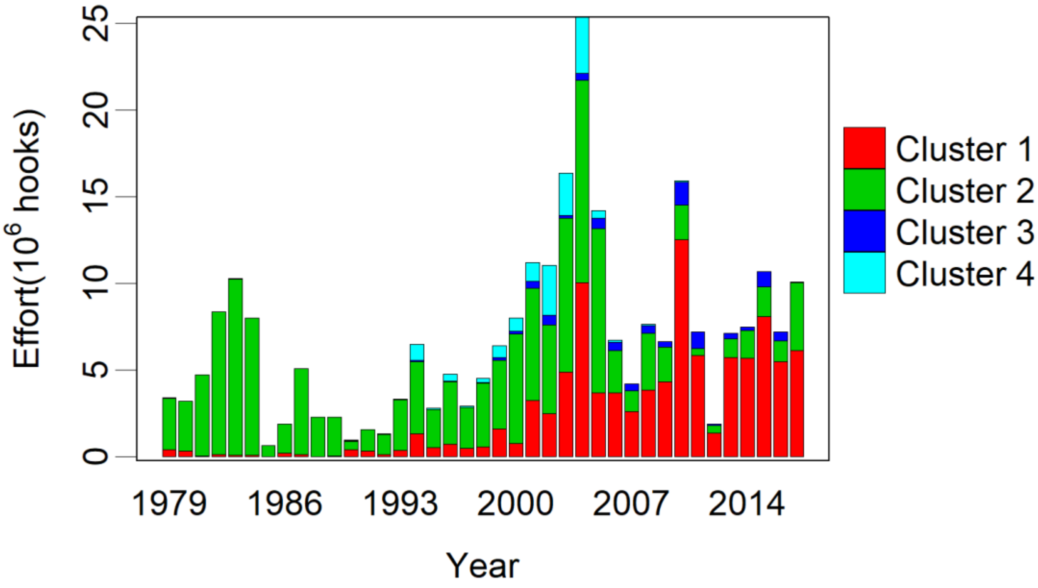


Fig. 31. Annual striped marlin catches for each cluster of Taiwanese large scale longline fishery in Albacore Area 4 of the Indian Ocean.

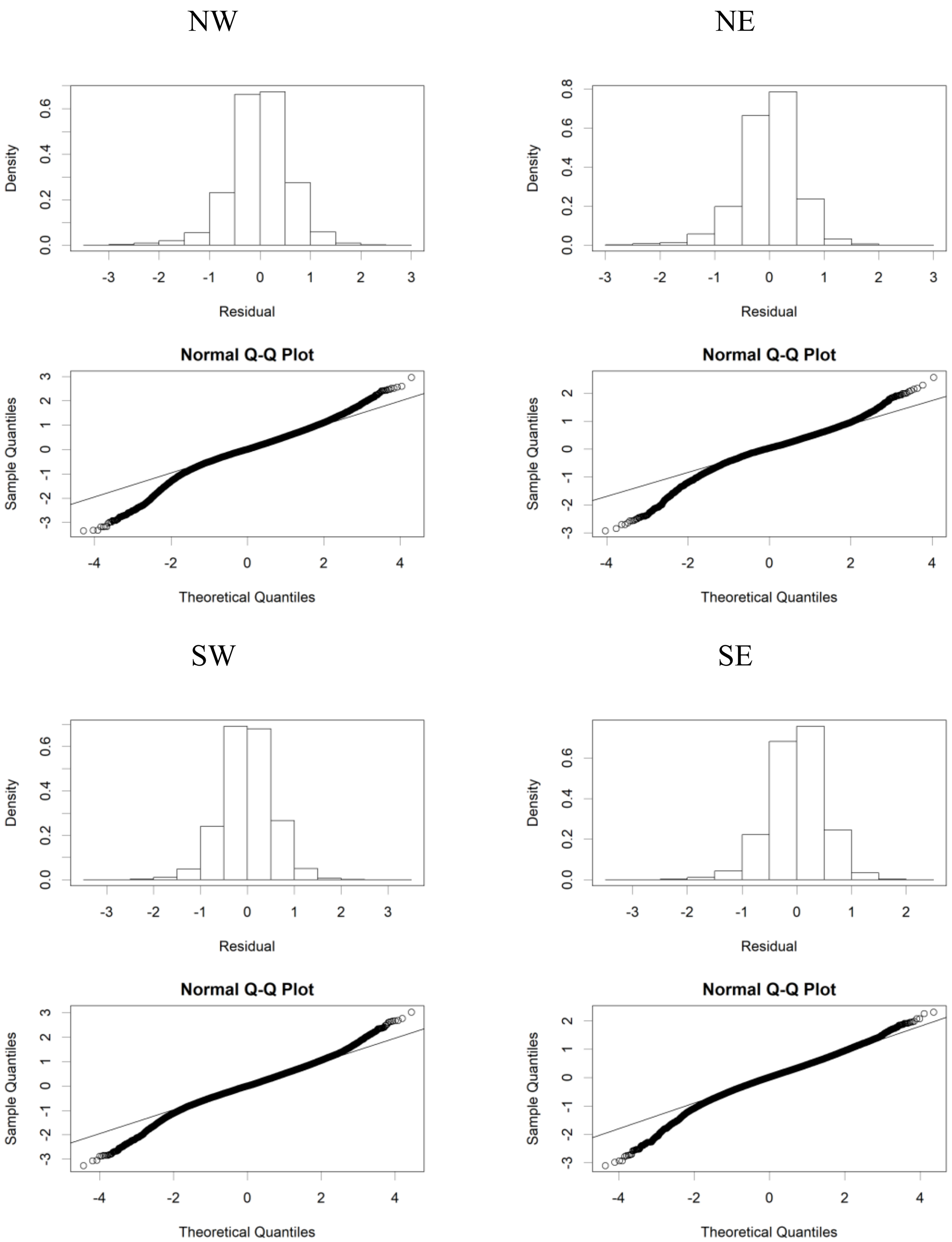


Fig. 32. Histogram and Quantile-Quantile plots obtained from the year-quarter GLM for albacore caught by Taiwanese large scale longline fishery in the Indian Ocean.

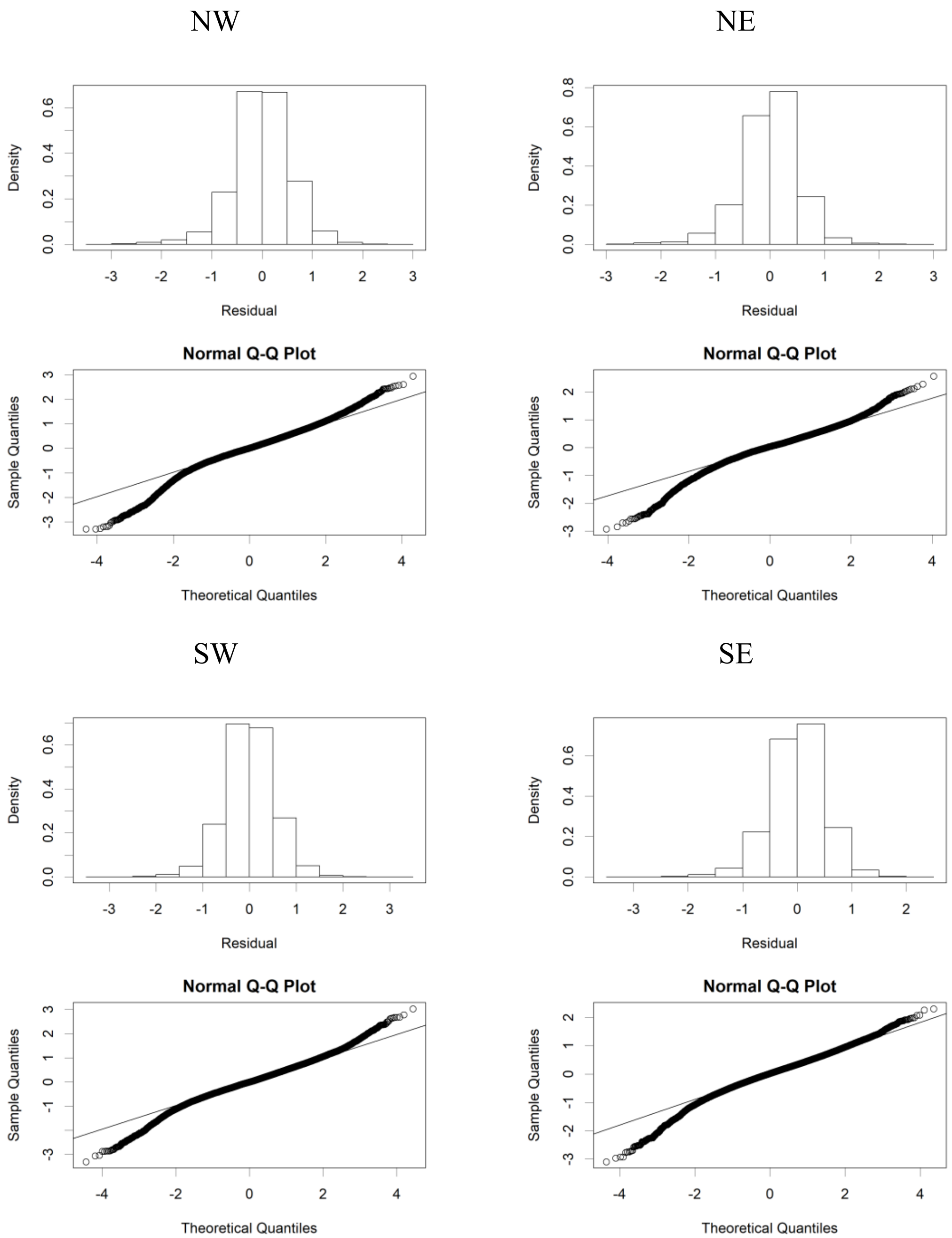


Fig. 33. Histogram and Quantile-Quantile plots obtained from the year-quarter GLMM for albacore caught by Taiwanese large scale longline fishery in the Indian Ocean.

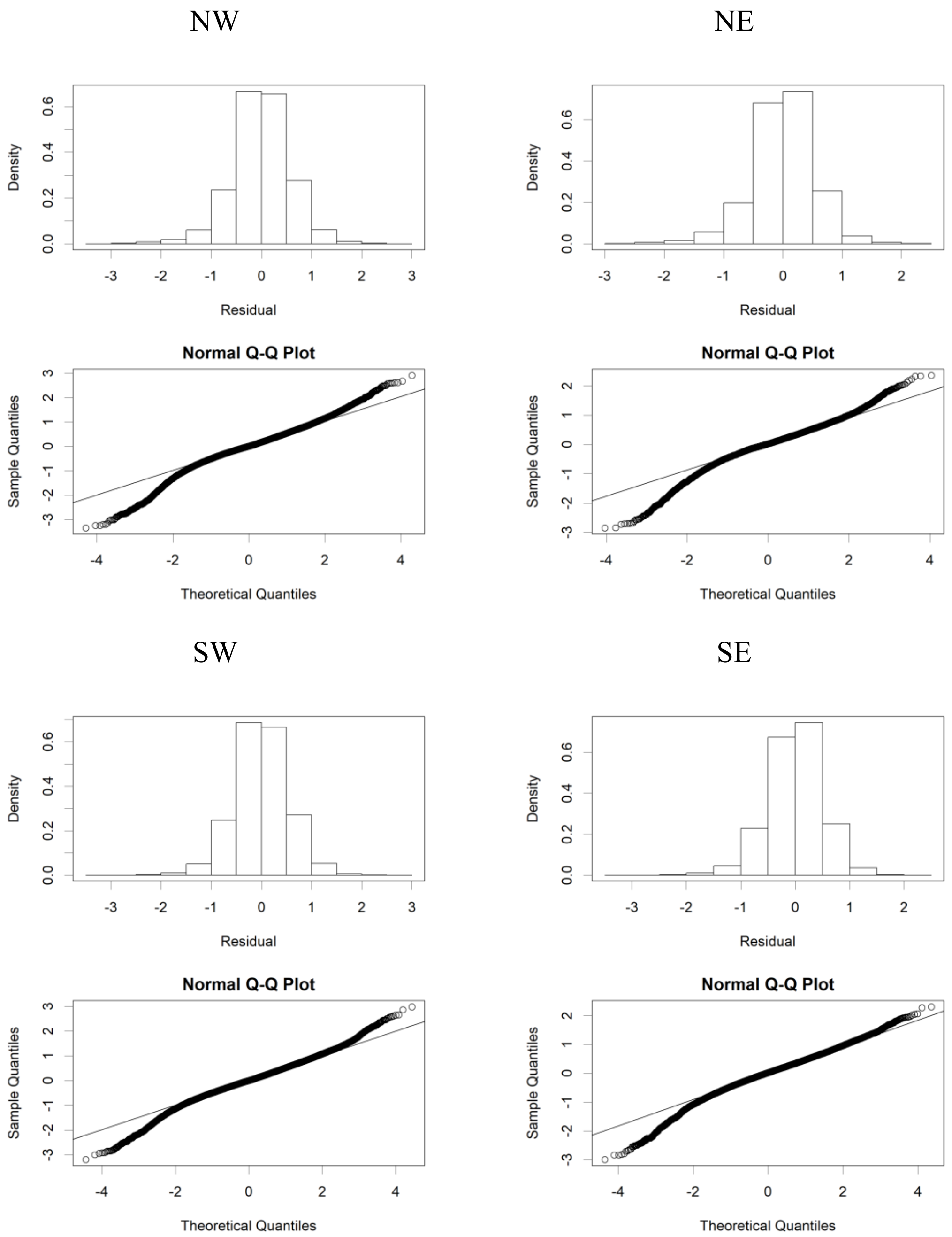


Fig. 34. Histogram and Quantile-Quantile plots obtained from the annual GLM for albacore caught by Taiwanese large scale longline fishery in the Indian Ocean.

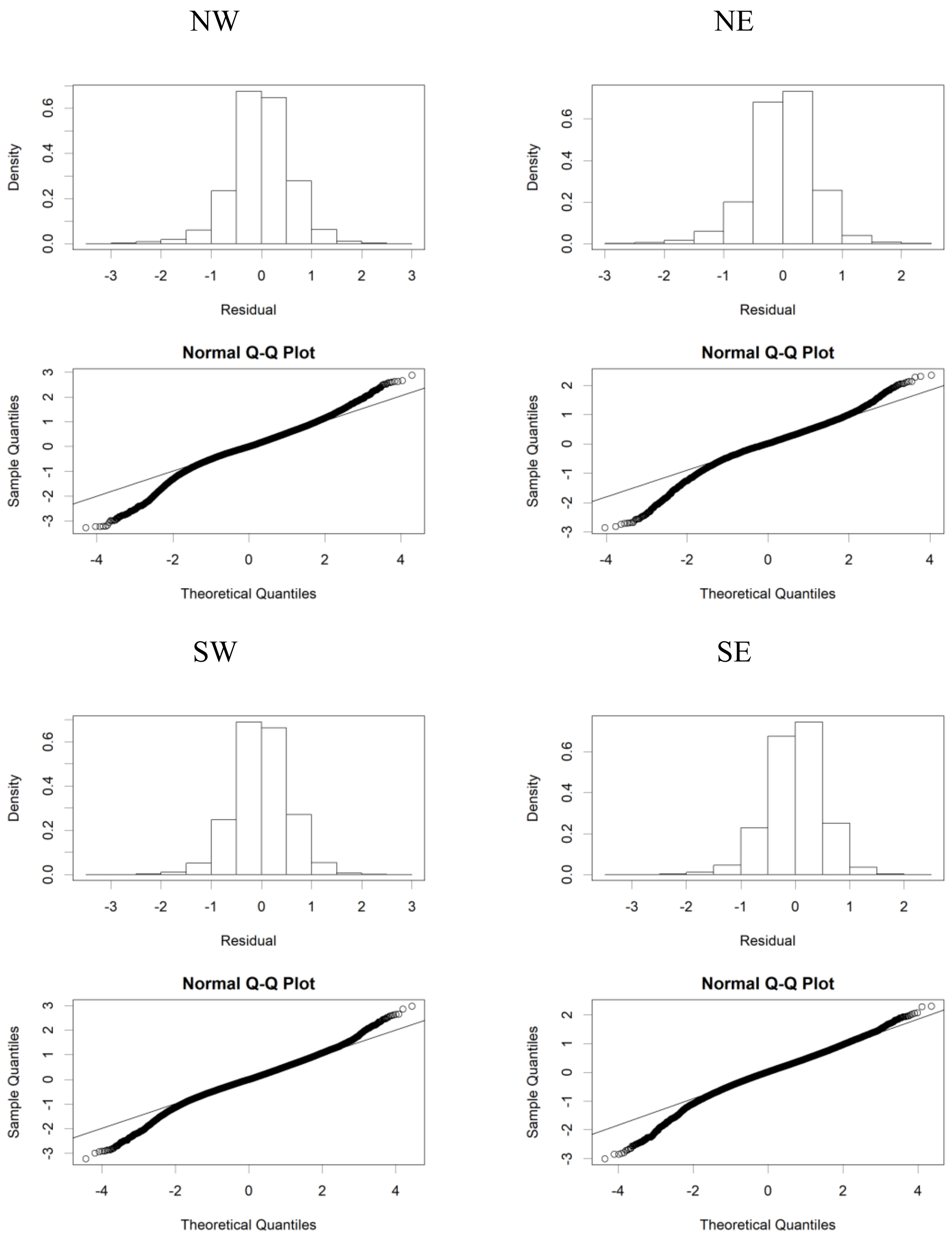


Fig. 35. Histogram and Quantile-Quantile plots obtained from the annual GLMM for albacore caught by Taiwanese large scale longline fishery in the Indian Ocean.

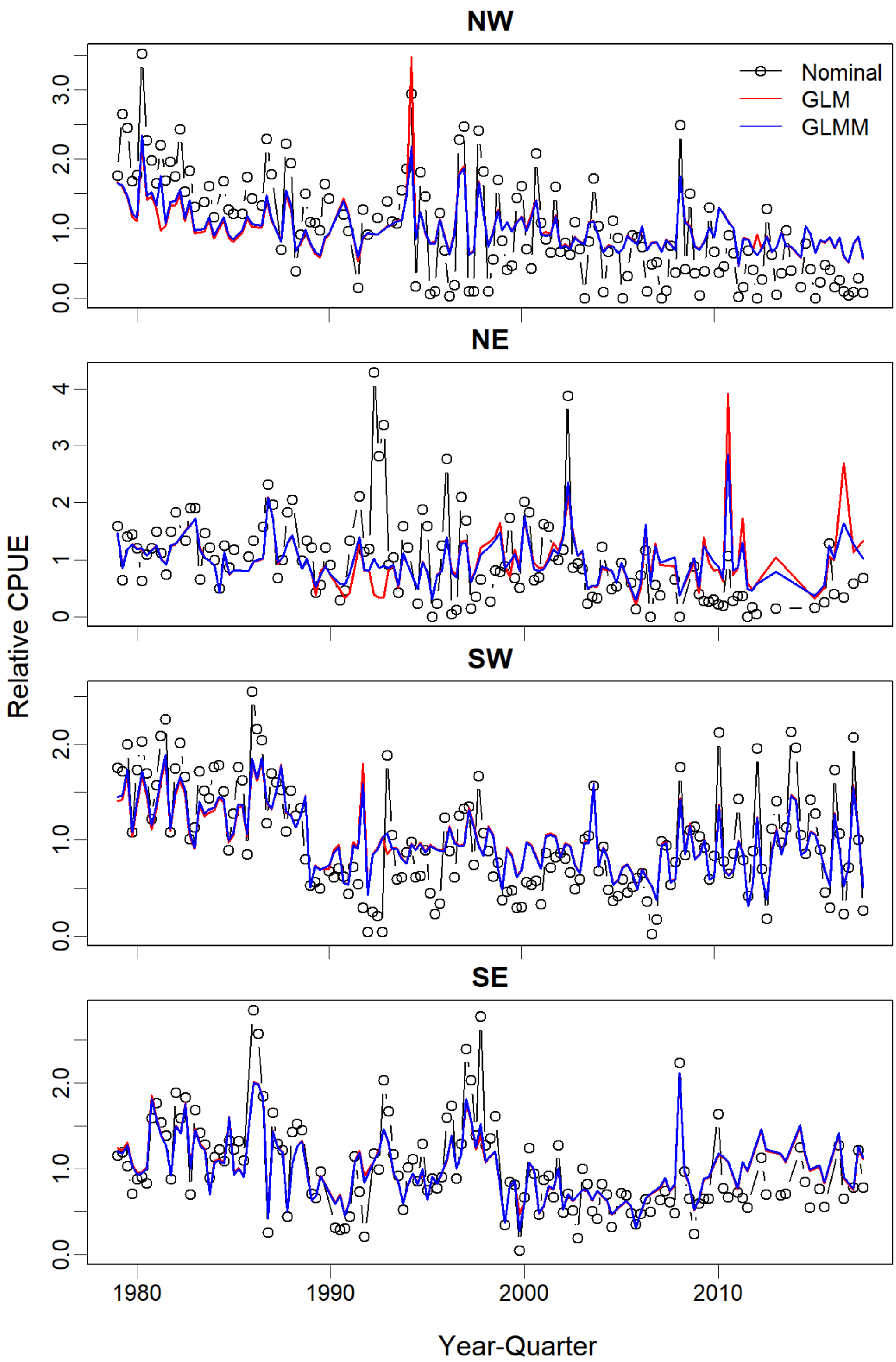


Fig. 36. Year-quarterly trends of standardized CPUE series for albacore caught by Taiwanese large scale longline fishery in the Indian Ocean.

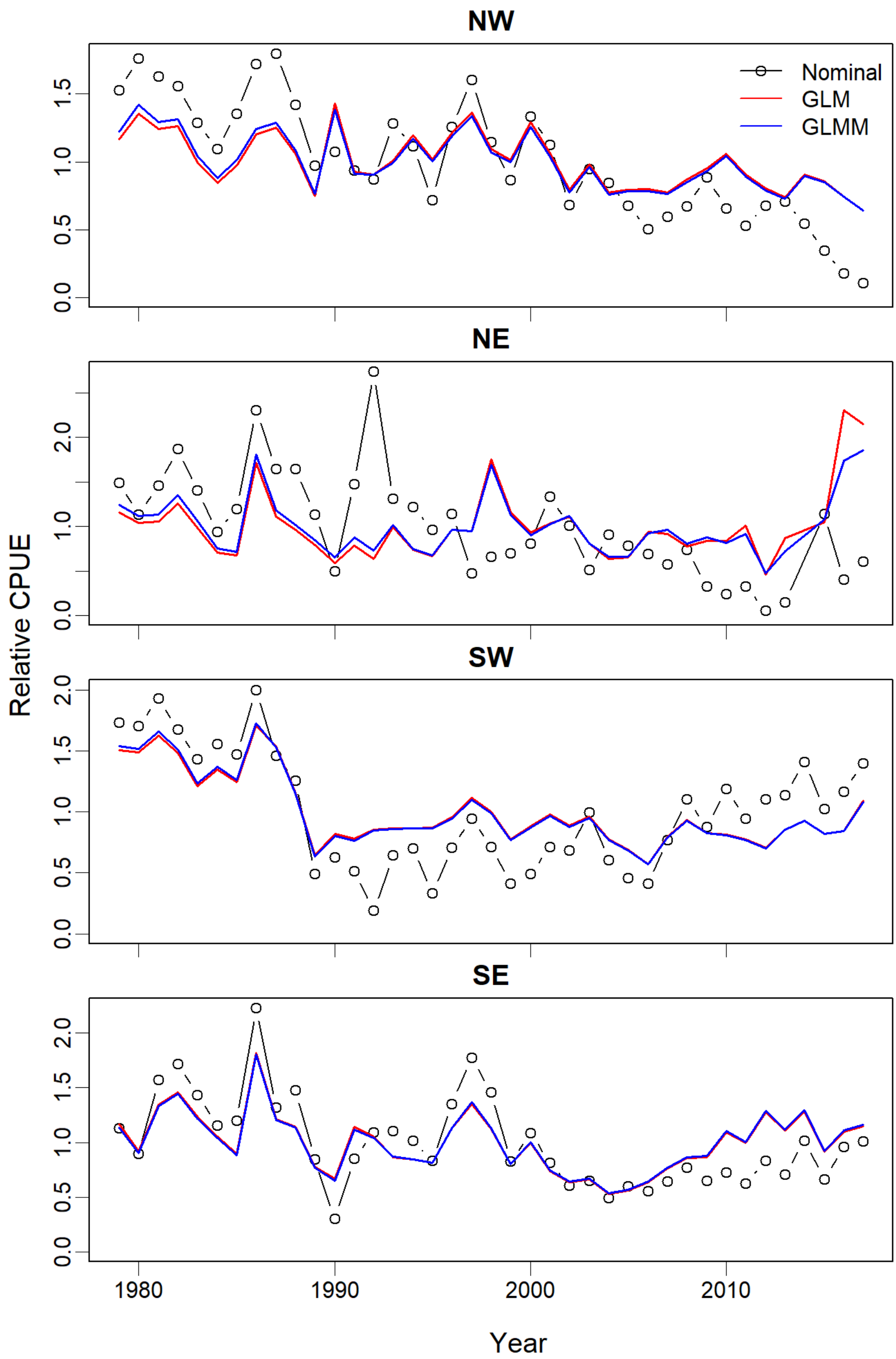


Fig. 37. Annual trends of standardized CPUE series for albacore caught by Taiwanese large scale longline fishery in the Indian Ocean.

Table 1. ANOVA tables for CPUE standardizations obtained from the year-quarter model for albacore caught by Taiwanese large scale longline fishery in the Indian Ocean using GLM.

NW

	Sum Sq	Df	MS	F	Pr(>F)
Model	56027	742	75.51	222.66	< 2.2e-16 ***
Residual	18558	54725	0.34		
Total	74585	55467			

	Sum Sq	Df	MS	F values	Pr(>F)
YQ	1626	144	11.29	33.29	< 2.2e-16 ***
G	697	23	30.31	89.38	< 2.2e-16 ***
T	3814	1	3814.10	11247.26	< 2.2e-16 ***
V	4258	574	7.42	21.87	< 2.2e-16 ***
Residuals	18558	54725	0.34		

NE

	Sum Sq	Df	MS	F	Pr(>F)
Model	13124	526	24.95	90.07	< 2.2e-16 ***
Residual	4883	17627	0.28		
Total	18007	18153			

	Sum Sq	Df	MS	F values	Pr(>F)
YQ	695	122	5.70	20.58	< 2.2e-16 ***
G	67	20	3.34	12.03	< 2.2e-16 ***
T	711	1	711.30	2567.64	< 2.2e-16 ***
V	1743	380	4.59	16.56	< 2.2e-16 ***
Residuals	4883	17627	0.28		

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

Table 1. (Continued).

SW

	Sum Sq	Df	MS	F	Pr(>F)
Model	102336	784	130.53	457.65	< 2.2e-16 ***
Residual	31147	109205	0.29		
Total	133483	109989			

	Sum Sq	Df	MS	F values	Pr(>F)
YQ	3050	154	19.80	69.44	< 2.2e-16 ***
G	848	30	28.27	99.11	< 2.2e-16 ***
T	12170	1	12170.40	42670.52	< 2.2e-16 ***
V	7085	599	11.83	41.47	< 2.2e-16 ***
Residuals	31147	109205	0.29		

SE

	Sum Sq	Df	MS	F	Pr(>F)
Model	19322	578	33.43	134.88	< 2.2e-16 ***
Residual	18124	73125	0.25		
Total	37446	73703			

	Sum Sq	Df	MS	F values	Pr(>F)
YQ	3220	133	24.21	97.69	< 2.2e-16 ***
G	188	20	9.39	37.89	< 2.2e-16 ***
T	2455	1	2454.60	9903.78	< 2.2e-16 ***
V	3211	423	7.59	30.63	< 2.2e-16 ***
Residuals	18124	73125	0.25		

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

Table 2. ANOVA tables for CPUE standardizations obtained from the year-quarter model for albacore caught by Taiwanese large scale longline fishery in the Indian Ocean using GLMM.

NW

	Sum Sq	Mean Sq	NumDF	DenDF	F value	Pr(>F)
YQ	1677	11.6	144	39695	34.32	< 2.2e-16 ***
G	718	31.2	23	54811	91.98	< 2.2e-16 ***
T	4116	4116.0	1	53478	12132.09	< 2.2e-16 ***

	npar	logLik	AIC	LRT	Df	Pr(>Chisq)
V	170	-54438.0	109217	9199	1	< 2.2e-16 ***

NE

	Sum Sq	Mean Sq	NumDF	DenDF	F value	Pr(>F)
YQ	717	5.7	125	8065	20.65	< 2.2e-16 ***
G	79	4.0	20	17456	14.24	< 2.2e-16 ***
T	816	816.3	1	15667	2939.45	< 2.2e-16 ***

	npar	logLik	AIC	LRT	DF	Pr(>Chisq)
V	148	-16870.0	34036	4164	1	< 2.2e-16 ***

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

Table 2. (Continued).

SW

	Sum Sq	Mean Sq	NumDF	DenDF	F value	Pr(>F)
YQ	3180	20.6	154	97626	72.38	< 2.2e-16 ***
G	860	28.7	30	109574	100.45	< 2.2e-16 ***
T	12496	12495.6	1	108243	43799.94	< 2.2e-16 ***

	npar	logLik	AIC	LRT	DF	Pr(>Chisq)
V	187	-98445.0	197263	19709	1	< 2.2e-16 ***

SE

	Sum Sq	Mean Sq	NumDF	DenDF	F value	Pr(>F)
YQ	3274	24.4	134	51278	98.53	< 2.2e-16 ***
G	190	9.5	20	73409	38.26	< 2.2e-16 ***
T	2484	2483.9	1	73547	10017.68	< 2.2e-16 ***

	npar	logLik	AIC	LRT	DF	Pr(>Chisq)
V	157	-59281.0	118876	10055	1	< 2.2e-16 ***

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

Table 3. ANOVA tables for CPUE standardizations obtained from the annual model for albacore caught by Taiwanese large scale longline fishery in the Indian Ocean using GLM.

NW

	Sum Sq	Df	MS	F values	Pr(>F)
Model	55371	639	86.65	247.26	< 2.2e-16 ***
Residual	19214	54828	0.35		
Total	74585	55467			

	Sum Sq	Df	MS	F values	Pr(>F)
Y	867	38	22.81	65.09	< 2.2e-16 ***
Q	82	3	27.33	78.00	< 2.2e-16 ***
G	736	23	32.01	91.34	< 2.2e-16 ***
T	4311	1	4310.50	12300.08	< 2.2e-16 ***
V	4695	574	8.18	23.34	< 2.2e-16 ***
Residuals	19214	54828	0.35		

NE

	Sum Sq	Df	MS	F values	Pr(>F)
Model	12813	443	28.92	98.61	< 2.2e-16 ***
Residual	5194	17710	0.29		
Total	18007	18153			

	Sum Sq	Df	MS	F values	Pr(>F)
Y	326	36	9.06	30.88	< 2.2e-16 ***
Q	68	3	22.57	76.99	< 2.2e-16 ***
G	88	20	4.41	15.03	< 2.2e-16 ***
T	863	1	862.50	2940.80	< 2.2e-16 ***
V	2202	382	5.76	19.65	< 2.2e-16 ***
Residuals	5194	17710	0.29		

Table 3. (Continued).

SW

	Sum Sq	Df	MS	F values	Pr(>F)
Model	101421	671	151.15	515.36	< 2.2e-16 ***
Residual	32062	109318	0.29		
Total	133483	109989			

	Sum Sq	Df	MS	F values	Pr(>F)
Y	1649	38	43.39	147.99	< 2.2e-16 ***
Q	470	3	156.67	533.87	< 2.2e-16 ***
G	1016	30	33.87	115.42	< 2.2e-16 ***
T	12887	1	12887.00	43940.48	< 2.2e-16 ***
V	7406	599	12.36	42.16	< 2.2e-16 ***
Residuals	32062	109318	0.29		

SE

	Sum Sq	Df	MS	F values	Pr(>F)
Model	18832	486	38.75	152.41	< 2.2e-16 ***
Residual	18615	73217	0.25		
Total	37446	73703			

	Sum Sq	Df	MS	F values	Pr(>F)	
Y	2543	38	66.92	263.21	< 2.2e-16	***
Q	107	3	35.80	140.76	< 2.2e-16	***
G	196	20	9.78	38.46	< 2.2e-16	***
T	2617	1	2617.30	10294.48	< 2.2e-16	***
V	3403	424	8.03	31.57	< 2.2e-16	***
Residuals	18615	73217	0.25			

Table 4. ANOVA tables for CPUE standardizations obtained from the annual model for albacore caught by Taiwanese large scale longline fishery in the Indian Ocean using GLMM.

NW

	Sum Sq	Mean Sq	NumDF	DenDF	F value	Pr(>F)
Y	907	23.90	38	45880	68.09	< 2.2e-16 ***
Q	79	26.20	3	55239	74.85	< 2.2e-16 ***
G	758	33.00	23	55007	94.00	< 2.2e-16 ***
T	4669	4669.10	1	53327	13318.36	< 2.2e-16 ***

	npar	logLik	AIC	LRT	Df	Pr(>Chisq)
V	67	-55566.00	111265	9856	1	< 2.2e-16 ***

NE

	Sum Sq	Mean Sq	NumDF	DenDF	F value	Pr(>F)
Y	332	8.98	37	11213	30.55	< 2.2e-16 ***
Q	76	25.46	3	17929	86.65	< 2.2e-16 ***
G	94	4.71	20	17766	16.02	< 2.2e-16 ***
T	975	974.56	1	16770	3317.01	< 2.2e-16 ***

	npar	logLik	AIC	LRT	Df	Pr(>Chisq)
V	63	-17761.00	35647	5016	1	< 2.2e-16 ***

Table 4. (Continued).

SW

	Sum Sq	Mean Sq	NumDF	DenDF	F value	Pr(>F)
Y	1778	46.80	38	99142	159.46	< 2.2e-16 ***
Q	470	156.50	3	109881	533.44	< 2.2e-16 ***
G	1032	34.40	30	109706	117.23	< 2.2e-16 ***
T	13209	13208.90	1	108512	45027.28	< 2.2e-16 ***

	npar	logLik	AIC	LRT	Df	Pr(>Chisq)
V	74	-99953.00	200054	20041	1	< 2.2e-16 ***

SE

	Sum Sq	Mean Sq	NumDF	DenDF	F value	Pr(>F)
Y	2589	68.14	38	65617	267.89	< 2.2e-16 ***
Q	108	36.14	3	73570	142.08	< 2.2e-16 ***
G	198	9.88	20	73533	38.86	< 2.2e-16 ***
T	2649	2648.57	1	73639	10413.08	< 2.2e-16 ***

	npar	logLik	AIC	LRT	Df	Pr(>Chisq)
V	64	-60269.00	120666	10414	1.00	< 2.2e-16 ***

Table 5. Model selection statistics obtained from the annual (Y) and year-quarter (YQ) GLM and GLMM for CPUE standardization of albacore caught by Taiwanese large scale longline fishery in the Indian Ocean.

GLM

	R^2	AIC	BIC
NW			
Y	0.2576	99888	105608
YQ	0.2488	98168	104807
NE			
Y	0.2885	29693	33167
YQ	0.2712	28737	32859
SW			
Y	0.2402	177898	184364
YQ	0.2333	174940	182492
SE			
Y	0.4971	108715	113209
YQ	0.4840	106929	182492

GLMM

	R^2_fixed	R^2_fixed and random	AIC	BIC
NW				
Y	0.6218	0.7190	101275	102018
YQ	0.6428	0.7324	99678	101546
NE				
Y	0.4432	0.6601	30505	31133
YQ	0.5031	0.6912	29576	31037
SW				
Y	0.6171	0.7221	179866	180736
YQ	0.6224	0.7263	177180	179363
SE				
Y	0.3821	0.5494	110124	110853
YQ	0.3961	0.5608	108508	110278